

**IX INTERNATIONAL SCIENTIFIC CONFERENCE
WINTER SESSION**

INDUSTRY 4.0

11 - 14 DECEMBER 2024, BOROVETS, BULGARIA

ISSN (Print) - 2535-0153

ISSN (Online) - 2535-0161



PROCEEDINGS



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Contacts:

108 Rakovsky Str., Sofia 1000, Bulgaria

web: www.fnts.bg

e-mail: info@fnts.bg



IX INTERNATIONAL SCIENTIFIC CONFERENCE - WINTER SESSION

INDUSTRY 4.0

11 -14.12.2024, BOROVETS, HOTEL ELA

Year IX

Volume 2/21

DECEMBER 2024

ISSN (Print) - 2535-0153

ISSN (Online) - 2535-0161

SESSIONS:

TECHNOLOGICAL BASIS OF "INDUSTRY 4.0"
DOMINANT TECHNOLOGIES IN "INDUSTRY 4.0"
BUSINESS & "INDUSTRY 4.0"
SOCIETY & „INDUSTRY 4.0"

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"INDUSTRY 4.0"**

108 Rakovski str., 1000 Sofia

e-mail: office@industry-4.eu

www.industry-4.eu

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Industry 5.0 and the new competency challenges

Borislava Galabova, Boryana Trifonova, Yoan Hristov
University of Mining and Geology "St. Ivan Rilski"
borislava.galabova@mgu.bg

Abstract: For the last ten years, Industry 4.0 has been available to address the industry's shortcomings. Therefore, Industry 4.0 has met some challenges and limitations. Consequently, we have entered the era of Society 5.0 and Industry 5.0. Smart factories and robots are driving up business productivity and growth, focusing on sustainability and resilience. This paper analyzes Industry 5.0 and its implementation challenges based on the competence profile of employees. The content and effects of entering Industry 5.0 to align with the competency profile of employees in the Era 5.0 were systematized. Industry 5.0 is transforming paradigms and bringing about resolution, as it shifts the focus away from technology and instead emphasizes the potential for progress through fruitful collaboration between humans and machines. In a business context, the advancements in technology necessitate the implementation of Industry 5.0 to secure competitive advantages and foster economic growth and development. Firstly, we discuss the definition and features of Industry 5.0 from the competency point of view. Secondly, we present two of the most recent and significant competencies—the entrepreneurial and green competencies. The question of their significance and necessity in the context of Industry 5.0 for industrial development on one hand, and for career development on the other hand, is discussed. On this basis, some conclusions and recommendations aimed at business and academia are made. It can also serve as a basis for further research in the field of skill development and workforce transformation in the face of the deep transformation framed by the green and digital economy.

Keywords: INDUSTRY 5.0, COMPETENCY, INDUSTRIAL ENTERPRISE, GREEN COMPETENCE, ENTREPRENEURIAL COMPETENCE

1. Introduction

In recent years, the new external factors of the economic and social environment and the established trends have changed the course of economic, technological, environmental, and social development. These new circumstances have led to the need for changes in technologies, processes, and relationships between economic actors. Consequently, given the numerous prerequisites and challenges, a transition from Industry 4.0 to Industry 5.0 became necessary. The Fourth Industrial Revolution focused on the digitalization of processes and the use of new technologies to increase productivity. Industry 5.0 complements and extends Industry 4.0 [1]. In Industry 5.0, human resources serve as the focal point and primary driving force of the production process. A supranational, European approach is imposing a new paradigm where technologies serve human needs and encourage active cooperation. If Industry 4.0 is based on the relationship between machines and information systems, then Industry 5.0 unites the strengths of humans and machines and seeks the intersection—their common usefulness and added value. The goal is to achieve a sustainable, resilient, and human-centric industry. This necessitates the development of a new strategy and plan to enhance relevant competencies, as it is crucial to upskill and reskill employees.

In this dynamic and challenging environment, possessing and developing knowledge, skills, experience, and attitudes are decisive factors for the prosperity of organizations in general and of individuals in particular. Against this background, two relatively new competencies receive attention: entrepreneurial competence and green competence. They ensure that the professional capacity of specialists meets the requirements of the production and business environment. The recruitment, retention, and development of quality and suitable human resources for the modern stage of economic development is a crucial and responsible process that underpins the organization's further activity and its effective functioning as a production system. An industrial enterprise tackles these challenging issues at every stage of its development. The new realities require new competencies and approaches to overcome challenges and to achieve a sustainable and resilient industry. This approach should also consider external dynamics and economic and social development prospects. Managers make strategic decisions related to personnel selection, retention, and development, which outline a long-term horizon. Without the rightly trained personnel, placed in precisely selected jobs, neither enterprises nor society can develop and achieve prosperity and economic development. Thus, by 2024, gaining competencies becomes crucial for the development and growth of the industrial enterprise.

2. Theoretical and methodological foundations of the study

In the context of new economic, technological, and societal trends and labor market requirements, this study explores the contemporary dimensions of the role and importance of competencies in Industry 5.0. The relevance of the study is proven and justified. Discussions on the topic are prevalent at national, European, and international levels. The research problem holds significant importance for the development of new competencies. These competencies play a crucial role in the professional realization and career development of specialists, as well as in the transition from education to employment. Today's trends and prospects for socio-economic development—Industry 5.0, green transition, digitalization, and innovative business development based on open approaches to innovation and human resource training—further heighten this interest and significance.

In this context, the importance of entrepreneurial and green competence as a key prerequisite for the professional realization of specialists in the conditions of Industry 5.0, digitalization, artificial intelligence, and green transition is checked. The study aims to confirm the extent to which entrepreneurial and green competence are essential for individuals seeking employment in the labor market, and for those who become realized, effective, and competent specialists in various sectors of the economy and the educational field. Industry 5.0, green transition, digitalization, and innovative business development require a change in the thinking, attitude, and concept of the business in terms of the workforce and its competencies. If the necessary competencies are not accumulated and developed, the challenges for the implementation of Industry 5.0 will be great in practice. The reason for this is that the imposition of the new paradigm is primarily driven by human resources and the impulse for action and change. The state of research on the problem indicates a need for in-depth analyses on the topic of industrial development that align with the new realities. Industry 5.0 already "frames" these realities, complementing the many existing challenges for business, industry, education, and the competence profile of future specialists. Adopting new ways requires workforce transformation, including reskilling and upskilling employees.

The research uses the following methods to achieve its goal: a review of the literature; an analysis of the content of entrepreneurial and green competence; an analysis of their significance for the implementation of Industry 5.0 and employees' career development; a survey and systematization of the results; and the formulation of conclusions and recommendations for business and educational institutions.

3. The paradigm of Industry 5.0 and the competency gap

Era 5.0 represents a profound transformation of society and humanity, emphasizing the enhancement of quality of life and the well-being of individuals, communities, the environment, and the economy. Issues such as climate change, warfare, social divisions, and cyber dangers are essential and demand more attention and concern from politicians, organizations, and communities.

Industry 4.0 is focused on ensuring consistency of the quality and data collection [2]. The moment for Industry 5.0 has finally come; it has been offered for the past ten years to help the industry and its shortcomings. In this context, the European Union (EU) has used the concept of Industry 5.0, a relatively new term, several times due to its importance as a key driver of the economic and social transitions we are going through. This concept extends beyond efficiency and productivity as the only goals. The Industry 5.0 concept is an evolution of Industry 4.0, using emerging technology and applications to integrate the virtual and physical domains, prioritizing human value at its core. This will lead to the creation of Society 5.0, which will be characterized by technologies and infrastructure that prioritize humanity and address social and environmental challenges. The main goal is to build a society grounded on sustainability, human value, and resilience. Compared to Industry 4.0, the most important difference is that Industry 5.0 puts workers' well-being at the heart of the manufacturing process, bringing prosperity beyond jobs and growth. As a consequence, the human-centered approach puts basic human needs and interests at the center of production processes.

The term "Industry 5.0" describes humans' use of robots and intelligent machinery. It is about robots using advanced technologies like big data analytics to assist people in working more efficiently. In fact, human workers and universal robots are boosting the productivity of the manufacturing industry [3]. Due to the Industry 5.0 revolution, industrial production is becoming more efficient as humans and machines collaborate. As a result, the manufacturing sector is becoming more productive thanks to both human labor and universal robots.

Industry 5.0, also referred to as the Fifth Industrial Revolution, reflects a shift in focus from an economic approach to one on social value and well-being. Industry 5.0 paves the way for a prospering development in the industrial sector [4]. This is a new phase of industrialization in which people work together with advanced technologies and robots controlled by artificial intelligence to improve work processes. Industry 5.0 refers to a revolution in which humans and machines collaborate to increase the methods and efficiency of manufacturing production. This form of next-generation industrial production relies on innovations in artificial intelligence (AI), 6G, the Internet of Things (IoT), autonomous processes and activities, robotics, 3D printing, nano- and biotechnology, quantum computing, blockchain technologies, network algorithms, and machine learning. Simultaneously, it underscores the significance of human intelligence, potential, and capabilities. As a consequence, supply chain 5.0 highlights the importance of collaboration among smarter machines like cobots and humans [5]. Industry 5.0 plus cobots is the heart that can combine people's creativity and craftsmanship with the efficiency and constancy of the robots [6]. In conclusion, it's "socially pulled and technologically pushed digital transformation of the industrial sector" [4].

Industry 5.0 possesses unique characteristics that qualitatively deviate from all previous perspectives on business development and economic growth. Behind Industry 5.0 are technologies representing a set of complex systems. Each of the categories can realize its potential only if combined with the others. The revolution of Industry 5.0 means that humans and machines are working together, improving the efficiency of industrial production [1]. Industry 5.0 mainly focuses on mass customization, where humans will be guiding robots [7, 8]. Integrating the human element to

manufacturing and development is the goal of Industry 5.0. Industry 5.0 added human-centric, sustainable, and resilient concepts to the industrial revolution. In light of this, it will revolutionize the manufacturing systems worldwide by preventing repetitive tasks from human workers [9].

The next generation of technology seeks to build intelligent and effective machines. Due to the Industry 5.0 revolution, industrial production is becoming more efficient as humans and machines collaborate. Industry 5.0 is bringing about a paradigm shift and resolution by acknowledging the possibilities for advancement through human-machine collaboration rather than only concentrating on technology. Through the use of customized products, the industrial revolution is increasing customer satisfaction. In modern industrial companies, Industry 5.0 is crucial for attaining competitive advantages and promoting economic growth in manufacturing due to technological advancements.

In fact, Industry 5.0 is considered the edge of the smart factory, where it communicates with robots and humans [10]. It is seen as a new production paradigm that emphasizes both human-machine interaction, but it leads to workforce and competence transformation. The goal of Industry 5.0 is to utilize human ingenuity and cooperation between increasingly precise machinery. It develops processes that recycle and repurpose materials to ensure sustainable production and a resilient economy. Industry 5.0 focuses on highly skilled people plus robots to create individualized products, from smart devices to cars for consumers [11]. With industry 5.0, the robots are starting to work together. The collaborative robots are accomplished with the tasks of heavy lifting plus ensured consistency, while skilled humans are provided cognitive skills of the craftsman [12]. It is to be expected that robots are changing relations among humans plus machines in the context of production [1]. People are required to develop competency skills, as working with the advanced robots, the human workers are required to get knowledge about collaboration with the smart machine and robot manufacturer [13]. Apart from the soft skills required, gaining technical skills is also an issue for human workers [14,15].

Industry 5.0 faces a number of challenges as it grows within the wider framework of Society 5.0. Industry 5.0 adoption is a demanding and complex process that requires highly qualified workers and smart machinery to boost output and efficiency. Both governments and companies ought to invest money developing and implementing education and training initiatives to provide workers the skills they need for Industry 5.0. Proactive steps, such as investing in education, collaborating on standards, and implementing ethical governance, can address societal issues and pave the way for a more technologically advanced and inclusive future. The increasing automation of industrial processes necessitates a major effort in skill development. This includes educating the workers on how to use cutting-edge technology and changing their behavior when interacting with them.

As a conclusion, Industry 5.0 promotes more skilled jobs compared to Industry 4.0, as intellectual professionals work in a challenging and entirely new environment. In the context of Education 5.0 and Society 5.0, the system should promote the planning and execution of training processes, facilitating the development of a wide range of skills. For instance, this includes developing work and soft skills, adapting to constantly changing environments, processing data, interacting with our environment and others, and fostering personal and social development. Education and training play a crucial role in implementing Industry 5.0 in practice. This transformation imposes the adaptation and improvement of new skills and abilities, including completely new competencies. Only this way Society 5.0 will be improved, a society centered on people, in which all citizens are intended to get involved in a dynamic way, introducing digital technologies for the benefit of the quality of life [16]. Personal skills (soft skills) will become ever more important in the future, while technical and digital skills will become much less essential. In addition to

technology, digital, and data acumen, soft skills (including the art of communication and also the ability to think in a creative and critical manner) are also going to be increasingly in demand [16]. Skills needs are evolving as fast as technology. The industry is struggling with a skills shortage, and educational institutions are unable to meet this demand. This applies to both the expert level and the general requirements for digital skills.

4. The entrepreneurial competence as a factor for career development

In recent years, entrepreneurial competence has gained prominence alongside other competencies. It is a competence that emerges as a fundamental pillar in building the entrepreneurial abilities of European citizens (European Council, 2006). As one of the key competencies, entrepreneurial competence encompasses a certain set of knowledge, skills, and attitudes that are crucial for career development and adequacy.

The EntreComp framework is the result of robust research work and a well-established methodology [17]. EntreComp offers a comprehensive description of the knowledge, skills, and attitudes that professionals need to develop in order to have an entrepreneurial mindset and act entrepreneurially in various work and social situations. The use of the framework as a self-assessment tool attracts the attention of specialists, business representatives, and the academic community. Entrepreneurial competence includes 15 competencies: learning through experience; working with others; coping with ambiguity, uncertainty, and risk; planning and management; taking the initiative; mobilizing others; financial and economic literacy; mobilizing resources; motivation and perseverance; self-awareness and self-efficacy; ethical and sustainable thinking; valuing ideas; vision; creativity; spotting opportunities.

Previous international practice proves that the development of entrepreneurial competencies integrated into entrepreneurial competence provides two advantages. First, it helps employees transition from individual roles to management roles. Second, it allows the organization to develop and grow with the help of its active and motivated employees, encouraging internal entrepreneurship and activity. An organization can stimulate the acquisition and development of employees' entrepreneurial competencies in two ways: knowledge sharing, an open and integrated approach to training, and process management; initiating programs and trainings that foster development and creativity and the generation of innovative and entrepreneurial ideas.

Entrepreneurial knowledge, skills, experience, and attitudes are becoming critically important not only for developing their own business initiatives but also for finding employment and keeping a job for practically every specialist. According to the available statements, entrepreneurial competence primarily refers to the ability to identify, create, and utilize opportunities, as well as manage processes that result in added value and usefulness. As a multifaceted and wide-ranging competence, it presupposes and requires an in-depth analysis and knowledge of the context, environment, opportunities, and risks, as well as its own potential, which can be further developed and upgraded over time. Entrepreneurial competence and the competencies that build it complement and enrich green competence, integrating new green and digital knowledge, skills, and attitudes. In the conditions of transition to Industry 5.0, entrepreneurial competence plays a connecting role and provides an impetus for the implementation of innovations, capacity expansion, and improvement of processes and business models.

5. The green competence as a factor for career development

The European Skills Agenda (2020) presents the approach to green skills. At the same time, one of the main tasks is to define a taxonomy of skills for the green transition, which will allow

statistical monitoring of the greening of professions. The European Sustainability Competence Framework (GreenComp) (2022) [18] lays out the solution. It consists of 12 competencies organized in the following four areas: embodying sustainability values, perception of complexity in the concept of sustainability, forecasting a sustainable future, and actions for sustainability. Given that knowledge is a resource that generates added value, mastering green competencies could enhance the added value of higher education by providing additional utility, aligning with the three priorities of the Europe 2020 strategic framework. These priorities are: (1) smart growth—building an economy based on knowledge and innovation; (2) sustainable growth—fostering a greener, more competitive, and more resource-efficient economy; and (3) inclusive growth—fostering an economy with high employment levels that creates the conditions for social and territorial cohesion [18].

Green competence therefore refers to the skills, knowledge, experience, and attitudes actually applied in a practical working environment and necessary to successfully address the challenges of sustainable and environmentally friendly business development. This competence becomes important for professionals, organizations, and society as a whole, as it helps to achieve a balance between economic development, social justice, and environmental protection. The key green competences that are integrated into the green competence are: 1) eco-awareness and eco-education; 2) eco-innovations and technologies; (3) sustainable resource management; 4) social economy; 5) ethics and responsibility; and 6) civic activity and participation. In the conditions of the transition to Industry 5.0, green competence plays a crucial role in the green transition, implementation of innovations, and improvement of processes and business models.

6. Research and discussion

In 2024, a survey between employers in the raw materials industry was conducted. One of the goals was to determine the necessary competencies for future employment and career development in the companies in the context of Industry 5.0, green and digital transition. The study involved 11 large companies from the industry (71% of them have more than 250 employees, and the rest are also more than 50 employees). The questions aim to verify the importance of entrepreneurial and green competence from the point of view of employers who face directly the challenges and changes in processes and models.

The following research questions were formulated and included in the survey. Research question 1 is “Do you think that entrepreneurial competence will be useful for the career development of your employees in the context of Industry 5.0?”.

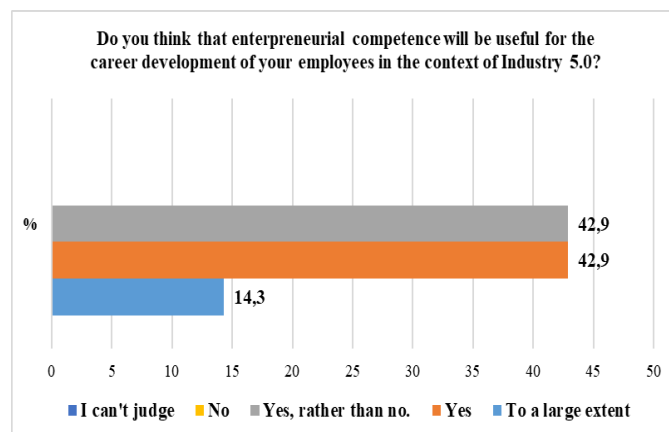


Figure 1. Research question 1

Source: Own survey among business representatives in RM industry

The respondents hold the belief that knowledge and skills related to entrepreneurial competence will significantly contribute to the career development of staff members. The responses are: “to a large extent” (14.3%), “yes” (42.9%), “rather yes than no” (42.9%).

Research question 2 is “Do you think that green competence will be useful for the career development of employees in the context of Industry 5.0?”.

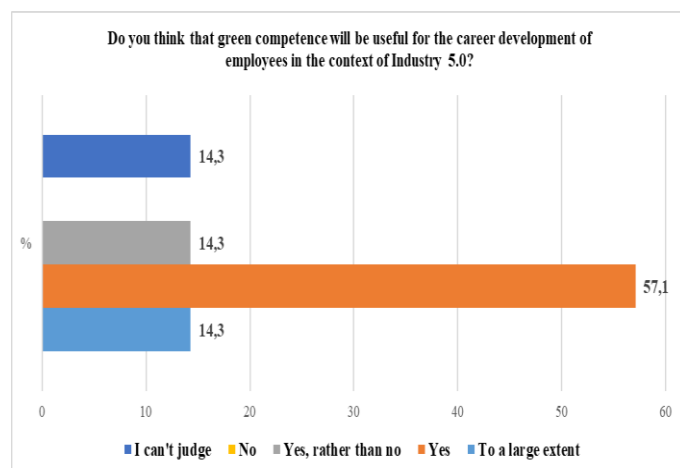


Figure 2. Research question 2

Source: Own survey among business representatives in RM industry

Managers believe that knowledge and skills related to green competence can also help develop the careers of employees in the companies. The responses are: “to a large extent” (14.3%), “yes” (57.1%), “rather yes than no” (14.3%), and “I can't judge” (14.3%). It appears that enterprises in the raw materials industry have recognized the importance of this competence and set requirements for ownership and mastery.

7. Conclusion

People are required to develop competency skills, as working with the advanced robots, the human workers are required to get knowledge about collaboration with the smart machine and robot manufacturer [13]. Some of the modern methods of organizational management include the use of competencies in practice, as well as the application of the competence approach in human resources management across various activities. Turning to new competencies is a prerequisite for developing, adapting, and overcoming the competitive battle. Moreover, the creation of innovations and their dependence on the conditions of Industry 5.0 is a guarantor of the passage through the transformation processes.

In order to effectively manage the potential of human capital, human resources management specialists should build and maintain an integrated system of complementary competencies as a whole and an adequate competence model. The goals of acquiring and using managerial, entrepreneurial, and green skills in combination are to achieve sustainable competitiveness, corporate development and growth, social justice, and a positive and healthy work environment. As a result, the growth of industry, business, and education places significant importance on these skills. Business and education should work in symbiosis in order to fulfill their common goals—a smooth but at the same time rapid transition of young professionals from education to employment and career development. The new vision and strategy for industrial development require the timely training of personnel, regardless of their previous work experience, who have entrepreneurial and green competence. To adapt educational and staff training programs in the direction of accumulation and sustainable upgrading of these modern competencies, specific policies and measures are required. To achieve this, we need specific policies and measures that adapt educational and staff training programs toward the accumulation and sustainable upgrading of these modern competencies.

All companies, not just those in the raw materials industry, are going to confront the challenges of green transition and sustainable development. They must adapt production processes and supply chains, establish standards, invest in research and innovation, collaborate, and share knowledge [19]. They should include in their

long-term corporate strategies increased investment costs related to training and adaptation to new realities. These investments should include training human resources to comprehend environmental and sustainability issues, as well as the potential environmental impacts of human activity. Employers expect their employees to have the skills to develop and implement innovative technologies that improve energy efficiency and reduce adverse environmental impacts. Future personnel training should prioritize environmental protection and emphasize socially and environmentally responsible behavior.

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Role of blockchain technology in the development of IOT networks

Mihaela Todorova¹, Gergana Spasova²

University of Economics – Varna, 77 “Knyaz Boris I” Str., 9002 Varna, Bulgaria¹

Technical University of Varna, 1 Studentska Str., 9010 Varna, Bulgaria²

mihaela_todorova@ue-varna.bg; g.spasova@tu-varna.bg

Abstract: The integration of two of the most significant technologies can lead to the revelation of many possibilities. The development is made to search for the role of blockchain technology in the development of the internet of the network. It examines how the two technologies can be combined and what will be achieved in building a blockchain-based IoT system. A theoretical summary of the contributions of blockchain technology to the Internet of Things network is made.

Keywords: Internet of Things (IoT), Blockchain, BCIoT

1. Introduction

Modern conditions are greatly influenced by the development of technologies because they have a significant role in society. Their improvement leads to the creation of new opportunities and changes people's well-being and way of life.

The Internet of Things is part of everyday life for a large part of the population and continues to evolve and increase in popularity and applicability. According to data from the National Statistical Institute [1] in Bulgaria, 34.5% of individuals use Internet devices and systems for personal purposes. This type of network is widely used as it supports and automates many processes.

One of the most current and global technologies is the blockchain, which is distinguished by high levels of security and transparency. Technology has a strong impact on the financial sector and currently continues to develop and find new applications in various fields.

Combining the Internet of the grid with blockchain technology can lead to significant developments in the capabilities and features of the scaled-down network. This in turn will show societal influence on lifestyle. This is where the importance and relevance of the chosen topic come from.

The object of the article is IoT networks, the application of which is developing and developing more and more. The subject of the study is IoT development. The purpose of this development is to explore the role of blockchain technology in the development of the Internet of the Web. To achieve the goal of the search the following specific tasks have been added and completed:

- A brief overview of the nature of IoT networks;
- Description of blockchain technology;
- Examining the role of blockchain in the development of the Internet of Things;
- Derivation of main conclusions and conclusion

2. Nature of IoT

The Internet of Things (IoT) is a concept of a sensor network of physical objects [2], [3] that have embedded electronic, communication devices between them. IoT networks are designed to comprehensively facilitate the automation of households, industries, and infrastructure while providing new opportunities for development and innovation in various sectors – healthcare, sports, education, and many more.

At the heart of IoT is the idea that devices that find the greatest application in a person's daily life, such as phones, home appliances, cars, and others, can communicate with each other and exchange information to improve their lifestyle.

Connectivity is the key property that distinguishes the essence of IoT [4]. This property is based on connecting different

components and devices through embedded electronics, sensors, or wireless connections. The exchange of information between devices makes it possible to control their actions and make decisions about their computer.

Sensors are elements that continuously collect information about their surroundings. The accumulated data is fed to the central system for processing and analysis. The advantage of IoT wireless connectivity is the absence of physical connections, which makes the implementation more flexible and inexpensive. Wireless technologies that find applications in IoT are Wi-Fi, Bluetooth, Zigbee, and others.

The storage, processing, and analysis of large amounts of data that are produced by the devices are used in a cloud infrastructure. It, on your end, provides access to data management and applications from various locations and devices that enable and monitor systems. To enable the integration of different devices and systems from different manufacturers, IoT networks support standards and compatibilities. This is of particular importance as it ensures interaction and joint use of data from different systems.

3. Nature of Blockchain

With the emergence of cryptocurrencies, the blockchain [5] began to be popularized, because Bitcoin [6], [7] was the first realized project developed based on the technology. At a later stage, the blockchain developed significantly and revealed new application possibilities [8]. Nowadays, technology is being adopted in various processes in the public and private sectors.

The development of blockchain technology stands out in 4 main stages. The first generation is associated with cryptocurrencies and financial services. The second is connected with the introduction of smart contracts. In the third generation of blockchain technology, its application is expanding in various sectors such as government, art, and others. The fourth stage of blockchain development is associated with its application in the private sector in real time [9].

A blockchain is a collection of blocks that are interconnected without the presence of a central server. The decentralization of the blockchain is one of the main advantages of the technology because, in this way, a higher security of the records on the network is ensured. All data is stored on all blocks in the system and the information will be preserved in the event of a natural disaster or any attempted hacking and malicious intervention.

All processes, transactions, and activities within the system are visible to anyone with network access. Blockchain provides transparency and this is another key advantage over other technologies. For this reason, the information in the blockchain cannot be tampered with.

Blockchain is currently being used in many areas in the public and private sectors - healthcare, logistics, education, manufacturing, e-voting, commerce, e-government and many others.

Implementing blockchain technology in Internet of Things networks provides new opportunities for developing IoT networks. In the following lines, the key advantages that can be achieved by integrating the two technologies are discussed and summarized.

4. Convergence of IoT and Blockchain

The topic of combining the Internet of Things (IoT) with blockchain technology presents significant potential for development and innovation in the digital realm. Main key applications in the adaptation of blockchain technology in the Internet of Things (Fig. 1):

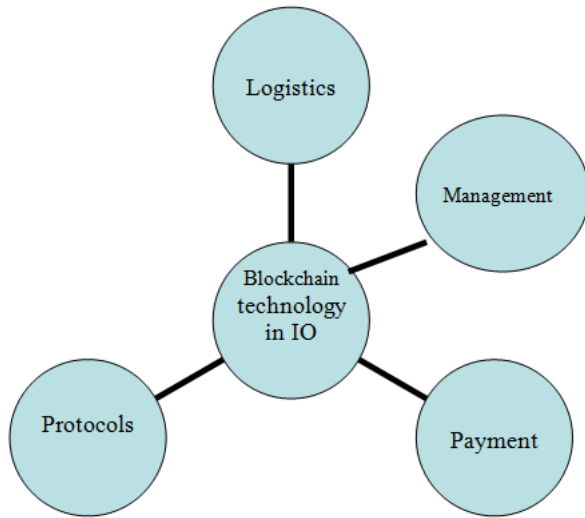


Fig. 1. Block chain technology in Internet of Things

- **Protocols** – Blockchain technology after the first generation enables the creation, execution, and maintenance of smart contracts. They are protocols that automatically check, execute, and control set contractual conditions. Their implementation in the IoT network can enable automatic payment and transaction processing.

- **Management** – Blockchain can be used to manage an existing IoT network. The efficiency and security of managing multiple IoT devices can be improved by creating decentralized registries on individual devices.

- **Payment** – Blockchain technology can significantly improve business models by reducing costs and facilitating payments between individual IoT network devices when needed for project needs.

- **Logistics** – Blockchain allows transparent tracking of all processes within the network. IoT devices allow tracking the location of certain objects in real time by extracting data from sensors. Combining the two technologies has great potential in tracking entire supply chains transparently, securely, and in real-time.

Blockchain can be adapted into IoT systems in different ways depending on the specific project's needs. The applications listed do not describe all the possibilities, because both technologies are constantly evolving, and with it, the ways to implement blockchain in the Internet of Things are growing.

After looking at how blockchain can be combined with the Internet of Things, the role that blockchain plays in the development of IoT networks is explored.

An analysis [10] of the security and privacy of blockchain implementation in IoT systems concluded that blockchain is one of the promising technologies that can offer many advantages. The development describes the main capabilities related to improving security, interoperability, automatic interactions, reliability, secure code deployment, and traceability.

The authors of the development summarize the following main roles of blockchain technology in IoT systems (Fig.2):

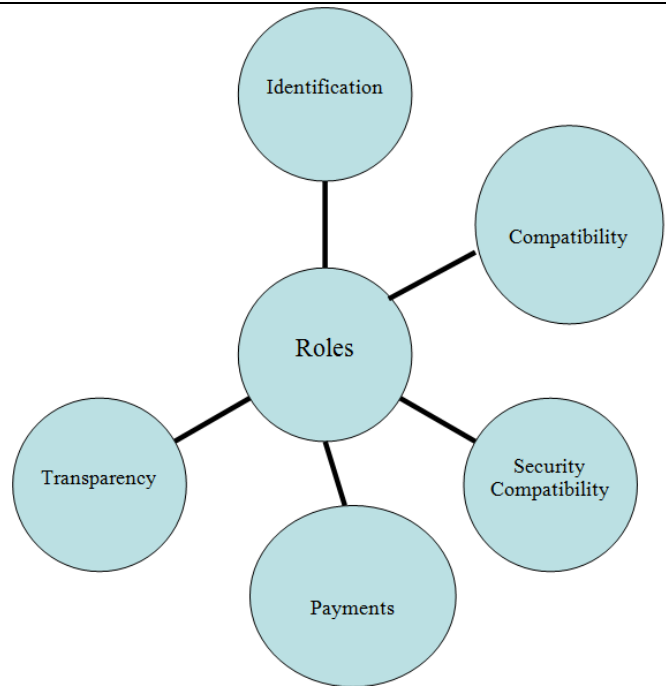


Fig. 2. Roles of blockchain technology in IoT systems

- **Security** – This is one of the main roles of blockchain technology in the development of the Internet of Things. Blockchain implementation can provide a more reliable form of data storage and processing. The distributed storage of the data and its encryption provides a higher level of security in case of possible malicious and hacker attacks. This is extremely important for IoT networks where large amounts of data and/or sensitive information are generated and exchanged between devices. At the same time, the use of blockchain for storing and processing large databases expands the possibilities for analysis, by which necessary decisions can be taken.
- **Identification** – This role of blockchain technology is important for the development of IoT networks because devices continuously exchange information without human intervention. Adapting blockchain into IoT networks can provide significantly higher levels of security and authenticity to any device. Blockchain can secure the processes of device identity authentication, device control, and rights to use the IoT network. This is extremely important for the efficient, safe, and reliable operation of IoT systems.
- **Transparency** – Blockchain technology, which is embedded in an IoT network, plays a role in the transparency of the system. All processes within the project are traceable and can be verified by any participant in the network. In this way, higher levels of confidence can be built in the efficiency and reliability of the constructed network. Increasing transparency in the Internet of Things can significantly improve data verification, accountability, and understanding processes.
- **Compatibility** – Improving compatibility is one of the main roles of blockchain in the development of IoT networks. For the Internet of Things to function effectively, all the devices involved need to be compatible and share common standards. By implementing blockchain technology, it can help create common standards using smart contracts and blockchain protocols. In this way, it will facilitate communication and increase the efficiency of interaction between devices, regardless of their manufacturers and countries.

- Payments – Another important role of blockchain in the development of the Internet of Things is to facilitate payments between devices. This will facilitate and increase the efficiency of IoT networks where financial transactions need to be made to use services or resources. A P2P (peer-to-peer) sales platform can be built between IoT devices and users. An example of the application of such a system is in the production of energy - those who wish will be able to purchase easily produced energy from decentralized sources (solar panels, wind generators, and others).

Combining the Internet of Things with blockchain technology can provide opportunities in the areas of device efficiency and reliability. The role of blockchain technology in the development of IoT networks is expressed in the fact that it helps to achieve higher levels of security, transparency, and compatibility. At the same time, it has the effect of building more reliable identification and facilitating payments.

Various types of research are being developed for the application of a network that combines both technologies – the Internet of Things and Blockchain. The integration of the two systems is a relatively new introduction that continues to be researched, developed, and popularized.

As of now, quite a few cryptocurrencies are being used for IoT. The brightest examples as of October 2023 are VeChain, IOTA, Fetch.ai, and IoteX according to one of the largest crypto exchanges [11].

In a study [12], an infrastructure is proposed in the combination of blockchain and the Internet of Things, which provides a strategy for the acquisition of IEQ (Indoor Environmental Quality) in real-time. Such a type of network can visualize the energy behavior of occupants and provide clarity on the spatial and temporal variations of personal impact on the environment.

The merging of blockchain technology and the Internet of Things in the healthcare field is discussed in a paper [13] that describes the characteristics, challenges, and various integrations of a BCIoT system. The role of the combined network in remote patient monitoring, electronic health record management, healthcare resource tracking, and more is highlighted.

In another study [14], a blockchain-based IoT model applied to criminal investigation was considered. In summary, these networks are primarily used to: improve the chain of custody of evidence; accuracy and completeness of information; origin of the data; privacy, and identity anonymity.

Authors [15] propose a blockchain-based IoT network that ensures the security and transparency of data generated in manufacturing industries. The proposed system in the study reveals the potential to offer a more reliable and verifiable environment that is significantly ahead of the current capabilities.

A blockchain-based IoT architecture solution was proposed in a study [16] to improve the environment in which third-party accessory vendors operate. To cope with the multiple challenges, a system is proposed that reaches 85% accuracy under a high rate of malicious attacks in a short time.

The table 1 summarizes a comparison between the blockchain-based Internet of Things and the Internet of Things. The former is more secure, decentralized, transparent, and efficient. The second is easier and cheaper to build.

Blockchain and the Internet of Things complement each other and create new opportunities and more efficient solutions. Both technologies are constantly evolving and various studies are being carried out. This allows us to conclude that in the future their application will be expanded, both individually and jointly.

Table 1 Comparison between the blockchain-based Internet of Things and the Internet of Things

Criteria	BCIoT	IoT
Decentralized	v	x
Security	v	x
Transparent	v	x
Effective	v	x
Cheap	x	v
Easy	x	v

5. Conclusion

Technologies are a part of every individual's daily life and this highlights their importance. Combining two current technologies can lead to many new possibilities. In this paper, the role of blockchain in the development of the Internet of Things is considered.

From the research done, it can be concluded that blockchain can have a significant role in the development of IoT networks. By combining the two technologies, the security, transparency, and efficiency of the operations that take place within the built IoT network can be significantly increased.

Blockchain can create more resilient and secure IoT infrastructures.

6. Acknowledgments

This report was developed under a project to develop the empirical part of a doctoral dissertation, № DNP-CS24-01-Blockchain, of the University of Economics - Varna. We express our gratitude to the entire team whose efforts have made it possible for us to explore the opportunities for the implementation of blockchain technology across various industries and its integration with other contemporary technologies.

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IIoT and cyber security in industrial enterprises

Petar Georgiev¹, Krasimira Dimitrova²
 Technical University of Varna, Bulgaria¹
 Technical University of Varna, Bulgaria²
 petar.p.georgiev@tu-varna.bg

Abstract: Digital transformation and sustainable development are key concepts that are actively developing in modern business and society. They go hand in hand, creating opportunities to improve efficiency, reduce the negative impact on the environment and increase people's quality of life. The Industrial Internet of Things is a powerful tool for connecting industrial devices, sensors, and equipment to a network to improve monitoring, analysis, and process automation. With the increasing digitization of business in recent years, cyber-attacks are also on the rise. To protect against such actions, organizations need cybersecurity technology solutions, as well as reliable tools to detect, prevent, and respond to cybersecurity breaches. This publication presents an exploration of the combination and interconnectedness of IIoT and cybersecurity in industrial enterprises, which are necessary to keep these systems secure and protected from cyber threats. A conceptual framework for multi-layered cyberattack defense designed for industrial enterprises is proposed.

Keywords: IOT, IIOT, IIOT NETWORKS, CYBER-ATTACKS, CYBER SECURITY.

1. Introduction

Digital transformation is the process of integrating digital technologies into all aspects of a business or organization, resulting in significant changes in the way a business operates and creates value for customers.[9] Sustainable development is a concept that aims to meet the needs of the present generation without compromising the ability of future generations to meet their own needs. [13]

The concept of IoT first appeared as a term and as a concept in the late 20th century. British digital transformation expert Kevin Ashton is considered the founder of this concept. It defines the Internet of Things as a collection of identifiable connected objects using radio frequency identification (RFID) technology. According to Ashton himself, this concept considers the organization of such networks as a phenomenon capable of reorganizing economic and social processes in such a way as to exclude the need for human participation in some of the actions and operations. This practically marks the beginning of another revolutionary concept - Industry 4.0. This concept represents a profound transformation of the industrial sector, leading to new levels of productivity, efficiency, and sustainability. Combining technologies from different fields, it offers not only the improvement of existing processes, but also the creation of new opportunities for innovation and development. This integration will continue to change the way people live and work, ensuring a more sustainable and productive future.

IIoT is a specialized part of the broader IoT concept that focuses on connecting industrial devices and systems in a network. This technology aims to optimize industrial processes through real-time data collection and analysis, automation, and integration of various systems. [19] IoT is a concept where physical objects and devices are equipped with sensors, software, and network capabilities to collect and exchange data over the Internet. Key aspects of IoT are smart devices, data collection and analysis, automation and convenience, user applications, etc.

IoT and IIoT are two closely related but also different concepts that are used to improve processes and systems in different fields. Both technologies aim to use data and connected devices to improve various aspects of life and work but are used in different contexts and for different purposes.

At the same time, they are also strongly related to cyber security, as industrial IoT systems that connect machines, sensors and control systems are vulnerable to various cyber threats. IIoT networks automate and optimize industrial processes in sectors such as manufacturing, energy, and transportation, but also open new opportunities for cyberattacks that can cause serious damage to critical infrastructure. According to Fortinet's Forti Global Threat Landscape Report 2H 2023 [25], cybercriminals are exploiting new industry vulnerabilities 43% faster than the first half of 2023.

Organizations need a robust framework to help them define their approach to cybersecurity and minimize the consequences of a potential attack. It should emphasize protecting critical systems, detecting, and responding to threats, and recovering from an attack.

2. Industrial internet of things (IIoT)

For industrial enterprises, the concept of IIoT is of particular importance. IIoT represents a powerful tool for the transformation of industrial processes. Through the integration of connected devices, sensors, analytical tools, and automated systems, IIoT offers significant benefits such as increased efficiency, improved quality, and reliability, as well as greater flexibility. Although there is security, interoperability and change management challenges, the potential of IIoT to revolutionize the industry is significant and will continue to develop in the future.

IIoT offers significant advantages for optimizing production processes but requires complex infrastructure and advanced technologies. To ensure the security and efficiency of these systems, it is necessary to implement strict cyber security measures, use modern communication networks, cloud, and distributed computing resources, as well as constant monitoring and analysis of data. [19] These measures will help minimize risks and ensure the continuous operation of industrial systems in an increasingly digitized and connected environment.

IIoT integration in industrial enterprises brings significant advances in efficiency, productivity, and automation. However, it also introduces new cybersecurity challenges that must be addressed to protect critical infrastructure and sensitive data.

The most important benefits of IIoT for industrial enterprises can be classified as follows:

- *Improved operational efficiency:* IIoT devices enable real-time monitoring and control of industrial processes, resulting in optimized productivity and reduced downtime.
- *Predictive maintenance:* Sensors and analyses can predict equipment failures before they occur, enabling timely maintenance and reducing unplanned downtime.
- *Improved productivity:* Automation and data-driven decision-making streamline processes and increase overall productivity.
- *Supply Chain Management:* Real-time tracking and analyses improve supply chain visibility and efficiency.

Despite the benefits they bring to businesses, many industrial IoT devices are designed with an emphasis on functionality rather than security. This makes them easy targets for attacks. Connecting multiple devices creates a complex network where even a weak connection can open access for cybercriminals. Attacks against IIoT systems can have physical consequences, such as stopping

production or damaging equipment. Many IIoT devices do not support regular security updates, making them vulnerable to new threats. Therefore, as IIoT networks evolve, cybersecurity becomes a critical aspect for these technologies.

3. Cybersecurity challenges in IIoT

While IIoT offers numerous benefits to industrial enterprises, it also presents significant cybersecurity challenges that must be proactively managed. Implementing robust cybersecurity measures, being aware of emerging threats, and continuously updating security protocols are essential steps to protect industrial systems and ensure the reliable and secure operation of Internet of Things networks. [8] By prioritizing cybersecurity, industrial enterprises can fully take advantage of IIoT benefits while minimizing risks. Some of the most serious IIoT challenges are related to:

- *Cybersecurity*: Protecting connected devices and data from cyberattacks is critical.
- *Data and Privacy*: Ensuring data privacy and integrity.
- *Compatibility*: Integration of devices and systems from different manufacturers requires standardization and compatibility.
- *Change Management*: Adapting new technologies and processes can be complex and requires effective change management.

The study is done in close cooperation with specialists from Schneider Electric Bulgaria Ltd.24 and Testel Engineering Ltd.

The results can be summarized as follows:

- *Expanded scope for attack*: The proliferation of connected devices expands potential entry points for cyberattacks.
- *Legacy obsolete systems*: Many industrial systems were not designed with cybersecurity in mind and are vulnerable to modern cyber threats.
- *Complexity and integration*: Integrating IIoT devices with existing information and operational technologies and networks adds complexity, making security management more challenging.
- *Data confidentiality*: Ensuring the confidentiality and integrity of data collected and transmitted by IIoT devices is critical.

The results show that IIoT requires a complex infrastructure and multiple complementary technologies to ensure efficient connectivity, processing, and data transfer.

4. Key tools and techniques used in cyber attacks

Cyber-attacks pose a serious threat to modern computer systems, networks, and data. Attackers use a variety of tools and techniques to compromise systems and achieve their goals. The main tools and techniques used for cyber-attacks can be grouped into several groups:

1. Malware: [18]

- *Viruses*: Programs that spread and infect files on computers, changing or deleting data.
- *Trojans*: Malware that pretends to be legitimate and is used to gain access to the victim's system.
- *Worms*: Only spreading programs that spread over networks and cause damage to systems.
- *Spyware*: Programs that track and collect information about the user without their knowledge.
- *Ransomware*: Software that encrypts the victim's data and demands a ransom to restore access to it.

2. Attack tools [14]

- *Metasploit*: A popular framework for developing and executing exploits and penetration tests. Often used for vulnerability testing. [16]
- *Nmap*: A network scanning tool that helps detect active hosts and open ports. [1]
- *Wireshark*: A network analyzer used to capture and analyze network traffic. It can be used to monitor communication and discover data. [24]
- *Burp Suite*: A web application analysis tool used to identify vulnerabilities and weaknesses in web-based applications. [22]
- *Aircrack-ng*: A set of tools for analyzing and cracking WEP and WPA/WPA2 cryptographic protocols in wireless networks. [7]

3. Techniques and Strategies

- *Phishing*: Social engineering, where attackers send fake messages (emails, messages) in order to gain personal information or access to systems. [4]
- *DDoS attacks (Distributed Denial of Service)*: Attacks that use multiple compromised devices (botnets) to overwhelm the target server with traffic and make it unavailable.[6]
- *SQL Injection*: Attack where malicious code is injected into an SQL query to gain unauthorized access to a database. [2]
- *Cross-Site Scripting (XSS)*: A technique where malicious code is embedded in a web application to execute in the user's browser. [21]

5. Key cybersecurity measures for IIoT

To protect IIoT networks, companies are taking measures as:

- *Network segmentation*: Isolate IIoT devices from other network segments to contain potential breaches.[25]
- *Strong authentication and authorization*: Implement multi-factor authentication and strict access control to ensure only authorized users and devices access the network. [5]
- *Encryption*: Encrypt data both in transit and at rest to protect it from interception and tampering. [12]
- *Regular updates and fixes*: Ensuring that all devices and systems are regularly updated with the latest security patches. [10]
- *Monitoring and detection of anomalies*: Using advanced monitoring tools and anomaly detection systems to identify and respond to suspicious activity in real time. [15]
- *Incident response planning*: Develop and regularly update incident response plans to quickly and effectively respond to cyber security incidents. [17]

Exploitation and analysis tools

- *Cobalt Strike*: An attack simulation and network defense testing platform used by security professionals and cybercriminals.
- *Empire*: A command-and-control framework was discovered that allowed attackers to control compromised systems.
- *Kali Linux*: An operating system specifically designed for penetration testing and vulnerability analysis, featuring multiple cybersecurity tools. [11]

6. Tools for ongoing evaluation and maintenance

- *Nessus*: A vulnerability scanning tool that identifies potential weaknesses in systems. [20]

- *OpenVAS*: A vulnerability management system that scans and assesses vulnerabilities in networks and systems. [23]
- *Snort*: Network intrusion detection and network traffic analysis tool. [3]

7. Preventive protection measures

The common preventive measures that companies apply are:

- *Regular updates*: Keeping software and systems up to date to protect against known vulnerabilities.
- *Password security*: Use of strong and unique passwords and implementation of two-factor authentication.
- *Training and awareness*. Constant training and caution when opening files and links from unknown sources, recognizing phishing attempts and safe browsing practices.
- *Monitoring and reaction*: Implementing incident monitoring and response systems to detect attacks in time and respond quickly.
- *Regular backup*: Regularly back up critical data and systems to recover information in the event of an attack. Maintaining up-to-date archives of important data. Storage of backup copies in a safe place - offline or in a cloud structure with enhanced security measures
- *Attention by email*: Beware of email attachments and links, especially from unknown or unsolicited sources.
- *Network security*: Implementing special network security measures, including firewalls and intrusion detection systems.

Understanding the tools and techniques used by hackers is an important part of building an effective cybersecurity and data protection strategy.

The information from this survey shows that more than half of the survey participants face challenges related to the many failed tools and individual solutions for data protection, security, sovereignty, localization, storage, and privacy. That information clearly shows the need for a multi-purpose and multi-aspect cyber security system that covers all processes and resources of industrial enterprises.

8. Multi-layered protection against cyber attacks

Based on the literature review and the study of global practices and in close cooperation with specialists in the field of information and communication technologies, the idea was born to develop a conceptual framework of a model for the multi-layered protection of all assets and processes of the industrial enterprise from cyber-attacks.

This defense against a cyberattack is a cybersecurity strategy that involves the use of several layers to prevent and minimize the risks associated with attacks. It is because no single defense mechanism is reliable, therefore several different systems are implemented at different levels to provide a more complex and sustainable protection.

Multi-layered cyber defense is an approach that involves the use of various defense measures at multiple levels to provide maximum protection against cyber threats. This approach is important because cybercriminals use a variety of methods and tools, and no single measure can provide complete protection. The protection provides flexible and comprehensive protection by combining different technologies and strategies to address diverse cybersecurity threats. By integrating various security measures and approaches, organizations can reduce the risk of successful attacks and provide a higher level of security to their systems and data. The need for this type of reliable protection is becoming more and more tangible and imperative, especially in industrial enterprises, given the fact that they create and operate a large volume of sensitive information about their products, processes, customers and partners, as well as for

scientific research, innovation, markets, contracts, etc., which is directly related to their competitiveness and sustainable development. This information is very often subject to malicious attacks.

IIoT and cybersecurity are critical aspects of modern industrial automation. As connected devices and systems increase, so does the risk of cyber attacks. Cybersecurity for IIoT is critical because these devices are often connected to the Internet and are vulnerable to various types of cyberattacks. Cyber attacks are a global problem and every organization needs to find the most secure and effective way to protect itself.

In the development of the concept of the model, well-known cyberattack protection tools were used, but they were integrated and interconnected in a system that provides three-layer protection against cyberattacks in real time to all assets, processes and resources of the enterprise. The model is universally applicable, and additional software modifications can be made for each specific enterprise, with a view to adapting it to the specifics of its activity.

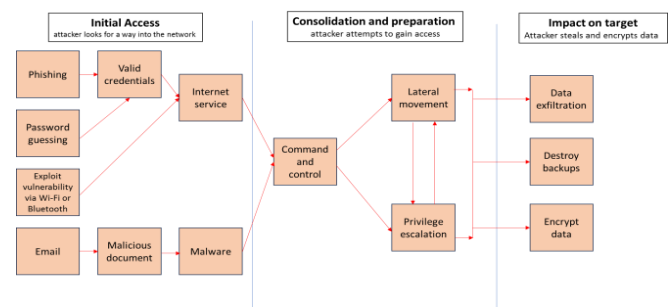


Fig. 1. A multi-layered cyber attack protection model designed for an industrial enterprise (Cybersecurity Framework)

The proposed network security concept is three-level:

First level (Initial Access) - at this level, the protections that operate stop the attacker and his access to the network by providing protection for the services performed in the Internet space (Internet-exposed services). The actions that are performed at this level are:

- Protection of Internet-exposed services act after Valid credentials and Exploit vulnerability and before Internet service,
- Correction of devices (Patching) works after Exploit vulnerability and before Internet service.
- Implementation of MFA (Multi-Factor Authentication) works before Valid credentials and before Internet services.
- Disable macros works after Malicious document and before Malware.
- Application allowlisting works after Malicious document and before Malware and also works at the end of Level 1 and before Level 2.
- Use of logging and alerting (Logging and alerting) operates immediately after Valid credentials, Exploit vulnerability and Malicious document and after the end of Level 1 and before Level 2.
- Password manager works after Password guessing and before Valid credential.

At the second level, Consolidation and Preparation, the defenses that work together to prevent an attacker from accessing network devices are:

- Correcting the devices (Patching), using network Network segmentation,
- Applying the principle of Principle of least privilege,
- Application of MFA (Multi-Factor Authentication)
- Logging and alerting usage.

All of these protections work after Command and control and before Lateral movement and Privilege escalation.

At the third level, Impact on Target, protections that try to stop or reduce the impact of an attacker from stealing or encrypting data are:

- Using Logging and alerting works before Encrypt data and Data Exfiltration. Using and maintains of (Backups) works before Destroy backups.
- Using a list of permitted applications (Application allowlisting) operates before Encrypt data.

These levels represent three layers of protection for all parts of the information system. The goal is that if one level is overcome by the attack, it will be stopped at the next levels, thereby limiting the damage to the security, data and information of the enterprise. The proposed protection framework provides an opportunity to significantly reduce the risk of successful attacks and improve the resilience of industrial systems and networks.

9. Conclusion

In an increasingly interconnected and digital world, robust vulnerability management is paramount to protecting critical information assets and maintaining the integrity of network infrastructures.

IIoT offers significant benefits to industrial processes, but these benefits come with new security risks that require a proactive and comprehensive approach to cybersecurity.

This study provides a comprehensive overview of the vulnerabilities of information security systems in industrial enterprises and the tools to counter cyber attacks against them. As a result of the study, a conceptual model of a system for multi-layered protection against cyber-attacks, designed for industrial enterprises, is proposed. The multi-layered protection provides an effective and reliable cybersecurity strategy that aims to minimize the risks associated with cyber-attacks. Different levels of protection provide a comprehensive approach to protecting data, infrastructure, and users, reducing the likelihood of successful attacks, and increasing the safety of the company across the country.

10. Acknowledgment

The authors express special thanks to Schneider Electric Bulgaria Ltd. and Testel Engineering Ltd. for the assistance provided in conducting the study and developing the concept of multi-layered cyber attack protection model.

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Transformation of industrial enterprises to a circular economy in the conditions of Industry 4.0

Krasimira Dimitrova
Technical University of Varna, Bulgaria
krasimira.dimitrova@tu-varna.bg

Abstract The transformation of industrial enterprises to a circular economy in the conditions of Industry 4.0 is a key step towards sustainable development and reducing the carbon footprint on the nature. The main objective of the circular economy is to reduce the waste and utilize resources as efficiently as possible by reusing, recycling and extending the life cycle of products. This transformation requires changes to both the production processes and the business models of enterprises. The transition of industrial enterprises to a circular business model will have a beneficial effect on the environment, increase their financial results and improve their competitiveness. The circular business model requires a rethinking of internal processes, products and strategies. This research aims to analyse the opportunities of industrial enterprises to rethink their product strategies, optimize resources, effectively manage waste and promote a circular organizational culture.

Keywords: INDUSTRY 4.0, CIRCULAR ECONOMY, SUSTAINABLE DEVELOPMENT, CIRCULAR BUSINESS MODEL, INDUSTRIAL ENTERPRISES

1. Introduction

The circular economy is an economic system that aims to eliminate waste and ensure continuous use of resources. It is in the context of the traditional linear economy that follows the "take, produce, throw away" model. The concept of circularity focuses on closing the product cycle by increasing resource efficiency and reducing waste.[8] Modern living conditions with great acuteness pose the question of more efficient use and management of limited natural resources.[4]

The transition of industrial enterprises to a circular economy within the framework of Industry 4.0 is a key step towards sustainable development and reducing the carbon footprint on nature. Industry 4.0 is a comprehensive system of information and knowledge that increases productivity, supports sustainability and optimizes process management.[5] The aim of the circular economy is to minimize waste and use resources as efficiently as possible by reusing, recycling and extending the life cycle of products. For the successful implementation of this transition, changes are needed both in the production processes and in the business models of the enterprises. As the transition to a circular economy is already underway, understanding its characteristics and current state is essential to create effective policies and strategies.[11] The main contribution that the circular economy can make to the strategic transition to a sustainable production model covers the entire life cycle of products that become waste after use and are recycled to feed the same or different life cycles.[3] Companies that are at an early stage of readiness for Industry 4.0 can strengthen their competitiveness by combining the principles of the circular economy with the technologies of Industry 4.0. The effect of combining circular economy and Industry 4.0 technologies can improve the overall performance of the company and become a source of distinctive competitive advantage.[10]

Moving to a circular business model will not only help protect the environment, but also increase companies' financial results and improve their competitiveness. The circular model requires a rethinking of internal processes, products and strategies. The present study aims to analyze the possibilities for the transformation of industrial enterprises' product strategies, resource optimization, effective waste management and the establishment of a circular organizational culture.

2. Main aspects of the transformation of industrial enterprises to a circular economy

The transformation of industrial enterprises towards a circular economy involves a series of strategic and operational changes aimed at creating a more sustainable and efficient resource management system. This transformation is a long and complex process that requires a change in mindset and adaptation at all levels of the organization. The transition to a circular economy brings not

only economic advantages, but also contributes to protecting the environment and building a more sustainable economy. The main aspects of this transition include:

1) Product redesign

Industrial enterprises must rethink the design of products to increase their durability, ease of repair and reuse. This includes using more sustainable materials that can be recycled or composted, and developing modular designs that facilitate repair and renovation. Incorporating circular economy principles at the initial stage of product design is essential, as once product specifications are defined, usually only minor adjustments can be made. Once resources, infrastructure, and activities are committed to a particular design, change becomes difficult to implement.[2] Already at the design stage, products can be planned to have a longer life cycle through the use of durable materials and modular components that are easily replaced and repaired. Innovative companies improve the economic environment by introducing new ideas, on the quality and quantity of which future business growth depends.[1]

2) Optimization of production processes and resources through digital technologies and automation

Process optimization focuses on waste minimization, energy conservation and efficient use of water and other natural resources. In this context, companies often introduce technologies such as automation, IoT and big data that enable precise tracking and control of resources. Concepts such as Industry 4.0 and the Internet of Things (IoT) enable enterprises to collect and analyze data in real time, making production processes more flexible and able to adapt to rapidly changing market demands. Technology and innovation not only improve production efficiency, but also impact product quality and sustainability and optimize resource management. The transition requires the introduction of technologies and practices that ensure efficient use of raw materials, energy and water, such as the integration of water recycling systems or the use of renewable energy sources in production activities. They facilitate the transition to a circular economy by enabling the traceability of resources throughout their life cycle.

3) Recycling and use of recycled materials

Industries are beginning to use secondary raw materials (waste products or recycled materials) instead of new resources. This reduces the need to extract primary materials and helps preserve natural resources. The recycling of waste materials is a key part of the circular economy. Industrial enterprises are working towards the integration of recycled materials in production, which helps to close the cycle of resources and reduce the dependence on new raw materials.

4) Extending the life cycle of products

The main approaches to extending the life cycle of products include repair, refurbishment, reuse and recycling, which allows materials and products to retain their value for as long as possible.

Models such as "product as a service" can also be applied, where companies instead of selling their products make them available for rent or through subscription. This incentivizes manufacturers to develop more durable products and retain control over them even after their initial use is over.

5) Partnerships and collaborations

For a successful transition to a circular economy, businesses need to work closely with other organizations, including suppliers, partners and even competitors. A good opportunity is the creation of industrial clusters, where waste from one production is used as a resource for another. Cooperation between industrial enterprises is a fundamental element for the realization of the circular economy, as it leads to the optimization of resources, the reduction of waste and the creation of new economic and environmental opportunities. Partnerships with governmental and non-governmental organizations also support businesses in the transition to a circular economy by finding funding opportunities, technical assistance and guidance on implementing sustainable practices. Through partnerships, businesses achieve sustainable development that brings benefits to both business and the environment.

6) User engagement

Consumer engagement in the circular economy is a key factor in the successful implementation of sustainable business models and practices. The circular economy cannot be fully realized without the active participation of consumers, who play an important role through their purchasing decisions, usage behavior and attitudes towards product reuse and recycling. The increasing demand for sustainable products is driving manufacturers to create products with a long life cycle, repair and recycling capabilities, and use environmentally friendly materials. Changing the mindset and behavior of consumers is also an important aspect. By educating customers about sustainable products and services, businesses can stimulate greater demand for green solutions, which will help build sustainable supply chains.

7) Change in business models

Traditional linear business models (production - use - disposal) must be replaced by circular models that encourage collaboration between different sectors and supply chains to ensure maximum use of resources and minimization of losses. An important aspect of the transformation is the internal management of sustainability processes. This includes creating dedicated sustainability departments that monitor and manage progress towards a circular economy and report to the public on the results of these practices.

3. Challenges in the transformation of industrial enterprises

Based on the analysis, it is established that there are a number of difficulties and challenges facing industrial enterprises on the way to their transformation to a circular economy. The majority of enterprises do not have a scientific basis, do not carry out independent research and development activities and do not have qualified personnel available for the development and implementation of new technologies.[7] The main challenges that industrial enterprises have to deal with in their transition to a circular economy are:

1) Technical complexity

The transition to a circular economy requires the implementation of new technologies and significant investments in infrastructure. Technology transfer is, in practice, one of the main approaches to achieving competitive advantage. It is specifically related to innovation in the manufacturing sector and is responsible for the integration of innovation activities in the economic sphere and the application of the achievements of scientific development. [6] In the conditions of Industry 4.0, the advantages of a higher scope, such as the ability of the sector to develop high-tech productions, to produce and export goods with an intellectual component and a higher degree of processing, are increasingly important. [6]

2) Regulations and standards

Support is needed from governments to create legislative frameworks to promote the circular economy, including standards for recycling, waste management and incentives for the use of renewable resources. Circular economy regulations and standards are important tools to promote sustainable resource management and waste minimization. They set frameworks and rules that encourage companies and consumers to adopt circular practices in production, consumption and waste management. These regulations and standards aim to facilitate the transition to an economy that is based on the reuse, repair and recycling of materials, while reducing harm to the environment.

3) Cultural changes

Cultural changes are a critical factor for the successful development of the circular economy, as its introduction requires a change in the way society perceives consumption, resources and waste. The traditional model of a linear economy based on production, consumption and disposal must be replaced by a new way of thinking that promotes sustainability, reuse and conservation of resources. The traditional maintenance and repair culture that was prevalent in the past is being encouraged again to extend the life cycle of products. Many companies are also starting to offer repair and refurbishing services, incentivizing customers to keep their products longer. The attitude of consumers and producers must change. It is necessary to promote more responsible consumption and raise awareness of the benefits of the circular economy. The cultural dimension affects not only the business sphere, but also the market, the behavior and the choice of customers.

4. Model for transformation of industrial enterprises to a circular economy

The transition to a circular economy offers long-term benefits for both industrial enterprises and the environment, while creating opportunities for innovation and new business models. The transition to a circular economy is a large-scale transformation that requires a new way of thinking and a different approach to business management. The more significant the technical or product innovation, the greater the challenges and the likelihood of the need for changes in established business models.[9] The transformation of industrial enterprises towards a circular economy includes strategic approaches and steps that aim to maximize resource efficiency, minimize waste and create sustainable products and processes. This requires the implementation of specific models to make this transition. Based on a literature review and studies in real enterprises where the transformation has already occurred or is in the process of implementation, a conceptual model is proposed that would help managers in industrial enterprises to plan and implement this transition to a circular economy in conditions of Industry 4.0 and to deal with challenges and problems more easily. (Fig. 1) The main transition stages in this model cover:

1) Analysis of the current state and identification of opportunities:

- Assessment of current flows of materials and energy, as well as waste products and opportunities for their reduction or recycling;
- Identifying key areas for improvement where resources can be used more efficiently or new sustainable practices implemented.

Analyzing the current state and identifying opportunities is an important process for any organization seeking to optimize its operations and thrive in a dynamic business environment. The main purpose of this analysis is to assess the current situation of the organization, to discover the strengths and weaknesses, as well as to identify new opportunities for growth and improvement.

2) Development of strategies for the transition to a circular economy:

- Choosing appropriate strategies such as recycling, re-use, extending the life cycle of products or developing "products as a service";

- Designing products and processes with a focus on sustainability and easy disassembly, repair or recycling. Developing strategies for the transition to a circular economy requires a comprehensive approach and coordination between different stakeholders. Industrial enterprises must commit to innovation, effective resource management, sustainable product design and cultural change. These strategies, when applied consistently, contribute not only to environmental protection, but also to economic benefits, while promoting social responsibility and long-term sustainability of businesses and society as a whole.

3) Technological transformation and innovation:

- Investing in basic and innovative technologies that support the circular economy, such as waste management systems, digitization to track resources and 3D printing for recycled materials;

- Using automation and digital twins to optimize processes and minimize waste.

Technological transformation and innovation are key drivers for implementing the circular economy, as they enable companies to develop sustainable business models that maximize resource utilization and minimize waste. Innovating in the circular economy is transforming the ways products are designed, manufactured, used and recycled.

4) Supply chain integration:

- Creating sustainable supply chains that include partners for the collection and processing of waste materials;

- Applying methods to effectively track and manage materials along the supply chain, encouraging collaboration for resource reuse.

Supply chain integration in the circular economy is a process that requires collaboration, innovation and flexibility. Through closed chains, traceability, reverse logistics and partnerships, companies can achieve significant economic and environmental benefits.

5) Development of new business models:

- Shifting to service-based business models, such as renting, sharing or selling "functionality" instead of a product;
- Creating hybrid models that combine the traditional sales approach with circular economy models.

Each model offers different opportunities for industrial enterprises, allowing optimization of processes, reduction of the ecological footprint and long-term preservation of competitiveness. These new approaches in business models create a sustainable basis for future economic development by promoting a responsible attitude towards resources and the environment.

6) Sustainability assessment and monitoring:

- Building systems for measuring and evaluating the environmental, social and economic sustainability of products and business processes;

- Using metrics such as carbon footprint, resource savings and social impact to track progress towards sustainability and efficiency.

Assessing and monitoring the sustainability of industrial enterprises in the circular economy is complex but vital to a successful transition to a circular economy

7) Creating an organizational culture oriented towards change and learning:

- Training employees for a new way of thinking through circular economy and environmental responsibility training;
- Promoting a culture of innovation and sustainability where all levels of the organization understand and support circular practices.

These measures will create a culture where sustainability is not only understood but supported by all employees. The organization will be able to achieve long-term success in the circular economy, with all levels working in sync and sharing common goals.

The proposed model aims to help industrial enterprises more easily adapt to changes in the economic, social and technological

environment. It is also aimed at increasing their ability to respond to market fluctuations, new competitive threats and changes in consumer preferences. Flexibility is a key factor in increasing competitiveness and ensuring sustainability. It is of particular importance in the modern world that industrial enterprises form behavior oriented towards effective strategic management of resources, implementation of innovative technologies, constant quality control and adaptability to external changes. The conceptual foundations of the model are based on a combination of different management approaches, strategic directions and technical aspects that influence the efficiency and sustainability of all processes in the industrial enterprise. This model is cyclical and requires continuous improvement and adaptation to new technologies and market demands, each step contributing to a more sustainable and efficient economy. Effective measurement of sustainability requires the use of clear and reliable indicators and tools that reflect the environmental, economic and social aspects of the circular economy.

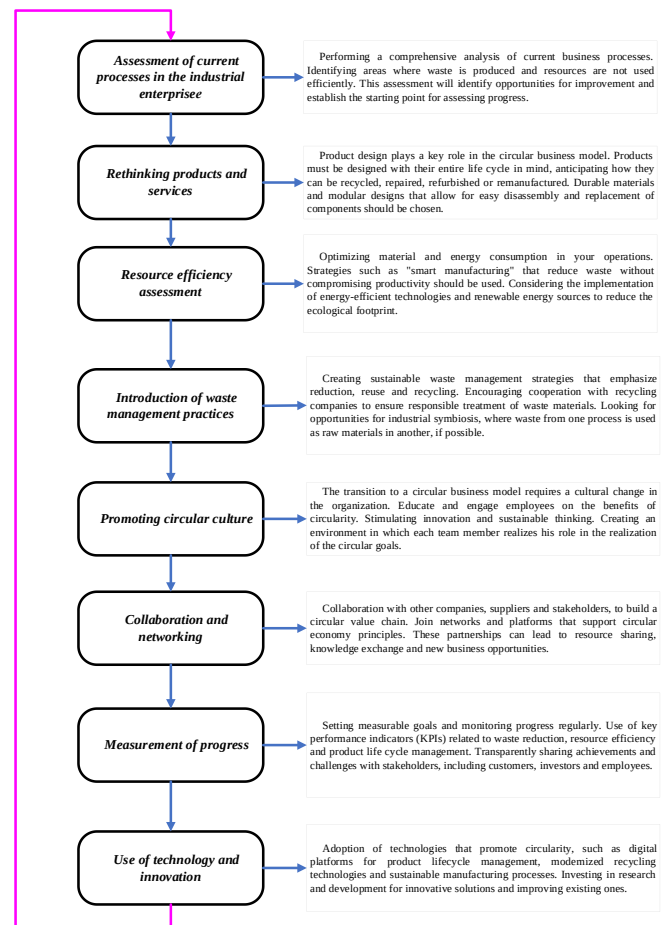


Fig. 1 A model for transformation of industrial enterprises to a circular economy

For the implementation of the model, a program has been developed, which includes 4 main sections:

1) Diagnosis of the condition and identification of environmental hazards

This includes:

- environmental pollution and their corresponding characteristics and parameters as a result of the enterprise's production activity;
- sources, causes and trends of pollution;
- environmental problems;
- the importance of the identified environmental problems, according to quantitative assessments, but different groups and criteria.

Diagnosis of the condition and identification of environmental hazards are critical activities aimed at preventing environmental risks and protecting natural resources and human health. Early

identification of hazards allows preventive measures to be taken to reduce or eliminate the negative impact on nature. This prevents future problems that could be more expensive and difficult to fix.

2) Setting goals

Precise formulation of the main goals and sub-goals and an easily understandable algorithm of activities and their sequence. The main goal is formulated as a result of the diagnostics of the processes in the entire system. When formulating it, economic, social, political and other factors are taken into account. The goals and sub-goals should aim at a differentiated, logical movement towards tackling environmental problems, step by step. Objectives must meet the following requirements:

- to be feasible;
- not to contradict each other;
- be relatively flexible and adapt to changing external factors;
- are based on objective information and are understandable;
- be measurable and allow reporting of the achieved results.

This part of strategic planning contains a set of activity tasks that define different strategies and tools to achieve the goals, such as:

- standards - creation and improvement of the legal framework;
- investments - development and implementation of investment projects, technical activities, implementation of technologies;
- organizational and technical measures - changes in the organization, technologies to achieve better environmental indicators.

3) Resource provisioning

The resource part of the program includes:

- summary assessment of the set of necessary resources;
- sources of resource provision;
- resource allocation tasks;
- allocation of resources by the implementing organizations.

4) Organization and management of the transition to a circular economy

The transition of the industrial enterprise to a circular economy requires the reorganization of its structures and processes so that they meet the new requirements for sustainable production, resource management and waste minimization. Effective management in this transition includes strategic planning, integration of new technologies, and continuous improvement approaches to business processes. The successful application of circular principles and the achievement of competitive advantages in an increasingly sustainable and ecological market depend on a systematic approach and commitment at all levels of the enterprise. The choice of management model, especially in the manufacturing sector, becomes a strategic factor in the transition to a circular economy oriented business model. [3]

The model and the program have been developed in close cooperation with managers from various industrial areas, who are interested in finding effective ways to practically implement the transition to a circular economy.

5. Conclusion

Adopting a circular business model can bring significant economic benefits, including cost savings through efficient use of resources, new revenue streams from recycled materials, and increased customer loyalty through sustainable practices. In addition, such an approach contributes to environmental sustainability by reducing waste and conserving natural resources. A business transition to a circular model is a strategic move that can ensure long-term sustainability and profitability. By rethinking products, optimizing resources, managing waste effectively and promoting a culture of circularity, companies can thrive in conditions of limited resources. This transformation will contribute to a more sustainable future and achieve competitive advantages.

This study contributes to the understanding of Industry 4.0 technologies and their relationship to sustainability, setting the stage for future research in this area. Future work will cover key aspects such as the supply chain, key technologies and infrastructure, as well as the development of methods to assess the environmental, social and economic sustainability of circular products and business models. Future research will concentrate on the cooperation between all stakeholders in the production chain, placing a strategic emphasis on actors involved in recycling and recovery activities.

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Integration of methods based on artificial intelligence in the processing of images in photography

Stefanov Ivan¹, Ivanova Eleonora¹

¹Faculty of Computer Systems and Technologies, Technical University - Sofia, Blvd. Kliment Ohridski 8, 1000 Sofia, Bulgaria

E-mail: ivan.ts.stefanov@tu-sofia.bg, el_ivanova@tu-sofia.bg

Abstract: The article examines modern artificial intelligence technologies used in photo processing, as well as their capabilities and limitations. The focus is on machine learning and deep learning algorithms that automate image editing processes, improve photo quality, and create unique artistic effects. The article also explores the ethical and technical limitations associated with the use of AI, such as processing quality, technology availability, and the impact on photographers' creative process. The author describes the prospects for the further development of AI in the field of image processing and its potential to transform approaches to visual art. The article will be useful to both professional photographers and researchers interested in the intersection of technology and artistic expression.

KEYWORDS: GENERATIVE ARTIFICIAL INTELLIGENCE; COPYRIGHT; PHOTOGRAPHY; INTELLECTUAL PROPERTY; AUTHOR; ARTIFICIAL INTELLIGENCE

1. Introduction

The relevance of the study is due to several key factors that indicate the importance and relevance of this problem.

First, with the increasing availability of digital technology and the increasing volume of visual content created, photo editing is becoming an important aspect in various fields, from professional photography to social media and marketing. Artificial intelligence (AI) offers new tools and techniques to improve image quality, automate editing processes and create unique visual effects [1].

Second, AI technologies such as machine learning and neural networks show impressive results in image recognition, detail recovery, and styling tasks. This opens up new horizons for creative professionals, allowing them to realize ideas that were previously unavailable or required a significant investment of time.

2. Image analysis

However, despite the many advantages, the use of AI in photo processing also raises a number of questions and limitations. This includes ethical considerations [2] related to copyright, image manipulation and potential reality distortion. Furthermore, technological limitations may affect the quality of the resulting work as well as the accessibility of such tools to a wider audience.

The purpose of this research is to comprehensively analyze the current artificial intelligence technologies used in the field of photo processing in order to identify their potential to improve the quality of visual content, as well as to determine the existing limitations and ethical aspects of the use of these technologies.

In our fast-paced world, we are faced with a huge number of photos every day. From social media to advertisements, images are everywhere. Some of them captivate our attention for a long time, and others seem elementary and insignificant. There are many ways to improve the quality of your photos and make them more pleasing to the eye. Artificial intelligence and advanced technologies help us turn ordinary photos into true works of art. Modern image editing programs offer various functions [3, 4]: from color and contrast correction to removing unnecessary elements and correcting imperfections in the photo. This is where artificial intelligence manifests itself by automating the process of image processing and corrections. With the development of artificial intelligence and the expansion of its capabilities, a new era has dawned in photo processing. Artificial intelligence has become an indispensable tool for enhancing and transforming images thanks to its new algorithms. Its role in photo processing cannot be overstated. Artificial intelligence improves image quality by removing noise, increasing sharpness and expanding dynamic range. It also automatically adjusts the color balance and brightness of photos and removes unwanted defects such as dust and scratches. Using machine learning techniques, artificial intelligence is able to recognize objects and faces in photos and automatically perform retouching, improving contrast and adjusting lighting. This allows you to create impressive and professional images without having to manually adjust each element. Thanks to artificial intelligence, everyone can benefit from modern photo processing techniques. The use of AI in image processing speeds up the process and

improves the results, making them more realistic and attractive [5, 6]. Artificial intelligence plays an important role in photo processing, providing the ability to improve quality, retouch and automatically optimize images. Anyone can become a professional photographer and create amazing images without having extensive knowledge and skills in photography and image processing. Today's innovative approaches provide capabilities that go beyond simply changing color saturation or removing noise. Using artificial neural networks, photographers have access to tools that can enrich images by imparting new textures and styles, changing shape and perspective, and creating realistic simulations of photographic effects and settings. Intelligent exposure correction, automatic removal of defects, restoration and restoration of old photos, creation of images that resemble artistic masterpieces, advanced retouching and processing of portraits - all this is possible thanks to the new capabilities of artificial intelligence.

3. The methods of evaluating the quality of photographs using intelligent algorithms

Let's look at the methods for evaluating the quality of photos using smart algorithms (Table 1). Thanks to artificial intelligence, it is possible to accurately determine the level of image quality without taking into account the subjective preferences of a person. The analysis is based on various image parameters, including clarity, color rendering, contrast, and more.

Table 1. Photo quality assessment methods using intelligent algorithms

No	Methods	Description
1	Comparison with reference images	Intelligent algorithms process the provided selection of images and determine the main quality criteria. The new image is then compared to reference samples and the degree of agreement is determined
2	Human Perceptual Processing	From an aesthetic point of view, an intelligent algorithm evaluates how well an image matches a person's perception. This includes studying structure, harmony of hues and tones, and assessing the level of noise and distortion
3	Statistical methods	Using a large amount of data, the artificial intelligence is trained to recognize patterns between the quality of photos and their characteristics. Based on such training, the algorithm can evaluate the quality of the new image

Using AI to assess photo quality opens up many possibilities. This helps you choose the best images for print, contests, advertisements, and other areas where image quality matters. Image enhancement includes various procedures such as improving clarity [7], removing noise, adjusting brightness and contrast [8] and adjusting color balance. To qualitatively modify the color properties of the image, color correction methods are actively

used. They allow you to change the shades, saturation and brightness of colors, which makes the image more saturated and expressive. You can also use color correction to balance whites and correct color distortions caused by incorrect exposure or lighting. Another key aspect to improving image quality is noise reduction. Noise in photos can occur due to various factors, such as low lighting, high camera sensitivity, or poor lens quality. There are various noise filtering methods that help improve image quality and make it clearer and more detailed. Automatic retouching [9, 10]: is based on computer vision and machine learning algorithms. These algorithms analyze the image for various defects such as spots, scratches, wrinkles and other unwanted elements. The program then automatically applies appropriate corrective methods to correct these defects. Thus, the retouching process is optimized and performed automatically without human intervention. Various algorithms and methods are used to effectively use automatic retouching and defect removal. For example, one of the most popular approaches is to use filters and improve the contrast of the image, which helps to hide small imperfections, making the photo more attractive and natural. Machine learning methods are also used, which allow the program to learn to recognize and remove certain defects, thereby increasing the accuracy and efficiency of processing. It is important to note that automatic retouching and removal of defects does not replace professional retouching and work with Photoshop, but it can save time and effort when processing many photos. Additionally, these techniques can be useful for those who don't have specialized retouching skills but want to improve their photos.

4. Using neural networks

Here are some key areas where neural networks are used in image processing:

- Image quality improvement:

Super resolution: Neural networks can increase the resolution of images by adding details based on learned patterns in other images.

Noise Reduction: Used to remove noise and artifacts from photos, improving overall quality.

- Image segmentation:

Neural networks such as U-Net are used to segment an image into different regions, enabling precise object and detail extraction, which is useful in medicine, autonomous transportation systems, and other fields.

- Object recognition:

Networks such as YOLO (You Only Look Once) and SSD (Single Shot Detector) are used to identify and locate objects in images with applications in video surveillance, security and autonomous driving.

- Style transfer:

Neural networks can change image styles by applying the style of one picture or photo to another, creating unique artistic effects.

- Data Augmentation:

Neural networks can create new images from existing ones, which helps train other models and increases the amount of data available.

- Automatic coloring:

Networks can colorize black and white photos by using trained models on color images.

- Generate new images:

Generative adversarial networks (GANs) are capable of creating new, realistic images that can be used in art, fashion and design.

- To create filters and effects:

Algorithms based on neural networks allow you to create photo filters that change the lighting, color palette and other aspects of the image. Each of these areas opens up new possibilities for creative and professional use of photos, improving the quality of processing and expanding the tools available to artists and photographers. The abundance of data contributes to a deeper understanding and analysis of various image features by neural networks, such as palette, contrast and clarity. The richer the data set, the more opportunities the network has to develop skills to recognize and reproduce certain elements in photos. Rich data allows neural networks to learn from a wide variety of images covering different

scenes, objects and lighting conditions. This, in turn, leads to increased accuracy and quality of results in image processing and enhancement. [11]:

Artificial intelligence in photo processing offers many opportunities to improve and automate processes, but it also brings limitations and risks. By balancing the use of technology with remaining creative, photographers can make the most of AI in their work. The development of AI technologies in photo processing continues, and every year new opportunities and tools appear to improve the quality and creativity of photos. It is important to choose the right tools and technologies for a specific task and not to forget about the creative approach to image processing.

5. Conclusion

The use of artificial intelligence in the world of photography represents a significant innovation that is changing both the technical aspects of capturing and processing images, as well as the creative process of creating photos. AI offers benefits such as making processes more efficient, automating routine tasks, enhancing creativity and increasing access to quality photos for a wider audience.

However, the use of AI also raises concerns related to issues of authorship and originality, loss of individuality in creativity, ethical dilemmas, and a possible decrease in demand for professional photography services. These discussions reflect deeper questions about the role of technology in art and creativity in general.

Thus, AI in photography is a powerful tool that can enrich the photography industry, expand the boundaries of creativity, and make the art of photography more accessible. It is important to strike a balance between using technological innovation to empower others and preserving the human element that is at the heart of creative expression in photography.

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ALB-Stanza: A Stanza-based parser for the Albanian Language

Nelda Kote^{1,*}, Anila Çepani², Rozana Rushiti², Alba Haveriku¹, Elinda Kajo Meçe¹
 Polytechnic University of Tirana, Albania¹
 University of Tirana, Albania²
 nkote@fti.edu.al

Abstract: Fundamental tasks in Natural Language Processing include Part-of-Speech tagging, lemmatization, and dependency parsing, which provide crucial linguistic information essential for a wide range of NLP applications. POS tagging assigns each word in a sentence its grammatical category. Lemmatization identifies the dictionary form of each word, considering its contextual usage within the sentence. Dependency parsing, on the other hand, determines the structural relationships between words, producing dependency trees that capture the grammatical organization of sentences. In this paper, we introduce ALB-Stanza, a neural pipeline parser designed for sentence segmentation, tokenization, POS tagging, morphological feature annotation, lemmatization, and dependency parsing specifically for the Albanian language. To train the ALB-Stanza parser model, we used our own corpora annotated according to the Universal Dependencies schema and the Stanza neural pipeline. The model was evaluated on unseen data, demonstrating its effectiveness in accurately predicting POS and morphological feature tags, lemmas, and dependency relations for text in Albanian language.

Keywords: PART-OF-SPEECH, LEMATIZATION, PARSING, ALBANIAN LANGUAGE, STANZA

1. Introduction

The Albanian language represents a distinct branch of the Indo-European language family. It is the official language of Albania and Kosovo, a co-official language in the Republic of North Macedonia and is widely spoken within the large Albanian diaspora communities worldwide. Albanian is a linguistically rich language characterized by a grammatically complex structure and an intricate inflectional system, making it particularly interesting for morphological and syntactic annotation.

Despite some efforts to develop Natural Language Processing (NLP) tools for Albanian, it remains classified as a low-resource language due to the limited availability of annotated corpora, linguistic resources, and dedicated NLP tools. Addressing this gap is critical for advancing linguistic research and enabling the development of modern NLP applications for Albanian language.

NLP is a rapidly advancing field that aims to equip machines with the ability to process and understand human language. Foundational tasks such as Part-of-Speech (POS) tagging, lemmatization, and dependency parsing are pivotal in providing linguistic annotations that enable advanced NLP applications like machine translation, text summarization, and information retrieval. These tasks make possible detailed insights into the grammatical and syntactic structure of a language.

Part-of-Speech (POS) tagging involves assigning grammatical categories to words, such as nouns, verbs, and adjectives. Lemmatization refines this process by identifying the dictionary or canonical form of a word while considering its context. Dependency parsing extends this linguistic annotation by capturing syntactic relationships between words, resulting in dependency trees that illustrate sentence structure and grammatical dependencies. Together, these tasks facilitate deeper language understanding and enhance the performance of NLP tasks.

In this paper, we introduce ALB-Stanza, a neural pipeline parser for the Albanian language. ALB-Stanza integrates sentence segmentation, tokenization, POS tagging, morphological feature annotation, lemmatization, and dependency parsing. Built on the Stanza neural pipeline and trained using our Albanian treebank, which is annotated with the Universal Dependencies (UD) schema and consists of 24,537 tokens, this parser represents a significant advancement in addressing the linguistic complexities of Albanian.

The rest of the paper is organized as follows: Section 2 reviews related work on NLP tools and resources for Albanian language. Section 3 provides an overview of the UD Standard Albanian Treebank, detailing its annotation process and linguistic scope. Section 4 describes the development and evaluation of the ALB-Stanza model. Finally, the conclusion discusses the contributions of this work, its limitations, and potential directions for future research.

2. Related Work

Small scale and restricted research works have been conducted for the Albanian language, most of them being not available to be used for further studies. This means that the research on POS tagging and dependency parsing for Albanian is still in its initial steps, compared to highly studied languages such as English, German or French. The Albanian language has a rich morphological structure, but it has a limited attention in the NLP field. Approaches used for Albanian language relied on rule-based approaches. Meanwhile, nowadays more and more machine learning and deep learning based approaches are being considered to conduct studies in low-resource languages such as Albanian.

Regarding POS tagger for the Albanian language, we emphasize works presented by authors in papers [1-10]. The papers [5-14] contributed with small corpora and tag sets for standard Albanian and the Gheg dialect. The authors in [6] present a corpus in Albanian, containing 2,020 sentences and 31,584 tokens in total, used to train and test six different POS taggers. The accuracy of the model varies from 85.96% to 95.10%. In paper [7] is presented a corpus of 118,000 tokens, tagged morphologically following the Universal Dependencies (UD) scheme and a neural pipeline morphological tagger and lemmatizer.

The corpus [10], composed of 16.6 million tokens, represent the largest corpus used for a POS tagger in Albanian language, developed by the Saint Petersburg Institute. This corpus covers grammatical categories, such as nouns, verbs, pronouns. Despite this, the before mentioned research is not open, and does not provide the possibility to download the annotated corpora.

The UniMorph project [11] includes a small, annotated corpus for Albanian in morphological tagging. It is annotated based on the UniMorph schema and its features. The size of the corpus is 33,483 words, and 589 lemmas.

The sq-Globe corpus total [12], that has been created by the Beijing Foreign Studies University includes 1 million words annotated with PoS tags, allowing linguistic exploration, but still not available for download and impractical for NLP system.

The authors in paper [13] published the first official Albanian UD treebank with 60 annotated sentences. Later, in paper [14], the first UD treebank for the Gheg dialect of the Albanian language was presented. Our previous work, presented in paper [15], introduced the largest UD-annotated treebank for the Albanian language annotated by expert linguistics.

3. The UD Standard Albanian Treebank

The UD Standard Albanian Language treebank [15], used to train the proposed model in this paper, was developed in our previous work. The annotated treebank contains 24,537 tokens

(1,400 sentences), annotated with lemmas, part-of-speech tags, morphological features, and syntactic dependencies using the Universal Dependencies (UD) framework [16]. This comprehensive annotation allows for detailed syntactic analysis and serves as a valuable resource for developing NLP tools for the Albanian language.

Universal Dependencies (UD) [16] is a framework for advanced research in morphological and syntactic annotation across multiple languages. The aim of UD is to provide a standardized approach to linguistic annotation, facilitating cross-linguistic comparison and analysis. UD enables the consistent representation of grammatical structures in a multilingual context, supporting a wide range of languages with varying syntactic and morphological characteristics. Based on universal principles, UD promotes a unified methodology for linguistic annotation, for the development of robust NLP tools. The annotation in the UD schema is based on the principle that each token in a sentence must be assigned a distinct, individual tag, ensuring precise linguistic representation for every word.

The treebank text was collected by selecting sentences from grammar books, fiction books, and the Leipzig Corpora Collection, ensuring the use of open-source resources to make the data publicly available online. This diverse selection of sources enhances the linguistic richness of the treebank, making it representative of different styles and registers of the Albanian language.

The annotation of the treebank was done entirely manually by two expert linguists. This careful, manual annotation ensures a high level of accuracy and consistency, making the treebank a reliable resource for linguistic analysis and NLP applications.

The annotation based on the UD scheme includes:

- Sentence segmentation – Dividing the text into individual sentences based on punctuation.
- Word segmentation – Separating each word within a sentence using whitespace and punctuation marks, while also considering the synthetic-analytical nature of the Albanian language.
- Lemmatization – Assigning each token its dictionary form, taking into account the meaning of the word in context.
- Part-of-speech tag – Assigning each token the corresponding part-of-speech tag based on the context in which the word is used.
- Morphological features tags – Assigning each token a morphology feature tag based on its POS tag.
- Syntactic annotation – Identifying syntactic dependency relations between tokens within a sentence, based on the sentence structure.

This detailed syntactic annotation enables deeper linguistic analysis and enhances the performance of NLP applications.

The treebank contains of 24,537 tokens (14,000 sentences), including 87 multiword tokens, with an average sentence length of 18 words.

The treebank is saved in CoNLL-U [17] format. This format organizes the annotated data in a tabular structure, where each row represents a token, and the columns include information such as token ID, word form, lemma, part-of-speech tag, XPOS tag, morphological features, as well as the head and DEPREL for syntactic dependencies, and DEPS and MISC for any additional annotations.

We have used a total of 17 POS tags, with different morphological feature tags assigned depending on the part of speech, as shown in Table 1.

Table 1: List of POS tags and morphological features

	POS tag	Morphological features
verb	VERB / AUX	mood, time, person, number, voice; *verb form only in case of participle
noun	NOUN	gender, number, case, definiteness
proper noun	PROPN	gender, number, case, definiteness; Abbr in case of abbreviation
adjective	ADJ	gender, number, case, degree
pronoun	PRON	depends on the type (case, number, gender, person, prontype)
adverb	ADV	AdvType
numeral	NUM	NumType
interjection	INTJ	
preposition	ADP	case
particle	PART	
conjunction	CCONJ / SCONJ	
articles	DET	gender, number, case and prontype
symbols	SYM	
punctuation marks	PUNCT	
others	X	Abbr in case of abbreviation

A total of 42 tags have been defined for syntactic dependencies and a complete list of these tags is provided in Table 2.

Table 2: List of syntactic dependency tags

Tag	Tag
nsubj	mark
nsubj:pass	nmod
nsubj:outer	Appos
obj	nummod
iobj	Acl
csubj	Amod
csubj:pass	det
csubj:outer	clf
ccomp	case
xcomp	conj
obl	cc
case	fixed
vocative	flat
expl	compound
dislocated	list
advcl	parataxis
advmod	goeswith
advmod:emph	reparandum
discourse	punct
aux	root
cop	dep

Annotating text in the Albanian language, both morphologically and syntactically, is a challenge. The Albanian language is grammatically rich, and adapting annotations to a uniform schema like UD requires us to make important choices.

Fig. 1 shows an example of an annotated sentence with a compound verb in the Albanian language. According to the UD schema, each token must be annotated with an individual tag, which presents significant challenges when annotating complex constructions, such as compound verb forms and adjectives in their comparative and superlative degrees. Compound verb forms in Albanian combine two verbs, a verb with an adverb, or a verb with an article. The future tense, expressed analytically with auxiliary particles like “do” and “te” plus an inflected verb, lacks explicit mood or tense representation in the annotation, demanding precise tagging. Even the comparative and superlative degrees of adjectives, which are formed analytically through multi-word constructions rather than morphological inflection, cannot be annotated within the UD schema.

For comprehensive details on the corpus annotation process, please refer to the referenced paper [15].

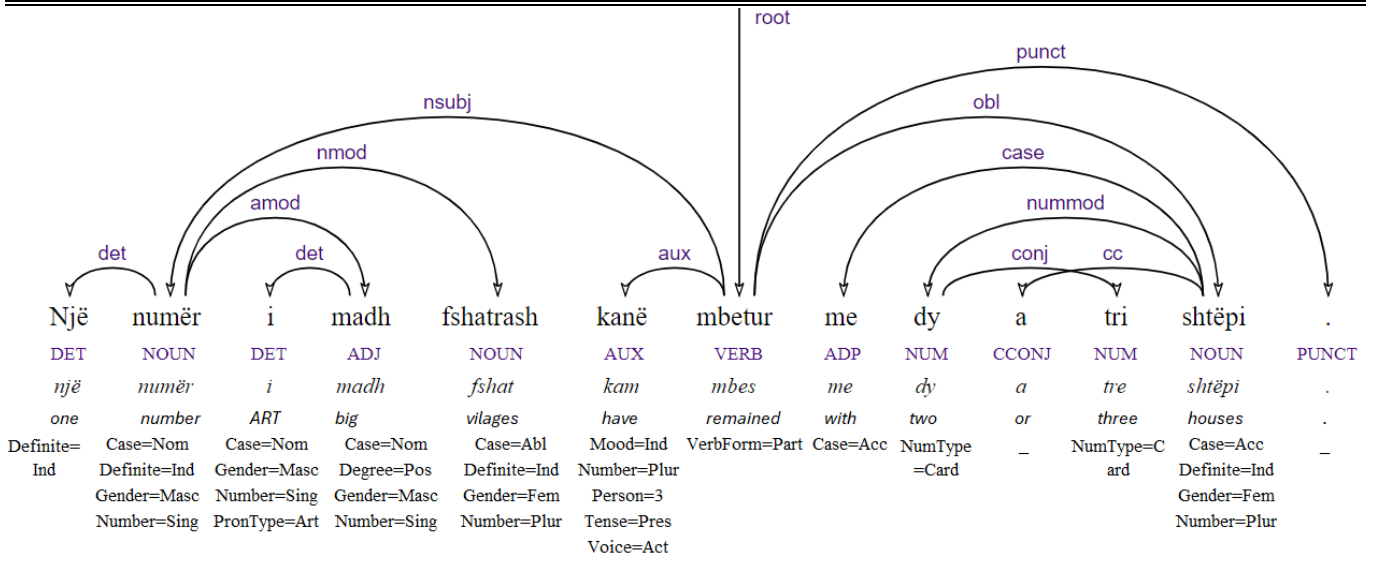


Fig. 1 Annotated sentence in Albanian language.

4. Albanian Stanza Model

In this section, we detail the training and evaluation process of the ALB-Stanza parser model. To develop this parser, the Stanza neural pipeline [18] was trained and tested using the Albanian treebank data described in Section 3. The training process was designed to optimize the model's performance in accurately predicting linguistic annotations, including Part-of-Speech (POS) tags, morphological features, lemmas, and dependency relations, while the evaluation focused on assessing its effectiveness on unseen data.

Stanza [18] is a Python-based NLP toolkit developed by researchers at Stanford University. It provides complete NLP neural pipeline for sentence segmentation, tokenization, POS tagging, morphological analysis, lemmatization, dependency parsing and Named Entity Recognition (NER). As a neural model it is designed to be used with a wide range of languages. Stanza supports over 70 languages using models trained on UD treebanks, making it particularly suitable for cross-linguistic research and low-resource languages. Stanza is a neural network model based on sequence-to-sequence models with Bi-LSTM layers, enhanced with pre-trained word embeddings for robust language representation and processing.

To train our model, we utilized the following processors: TokenizeProcessor, POSProcessor, LemmaProcessor, and DepparseProcessor. Pretrained word vectors from the Albanian FastText embeddings [19] were employed to enhance the model's performance. The corpus was divided into training, development, and test sets. For the test corpus, we specifically selected sentences unrelated to those in the training set to ensure a more accurate and unbiased evaluation of the model's performance. We used the default configuration of Stanza in the training.

Tables 3 and Table 4 present the evaluation results of the ALB-Stanza trained parser model. The model's performance is evaluated across several key linguistic processing tasks, including sentence segmentation, token segmentation, part-of-speech (POS) tagging, morphological feature tagging, and lemmatization, with metrics such as precision, recall, and F1-score used for evaluation. Additionally, the performance of the syntactic dependency annotation is measured using standard metrics: Unlabeled Attachment Score (UAS), Labeled Attachment Score (LAS), Complete Labeled Attachment Score (CLAS), Morphology-Aware Labeled Attachment Score (MLAS), and Bilexical Dependency Score (BLEX), providing a comprehensive analysis of the parser's accuracy and robustness.

Table 3: Albanian Model evaluation

Annotation	Precision	Recall	F1 Score
Sentence	95.45	97.67	96.55
Token	99.81	99.52	99.67
Words	99.33	98.96	99.14
UPOS	93.90	93.54	93.72
UFeats	69.30	69.04	69.17
All tags	67.97	67.71	67.84
Lemma	87.42	87.08	87.25

Table 4: Albanian Model evaluation for syntactic dependencies

Annotation	Precision	Recall	F1 Score
UAS	82.65	82.34	82.49
LAS	70.83	70.56	70.69
CLAS	65.05	63.81	64.42
MLAS	35.28	34.60	34.94
BLEX	52.91	51.90	52.40

The results achieved across these tasks underscore the robustness and reliability of the ALB-Stanza model as an effective tool for processing text in Albanian language. The evaluation demonstrates high performance in fundamental linguistic tasks, such as Tokenization (99.67 F1) and Word Segmentation (99.14 F1), alongside commendable results in Sentence Segmentation (96.55 F1) and UPOS tagging (93.72 F1). These findings highlight the model's precision and applicability in handling core aspects of Albanian language processing.

However, the evaluation also reveals areas requiring improvement, particularly in capturing morphological features (69.17 F1), all tags (67.84 F1), and syntactic dependencies, where scores for UAS (82.49 F1) and LAS (70.69 F1) are moderate, and performance in CLAS (64.42 F1), MLAS (34.94 F1), and BLEX (52.40 F1) is less robust. These results suggest the model is effective for basic and intermediate NLP tasks while highlighting the need for enhancements to handle more complex morpho-syntactic and syntactic interactions.

Overall, the evaluation validates the Albanian parser as a reliable and practical tool for many real-world NLP applications. With targeted improvements, it holds great potential to fully meet the demands of Albanian language processing across diverse and advanced tasks.

5. Conclusions

In this paper, we introduced the ALB-Stanza parser, a neural pipeline designed for comprehensive linguistic annotation tasks, including sentence segmentation, tokenization, Part-of-Speech

(POS) tagging, morphological feature annotation, lemmatization, and dependency parsing for text in the Albanian language. The model, built on the Stanza neural pipeline and trained on our annotated Albanian treebank, has archived a high performance in some core NLP tasks, offering valuable insights into the linguistic structure of Albanian language.

The evaluation results confirm the model's robustness in key tasks. The ALB-Stanza parser achieves high precision scores for Tokenization (99.81), Word Segmentation (99.33), and Sentence Segmentation (95.45), demonstrating its reliability in handling fundamental text processing. Similarly, UPOS tagging (93.90) and Lemmatization (87.42) further validate its accuracy in essential linguistic annotations. The parser also performs well in dependency parsing, with UAS (82.65) and LAS (70.83) indicating its effectiveness for syntactic analysis. Nevertheless, lower scores for CLAS (65.05), MLAS (35.28), and BLEX (52.91) highlight challenges in handling morpho-syntactic dependencies and advanced syntactic phenomena.

Our contributions address a critical gap in Albanian NLP, providing a reliable and good-performing tool for a low-resource language like Albanian. With the development of ALB-Stanza, we provide a tool that can aid in advancing Albanian language processing for a range of NLP applications, such as machine translation, information extraction, and semantic analysis.

However, despite these promising results, there are areas for further improvement. The model's performance in complex syntactic dependency tasks indicates the need for additional work, such as refining annotations and expanding the training treebank with diverse and representative data. These efforts could improve the parser's generalization and accuracy in morpho-syntactic interactions and dependency parsing.

In conclusion, the ALB-Stanza parser represents a significant advancement in Albanian NLP and lays the groundwork for further research and development of more sophisticated tools for the Albanian language. We hope that this work will inspire further development of NLP resources and tools for the Albanian language and similar low-resource languages.

As future work, we aim to focus on expanding the treebank by systematically identifying and addressing annotation errors generated by the model. This process will involve analyzing specific areas of mis annotation to better understand the model's limitations. Additionally, we plan to enhance the dataset by incorporating sentences with more complex linguistic structures, ensuring broader coverage of syntactic and morpho-syntactic phenomena. This enriched treebank will not only improve the model's performance but also contribute to the development of a more robust and comprehensive resource for Albanian language processing. Additionally, our corpus contains certain annotations that do not fully align with the universality of the UD annotation schema. Addressing these inconsistencies will be a priority in the near future, as we aim to refine the annotations to ensure compliance with UD standards and enhance the model's interoperability within the broader UD framework. Once these improvements are completed, the enhanced treebank will be published online as part of the Universal Dependencies (UD) project, making it accessible to the broader research community and supporting further advancements in Albanian NLP.

6. Acknowledgements

We sincerely thank the National Agency for Scientific Research and Innovation for funding this project through the National Research and Development Program.

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Design of an Industry 4.0-Based, Vertically Angular Automated Line Separator

Tahsin Topbaşoğlu¹, Enes Bitigen¹⁻², Ali H. Nazik¹⁻², Onur Çimen¹, İ.Etem Saklakoğlu¹⁻²
 KANSAN R&D Center, Izmir, Türkiye¹
 Ege University, Department of Mechanical Engineering, Izmir, Türkiye²
 tahsintopbasoglu@kansanmak.com

Abstract: In this study, an original design was developed to address the issue of insufficient packaging speed, a key challenge in wet wipe production lines. A separator/distributor was developed that enables a single wet wipe machine to work with three packaging units during the transfer of products from the wet wipe preparation unit to the packaging process. The developed separator moves angularly on the vertical axis and can transfer products to conveyor groups leading to three different packaging lines. Additionally, a unique movable upper conveyor was designed to operate across a range of product heights, which applies pressure to the products during movement to prevent them from scattering. One of the primary design criteria for the conveyor is lightweight construction, and this was a key focus during development. To achieve angular motion, a servo-driven flywheel mechanism was designed. The machine is equipped with sensors for Industry 4.0 compatibility, ensuring communication between units. In case one of the packaging machines becomes inactive, the separator automatically redirects the product feeding process to the remaining packaging machines, ensuring uninterrupted production.

Keywords: WET WIPE, PACKAGING, INDUSTRY 4.0

1. Introduction

In the modern industrial environment, optimizing production lines for efficiency and speed is crucial. Wet wipe production, in particular, faces the challenge of balancing product quality with high-speed packaging processes. A key issue in wet wipe production is the limitation in packaging speed, which can lead to bottlenecks and inefficiencies.

Industry 4.0 has revolutionized manufacturing by introducing smart technologies, including the Internet of Things (IoT), sensors, and automated systems, which enable enhanced communication and coordination between machines. This paper presents an innovative solution to increase packaging efficiency in wet wipe production by designing a vertically angular automated line separator that integrates Industry 4.0 technologies.

2. Literature Review

The literature on manufacturing automation, particularly in production line optimization, emphasizes the need for efficient systems that enhance productivity and flexibility. Recent advancements have allowed for the development of automated separators and conveyors that help address the challenges posed by high-speed packaging, especially in the context of multi-line production environments where efficiency is paramount. This review focuses on automation in manufacturing, the role of vertically angular systems, Industry 4.0 integration, and recent packaging innovations, with the aim of establishing a basis for the proposed design of an Industry 4.0-compatible, vertically angular automated line separator.

2.1. Automation in Manufacturing and Packaging Lines

Manufacturing automation, a cornerstone of industrial development, has undergone several transformations, with each phase introducing technologies that reduce human intervention, streamline production, and decrease operational costs. Initially, automation focused on simple mechanized tasks, but advancements in robotics and control systems have enabled more complex operations, including real-time adjustments and multi-directional product flow. Flexible conveyor and distribution systems have become essential in modern manufacturing environments, allowing lines to adapt dynamically to changing production demands [1, 2].

Flexible conveyor systems have been identified as a solution to minimize downtime and optimize product flow. Studies reveal that traditional conveyor systems, while effective, often struggle in high-speed production environments, particularly when dealing with products of variable shapes and sizes. By integrating modular and adaptive conveyors, manufacturers can meet these demands while reducing production costs. Research on the use of robotic arms and other mechanical actuators shows that automation systems with

precise control and flexibility can effectively handle variable product dimensions, achieving reliable, repeatable separation and distribution in packaging lines. These findings support the development of systems capable of transferring products to multiple packaging units, addressing a common need in high-output industries such as consumer goods and pharmaceuticals.

2.2. Vertically Angular Systems in Manufacturing

The implementation of vertically angular motion within conveyor systems presents a significant opportunity for optimizing space usage and enhancing flexibility in product handling. Traditional conveyor setups, typically limited to horizontal movement, can occupy large areas of the factory floor and restrict the ability of a production line to handle varying product heights. By enabling angular movement along the vertical axis, manufacturers can design systems that utilize available space more effectively, particularly in facilities where space constraints are a concern.

The design of vertically angular conveyors, especially in compact environments, has been shown to reduce operational complexity and improve the flow of products through multi-line processing systems. This approach not only conserves space but also allows for more efficient utilization of resources by aligning product flow with specific line requirements, such as directing items to different packaging stations based on real-time line status. Although the vertical movement is well-documented in material handling applications, studies reveal a lack of comprehensive exploration into systems that combine vertical and angular motion, especially with industry-specific applications. This study aims to bridge this gap by integrating a servo-driven flywheel mechanism for controlled angular movement, which ensures precise product positioning and transfer across multiple lines.

2.3. Industry 4.0 Integration and Smart Manufacturing Systems

Industry 4.0 represents a paradigm shift in manufacturing, bringing smart technologies and digitalization to traditional processes. By incorporating IoT, machine learning, and real-time data analytics, Industry 4.0 enables the creation of intelligent production environments where machines communicate autonomously, adjusting operations based on sensor inputs. This real-time communication and adaptability are particularly valuable in automated packaging systems, as they enable production lines to respond instantly to fluctuations in demand or disruptions within individual units [3].

The integration of IoT technologies allows for continuous monitoring of machinery, which is essential in high-speed production environments where equipment failure can result in significant downtime. The use of real-time data not only facilitates predictive maintenance but also enables optimization algorithms to adjust production rates, manage inventory flow, and maintain

product quality. For example, real-time tracking of product movement and adaptive control can ensure seamless transitions between different sections of the production line, reducing product loss and minimizing human intervention [4].

Smart manufacturing technologies also enable efficient coordination across interconnected units, which is crucial for multi-line systems that must operate in unison to achieve optimal throughput. Predictive maintenance models powered by machine learning provide a framework for forecasting equipment failures, allowing operators to address issues before they result in production stoppages. By implementing these smart technologies, the proposed separator design aims to maintain uninterrupted product flow even if one of the packaging lines goes offline, maximizing productivity and minimizing waste.

2.4. Innovations in Packaging Systems

Packaging is a critical phase in production, particularly in high-speed environments where products must be handled with precision to prevent damage or misalignment. Modern packaging systems incorporate modular and flexible designs that allow manufacturers to adapt to changing product requirements quickly. Studies indicate that modularity in packaging equipment offers significant advantages in terms of scalability and customization, as operators can reconfigure lines to handle products of different sizes, shapes, or packaging formats without extensive retooling [5].

Automated distributors and separators designed to work in tandem with packaging machines have proven effective in enhancing line efficiency. By directing products to multiple packaging stations, these systems reduce the likelihood of bottlenecks and improve overall throughput. For industries requiring high-speed packaging, automated separators that facilitate smooth transitions between preparation and packaging stages are essential for maintaining product integrity and consistency.

Modular design is another area of focus, allowing packaging systems to adjust quickly to new product demands. Research into modular packaging line architecture has shown that reconfigurable systems can meet varying production needs with minimal downtime, which is especially valuable in fast-paced industries like consumer goods. The proposed design incorporates a movable upper conveyor to accommodate products of different heights, preventing product scattering and ensuring secure transfer to the packaging units. The lightweight construction of the conveyor also supports rapid, angular movement, providing a compact and ergonomic solution to meet production demands [6].

2.5. Gaps in Current Research

Despite significant advancements in automation and Industry 4.0 technologies, there is still limited research on integrating vertically angular motion with Industry 4.0-enabled packaging systems. Most studies focus on horizontal automation systems or isolated technology implementations, without considering integrated solutions that combine angular motion and smart manufacturing capabilities. This study addresses this gap by developing a vertically angular separator that leverages smart manufacturing systems for seamless communication, real-time monitoring, and automated adjustments [7].

The proposed design aims to create an efficient, adaptable separator capable of directing products to multiple lines based on real-time operational conditions. By combining vertically angular motion with IoT-enabled monitoring, the system promises to increase productivity and flexibility in packaging lines, meeting the evolving demands of high-output industries. This novel approach to automation, which prioritizes space efficiency, real-time adaptability, and minimized downtime, represents a new direction for research in automated packaging technology.

3. Design and Methodology

The goal of this study was to address the demand for an efficient product transfer system in wet wipe production lines, where products need to be transferred from a single production machine to three separate packaging machines. The challenge lies in meeting a high throughput requirement—up to 300 packages per minute—while ensuring each packaging machine can handle a maximum of 100 packages per minute. To meet these demands, a vertical angular automated separator was designed, with a focus on ease of adjustment, maintenance, ergonomics, space efficiency, and the ability to perform product transfer via angular motion on the vertical axis.

3.1. Separator Unit Design

The separator unit was designed to move angularly on the vertical axis, allowing it to transfer products to conveyor groups leading to three different packaging lines. The angular motion is crucial as it enables the system to handle multiple packaging lines without requiring excessive floor space, thereby improving the overall factory layout. This design also makes it adaptable to varying production needs, especially in high-speed environments where flexibility is essential [8].

The key innovation of this design is the incorporation of a movable upper conveyor that can function across a wide range of product heights. This feature allows the separator to handle products of varying dimensions without disrupting the product flow. The upper conveyor plays an essential role in ensuring that the products are maintained in a stable position during the transfer process. By applying light pressure as the product moves across the conveyor, the risk of scattering is minimized, ensuring smooth and efficient transfer to the packaging machines.

3.2. Lightweight Conveyor Design and Servo-Driven Flywheel Mechanism

The design of the conveyor system is centered on minimizing weight without compromising performance. The lighter construction of the conveyor enables faster movement, reducing wear and tear, and ensuring the longevity of the system. Additionally, this lightweight design facilitates easier adjustments and maintenance, providing the operator with a more ergonomic system for day-to-day operations.

To achieve the angular motion of the separator, a servo-driven flywheel mechanism was developed. This mechanism is designed to allow for precise angular movement while maintaining stability and reliability at high speeds. The servo drive ensures that the separator can adjust its angle quickly and efficiently, making it adaptable to various packaging line configurations. This system is crucial for achieving the required speed of 300 packages per minute while also handling the product transfer to multiple packaging lines.

3.3. Industry 4.0 Integration and System Automation

The separator unit is equipped with sensors and communication interfaces that integrate with the overall production line, ensuring compatibility with Industry 4.0 standards. This allows for real-time data exchange between the separator and the packaging machines, optimizing the efficiency of the system.

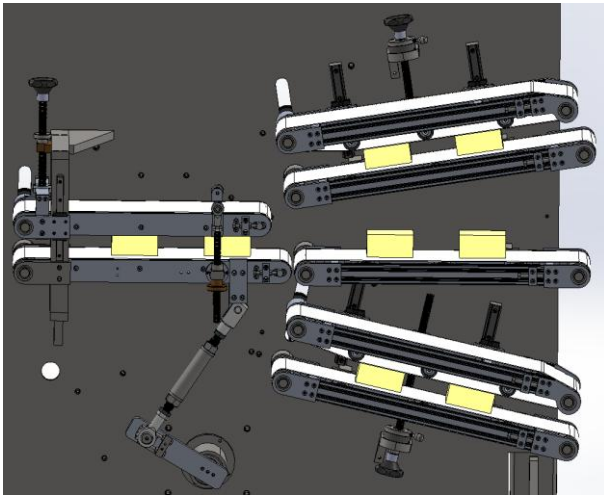
One of the key features of the design is its ability to maintain uninterrupted production. In the event that one of the packaging machines becomes inactive due to maintenance or malfunction, the separator automatically redirects the product flow to the remaining active packaging lines. This automatic redirection ensures continuous production without the need for manual intervention, thus reducing downtime and enhancing the overall efficiency of the manufacturing process.

3.4. Ergonomics and Maintenance Considerations

In addition to the technical functionality, the design emphasizes ergonomics and ease of maintenance. The system was built with user-friendly interfaces for quick adjustments and straightforward maintenance procedures. The lightweight design of the conveyors, along with their modular construction, allows for easy access to parts that require routine maintenance, reducing downtime and labor costs. The compact nature of the system also ensures that it occupies minimal space, making it ideal for factories with limited floor space.

The vertical angular movement of the separator further enhances the system's ergonomics, as it minimizes the need for large horizontal conveyors that could otherwise require more space and labor for adjustments. The angular motion system is easy to configure, and operators can quickly adapt it to meet different production requirements, making it highly versatile for various product types and packaging configurations.

The designed separator is shown in Figure 1a and the manufactured separator is shown in Figure 1b. In figure 2a the detail of design and figure 2b. detail of the manufactured separator is shown in front view. Rear view is shown Figure 3a and fig 3b.

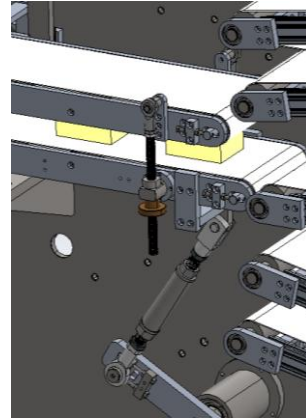


1a.



1b.

Figure 1a the designed and Figure 1b. the manufactured separator in front view

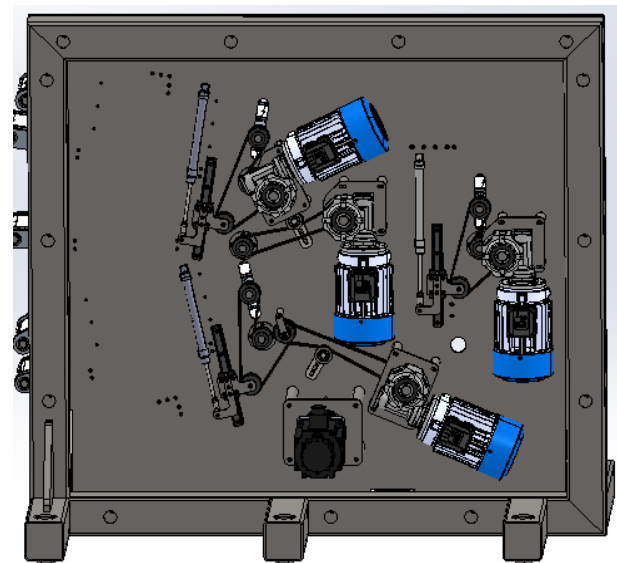


2a.



2b.

Figure 2a the detail of design and Figure 2b. detail of the manufactured separator in front view



3a.



3b.

Figure 3a-b. Rear view of designed and manufactured separator

4. Results and Discussion

The vertical angular separator was tested in a real-world wet wipe production environment to evaluate its performance in handling high-speed product transfer to multiple packaging lines. The results confirmed the separator's ability to efficiently direct products from a single production line to three separate packaging lines, each capable of handling up to 100 packages per minute. This setup allowed for a sustained throughput of 300 packages per minute, meeting the target production speed and ensuring a balanced distribution of products across the three lines.

The servo-driven flywheel mechanism proved crucial for achieving precise control over the separator's angular motion. This mechanism allowed the separator to quickly adjust to shifts in production flow and align with each of the packaging lines without delays. The lightweight conveyor design contributed to the system's ability to operate smoothly at high speeds, effectively reducing mechanical stress and wear over prolonged periods of use. By minimizing the stress on mechanical components, the design also helped extend the lifespan of the separator and reduced maintenance needs.

Integration of Industry 4.0 features was particularly advantageous. Through real-time monitoring and feedback from embedded sensors, the separator could automatically reroute product flow if one of the packaging machines went offline. This function minimized potential downtime, maintaining continuous production—a critical feature in high-output manufacturing lines where any stoppage can result in significant productivity losses.

Furthermore, a patent application has been filed for the developed system, reflecting its innovative contributions to automated packaging line technology and the novel approach to integrating vertical angular motion with Industry 4.0 capabilities. This patent application not only highlights the uniqueness of the separator's design but also establishes a basis for future developments and potential commercialization in automated production and packaging systems.

5. Conclusion

This study presents a novel design for a vertically angular automated line separator that addresses the challenges of transferring products between multiple packaging machines in a high-speed wet wipe production line. The design successfully integrates Industry 4.0 technologies to ensure seamless communication between production units and minimize downtime. With its lightweight construction, ergonomic design, and adaptability to varying product heights, the separator system provides a highly efficient and flexible solution for modern manufacturing challenges.

Further research could explore the integration of additional smart technologies, such as AI-based predictive maintenance and advanced data analytics, to further enhance system performance and efficiency.

6. Acknowledgments

This study was conducted at the KANSAN R&D Center, with the collaboration of the Department of Mechanical Engineering at Ege University. We extend our gratitude to all involved team members and institutions for their invaluable support and contributions to the success of this project.

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Mechanical Characterization of Al-Cu Materials Fabricated by Powder Metallurgy under Quasi-static and Dynamic Compressive Loadings

Tatiana Simeonova^{1,2*}, Rumen Krastev^{1,2}, Georgi Stoilov¹, Vasil Kavardzhikov¹

Institute of Mechanics at Bulgarian Academy of Sciences, Bulgaria¹

Institute of Metal Science, Equipment and Technologies with Hydro- and Aerodynamics Centre "Acad. A. Balevski" at Bulgarian Academy of Sciences²

tsimeonova@imbm.bas.bg

Abstract: This study investigates the mechanical behaviour of Al10Cu materials fabricated through powder metallurgy and subjected to quasi-static and dynamic compressive loadings. The materials were sintered and tested under controlled conditions to evaluate their compressive strength. Quasi-static tests were performed at a constant strain rate of 0.003 s^{-1} , while dynamic tests were conducted at strain rates corresponding to impact speeds of about 10 m/s and 20 m/s. The results indicate that sintered Al10Cu materials are suitable for applications under high-strain impact loadings due to their high energy absorption. These findings demonstrate the suitability of Al10Cu alloys, fabricated via powder metallurgy, for high-strain-rate applications, providing valuable insights into their potential for dynamic environments.

Keywords: Al10Cu MATERIALS, POWDER METALLURGY, COMPRESSIVE STRENGTH, HIGH STRAIN RATE PERFORMANCE

1. Introduction

Investigations of light metal matrix materials and composites produced under solid-state conditions have gained great attention in the last decade. Researchers have focused on solid-state processing due to its lower processing temperatures [1,4], which align with the EU's sustainable consumption and production policies. Generally, Aluminium and its alloy are widely used as a base for the production of metal matrix composites (MMC), reinforced by ceramic particles (SiC, B₄C, Al₂O₃, TiC and WC), because of their advanced properties like reduced weight, high specific stiffness, excellent strength/weight ratio, increased mechanical and thermal performance, improved strength, higher elastic modulus, and superior wear resistance compared to unreinforced matrices [1,2,4,7,12]. The production of MMCs with enhanced properties involves investigating matrix material quality, reinforcing particle type, size, and quantity and the influence of process parameters on the material structure and properties. And the first step is always choosing the best matrix material. The primary alloying elements in aluminium powder are copper, magnesium, and zinc [4], with copper being the most significant due to its ability to enable additional age hardening in Al-Cu alloys. In the Al-Cu sintering process, a eutectic liquid forms at 548°C along the Al-Al₂Cu boundaries [5]. This liquid phase enhances diffusion between the powders by penetrating grain boundaries during sintering [6]. From the literature review, it has been proved that Al-Cu matrices possess great potential for developing MMCs with improved properties via solid-state fabrication techniques such as powder metallurgy and are commonly used for the production of lightweight functional components. Different matrix content had been investigated as Al-4 wt% Cu [1,2,4,9], Al-3%Cu [3,10,13,19], Al-6%Cu [3,13,19], Al-4.5 wt.% Cu [8] and Al-9 wt.% Cu [13]. It is observed that the addition of copper to the aluminium matrix allows for a higher densification of the materials [4,19], which gets us to the point of this investigation aiming to investigate the properties of Al-10wt%Cu produced by the conventional PM technique. Some investigations are already made by increasing the amount of Cu till 9 vol.% for production of Al-Cu composite by vacuum and microwave sintering techniques [13] and an increase in steps of 5 wt% (5%, 10%, 15%, and 20%) for developing in-situ Al-Cu metal matrix composites using microwave sintering and friction stir processing [14] which revealed that the addition of copper enhanced the mechanical and electrical properties of the MMC up to 10wt%Cu and beyond which it decreased. The mechanical properties are accessed through compression testing particularly under dynamic conditions, due to the lack of sufficient data for the response of Al-Cu materials, produced by the PM technique, to high strain rates of deformation [15]. Although significant research has been conducted on the mechanical properties of aluminium-based alloys and their composites, the specific mechanical characterisation of Al10Cu alloys produced through powder metallurgy under

varying compressive loading conditions remains largely unexplored. Addressing this gap provides critical insights into the performance of Al10Cu alloys under diverse loading regimes, offering valuable data for high-strain-rate applications.

This study aims to comprehensively evaluate the mechanical behaviour of Al10Cu alloys fabricated through powder metallurgy under varying compressive loading conditions. Specifically, the research seeks to assess the compressive strength and energy absorption capabilities of sintered Al10Cu materials by subjecting them to quasi-static and dynamic compressive tests. By systematically analysing their performance under these distinct loading regimes, the research seeks to establish the suitability of Al10Cu alloys for applications demanding robust energy absorption and high strain-rate performance.

2. Materials and methods

Aluminium-based Al-10 wt.% Cu alloy was fabricated using aluminium powder and copper powder as the primary materials. The Al and the Cu powders employed had a particle size of ≤ 325 mesh. To create the Al-10 wt.% Cu base alloy, the Al and Cu powders were first mixed in the desired proportions. The combined powders were then subjected to ball milling with a ball-to-powder ratio of 6:1. This milling process was carried out for 5 hours at a rotation speed of 500 rpm using a high-energy ball mill, ensuring a uniform distribution of Cu particles within the Al matrix. Following ball milling, the powder mixtures were compacted using a hydraulic press. Compaction was performed in a cylindrical steel die with a diameter of 16 mm, resulting in the formation of green bodies. These green bodies were subsequently sintered in a controlled atmosphere furnace under argon (Ar) to prevent oxidation and contamination. The sintering process was conducted at 530°C for 3 hours. After sintering, the samples were allowed to cool slowly within the furnace to ensure uniform microstructural development and to minimise thermal stresses. The powder metallurgy technique utilised to produce the Al10Cu alloy is illustrated in Fig. 1.

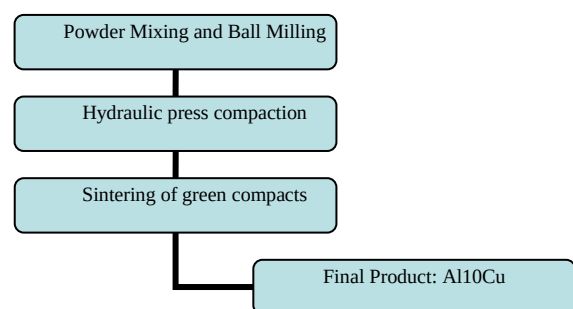


Fig. 1 Production process chart

The sintering process influences the material's microstructure and properties [6]. The specimens used to determine the mechanical

properties of the fabricated materials are cylindrical with a diameter of 10 mm and height of 15 mm (for quasi-static testing) and a diameter of 5 mm and height of 5 mm (for dynamic testing). The quasi-static compression tests were conducted on a Zwick Roell HA250 servo-hydraulic testing machine at a constant low strain rate of 0.003 s^{-1} . The dynamic compression tests by the Split Hopkinson Pressure Bar (SHPB) apparatus were carried out at high strain rates of about $\sim 1500 \text{ s}^{-1}$ and $\sim 3200 \text{ s}^{-1}$, corresponding to impact speeds of about 10 m/s and 20 m/s. A modified version of the Split Hopkinson-Kolsky Pressure Bar is used, specially designed for impact testing of porous and light materials, which includes an aluminium alloy incident bar and transmitted bar in the form of a steel tube. To access high strain rates compression properties of the tested materials the incident bar is stroked and a compressive pulse is generated which propagates through the incident bar. Part of the incident pulse signal is reflected as the reflected pulse into the incident bar at the incident bar/specimen interface. The remainder passes through the sample, deforming it plastically and continuing forward into the transmitted bar as the transmitted pulse [15]. The transmitted pulse is compressive, and its instantaneous amplitude is related to the instantaneous stress in the specimen. The stress information can be obtained as a parametric function of time. The instantaneous strain was obtained by integrating the incident and the transmitted pulse upon time. The modified version of the SHPB and the corresponding mathematical apparatus for calculating the strain are described in [22].

3. Results and discussion

The analysis of the compression test results is based on structural changes that occur during the PM production process of Al-Cu alloys. It is known, according to the Al-Cu phase diagram, that five intermetallic phases of Al_2Cu , AlCu , Al_3Cu_4 , Al_2Cu_3 , and Al_4Cu_9 could be formed in the Al-Cu system through solid-state phase transformation [10,11,18] and among these AlCu , Al_2Cu , and Al_4Cu_9 are the stable phases [14]. Thermodynamically Al_2Cu and Al_4Cu_9 phases evolve first due to their lowest formation energy [11,18] and the remaining intermetallic phases are formed after them depending on temperature and time. Al_4Cu_9 is a brittle intermetallic phase and its formation is desirable to be avoided [14]. Al_2Cu is more stable and the long thermal processing time is sufficient to convert AlCu to Al_2Cu , which can explain the fact that increasing Cu content only results in the formation of Al_2Cu in the fabricated composites [10]. When sintering the Al-Cu system at temperatures exceeding the solidus, a liquid phase forms, which migrates along particle boundaries, fills pores and infiltrates aluminium grain boundaries. Upon slow cooling after sintering, this phase precipitates at the grain boundaries as Al_2Cu [4]. Therefore, the microstructure of the Al10Cu matrix material is expected to consist of aluminium grains with dissolved copper surrounded by coarse copper precipitated in the form of the Al_2Cu phase at the grain boundaries of aluminium grains [1, 4]. The precipitate morphology shows a combination of linear structures at grain boundaries and dot-like features within the grains [4]. The Al_2Cu phase is believed to be the main reason for the enhanced mechanical properties of the tested Al10Cu alloys, summarised in Table 1.

Table 1: Average values of the mechanical properties of tested materials.

Specimen	quasi-static compression	high impact dynamic compression	
Dimensions [mm]	10x15	5x5	5x5
strain rate [s^{-1}]	0.003	1500-1900	3200
Modulus of elasticity [GPa]	10.4	7.8	5.62
YS(offset=0.2%) [MPa]	64.4	79	74
Compressive strength [MPa]	431	418	1445
Deformation ϵ [%]	60	44.6	79.1

Quasi-static compression test results are presented in Fig. 2, showing the stress-strain curves for six powder-metallurgy-derived Al10Cu specimens. The curves exhibit consistent behaviour under quasi-static compression. All samples go through the stages of elastic compression of the compact up to about the proportional

limit and yielding, strain hardening with particle inelastic deformation under normal and shear forces, and non-uniform deformation at compressive strength with two conic shear bands begin to develop along the diagonal axes of the compact, at 45° to the loading direction [20,21].

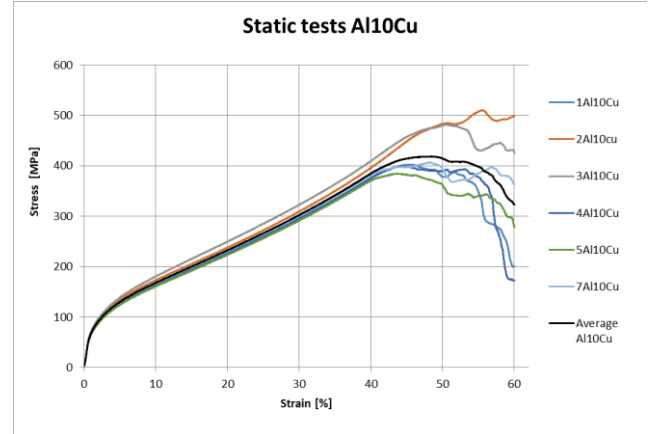


Fig. 2 Quasi-static tests result at a constant strain rate of 0.003/s

Deformation concentrated within shear bands leads to a decrease in the load-bearing capacity of the compact, culminating in complete failure as bonded particles separate along the shear bands, initiating from the corners of the cylindrical compact specimen [21]. The stress-strain curves are smooth up to 40% deformation in all tested specimens. The observations reveal that the yield stress in all the specimens is almost equal and the material continues to strain harden even after 30% plastic strain. The differences in quasi-static compression response are notable after 40% deformation, which is believed to be due to different amounts of pores and microcracks, formed at the grain boundaries during the production of PM alloys based on Al and Cu powders [1,4,8], even after the sintering process [19]. The pores primarily formed in the matrix, while the microcracks predominantly appeared at the joint between the matrix and Cu particles [20]. These defects act as stress risers causing components to fracture and deform more easily [19]. The actual crushing of different specimens is presented in Table 2.

Table 2: Actual crushing characteristics at different strains

$\epsilon, \%$	10%	20%	30%	40%	50%	60%
1						
2						
3						
4						
5						
7						

All specimens showed almost the same degrees of barrel-shaped deformation as the strain increased, although more serious failure behaviours were not observed. The first formation of the shear cracks is visible by the naked eye after 40 % deformation and the exact values for every specimen are shown in Table 3. At 50% deformation, all specimens possess severe failure cracks.

The results from dynamic compression tests are shown in Fig. 3 for moderate strain rates of 1500/s and Fig. 4 for high strain rates of 3200/s and the tested specimens are presented in Table 4. Figure 3 shows the results of dynamic tests at moderate strain rates of 1500/s. The resulting curves are not as smooth as the ones under quasi-static loading conditions.

Table 3: The formation of the visible shear cracks

Specimen	Deformation ϵ , %	Picture
1Al10Cu	42	
2Al10Cu	47	
3Al10Cu	43	
4Al10Cu	41	
5Al10Cu	40	
7Al10Cu	41	



Fig. 3 SHPB dynamic test results at 10-12 m/s

There is some gradual strain hardening up to 5% strain in the specimen tested at 1500/s strain rate after which the flow stress drops. The same fluctuations during the strain hardening are observed in the interval between 30 and 40% deformation. The

stress-strain curves under dynamic compression reveal the same failure mode at different strain rates. The ultimate strength and failure strain increased with the strain rate. The three types of failure could be observed in specimens under different impact velocities: plastic failure, splitting failure and smash failure [20]. Figure 4 shows the results of dynamic tests done at higher strain rates of 3200/s which reveal similar to quasi-static curves trends.

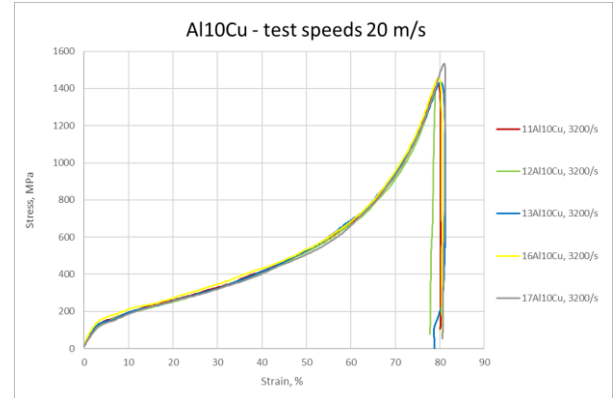


Fig. 4 SHPB dynamic test results at 20m/s

In our case, all tested at 1500/s specimens exhibited plastic failure, while at some tested at 3200/s partial splitting was observed. The plastic failure occurred at impact velocities greater than 9 m/s while smash failure occurred at impact velocities over 19 m/s. All tested specimens exhibited a distinct elastic stage, with the hardened state persisting under dynamic compression. A comparison of stress-strain relationships revealed superior dynamic mechanical properties at a strain rate of 3200/s compared to 1500/s, although the kinetic energy required for failure remained consistent. The comparison of the specimens at different strain rates showed that the compression strength of the material increases with the strain rate, but the variation in yield strength is negligible.

Table 4: Specimens – before and after dynamic compression testing

Before	After	Before	After	Before	After
8Al10Cu – 1500/s		9Al10Cu – 1500/s		10Al10Cu – 1500/s	
15Al10Cu – 1900/s		11Al10Cu – 3200/s		12Al10Cu – 3200/s	
13Al10Cu – 3200/s		16Al10Cu – 3200/s		17Al10Cu – 3200/s	

A comparison of all tested samples at all tested strain rates is shown in Fig. 5. The compressive strength increases from about 400 MPa at quasi-static rates (0.003/s) to 1400 MPa at high strain rates (3200/s) and the strain corresponding to the maximum compressive stress is shifted from about 40% to 80%. The specimens displayed very little change during the elastic stage. It was also found that the change in strain rate had little effect on the elastic modulus which lowers with the rise of the strain rate (table 1). The elastic modulus obtained under quasi-static loadings is approximately 10 GPa, about 50% higher than that obtained at strain rates of 3200/s (5 GPa). The yield strength at high strain rates is higher than that under quasi-static loadings. Generally, yield and ultimate strengths increased with strain rate, while the lower failure strain is observed at a strain rate of 1500/s. As mentioned before, the slight differences in properties could be due to the different densification of specimens [20], although this is not obvious from compression tests.

The difference between the quasi-static and moderate and high-strain dynamic tests is that the stress-strain curves reached higher stresses at high strain rates. The higher strain hardening at higher

strain rates is also notable, which is typical of fcc metals and is due to the suppression of dynamic recovery mechanisms at high strain rates [15]. The same trend of all the curves at all tested speeds leads to the conclusion of similarity in the intermetallic content of all of the specimens and based on previous research of the microstructural evolution of Al-Cu materials fabricated through powder metallurgy it is expected that Cu atoms diffuse into the Al matrix during the synthesis of Al-Cu alloy and Al_2Cu precipitates in a solid solution of Al(Cu). That is why we believe that observed mechanical properties are governed by indirect strengthening of the Al matrix which is expected to be due to Al(Cu) solid solution strengthening and the structural Al_2Cu precipitate strengthening [16]. Precipitation hardening of aluminium alloys can involve either precipitate shearing for coherent precipitates, or precipitate by-passing by the dislocations [16]. To be positive about the type of precipitation hardening mechanisms - precipitate shearing or precipitate by-passing, additional analysis and TEM observations must be done involving the determination of the precipitate radius.

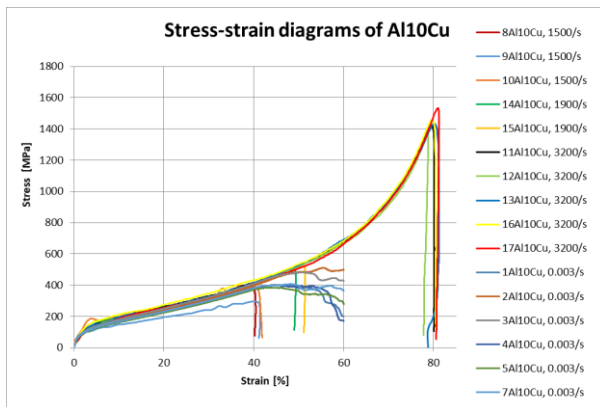


Fig. 5 Comparison of all tested samples at all tested strain rates

Generally, the advanced compressive properties of Al-Cu alloys are led by three possible strengthening mechanisms including the Orowan strengthening mechanism of uniform distribution of Cu particles, enhanced dislocation density due to the large mismatch between the thermal expansion coefficient of copper particles and the aluminium matrix and the dispersion hardening effect of the hard Cu particles into the soft Al matrix [13]. However, the strength of the composites does not depend on a unique mechanism and several mechanisms may act simultaneously. The dislocations could be piled up against the grain boundaries turning them into a barrier to dislocation motion and thus increasing the strength of the alloy [17]. The precipitates could also act as a barrier to the dislocation movement, requiring greater stress to move the dislocations [17]. Also, precipitates along the grain boundaries act as a pinning agent for the grain boundary sliding. That is why the distribution of the secondary phase precipitates within the grains and along the grain boundaries is responsible for increasing the compression strength [17].

The deformation mechanism of the tested compacts includes particle separation occurring primarily at the interparticle bond region with ductile fracture type of the interparticle bond while originally non-contacting particles are developing contacts with neighbouring particles during deformation and as a result of particle inelastic deformation the contact area between bonded particles increases over the interparticle bond area. During the non-uniform deformation in the samples voids and macrocracks were observed in the interparticle bond region. The growth and coalescence of these voids eventually led to the development of macrocracks and complete separation of the interparticle bond region [21].

4. Conclusions

The current investigation focuses on Al-Cu matrices material with enhanced mechanical properties under compression loadings, which will be incorporated with different ceramic particles in our future work. The major conclusions that could be drawn back are:

1. Aluminium-based Al-10 wt.% Cu alloy was successfully fabricated through the powder metallurgy method.
2. The increased compressive strength up to 1445 MPa and deformation up to 80% at high strain rates (3200/s) were experimentally validated by SHPB testing.
3. The significant improvement in mechanical properties is attributed to the dispersion hardening effect of hard Cu particles in the soft Al matrix.

5. Acknowledgments

The research was supported by the European Regional Development Fund within the OP Science and Education for Smart Growth 2014–2020, Project CoE “National Center of Mechatronics and Clean Technologies”, BG05M2OP001-1.001-0008.

6. Funding

This research was funded by the Bulgarian National Science Fund, Project **KII-06-H77/5** “Self-lubricating hybrid aluminum metal matrix composites: synthesis, experimental and computer modeling of mechanical and tribological properties”.

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Investigation properties of part – holder of breaking shoe beam made of SG60/SE300 steel cast

Sveto Cvetkovski¹, Nazif Jashari²,

Faculty of Technology and Metallurgy, Ss Cyril and Methodius University, Skopje Republic of North Macedonia¹ State University Tetova, Republic of North Macedonia²
sveto@tmf.ukim.edu.mk

Abstract: The main reason to perform this research investigation was to find a reason for appearing failures in exploratory condition of a part holder of breaking shoe beam. This part is incorporated in an assembly in railway wagon. This part together with few others was damaged in exploratory condition. It means that cracks were noticed on these parts. Some parts were completely broken. Because of that purchaser of parts complained of received parts to the producer. One of these parts was delivered to Prof Cvetkovski to find a reason and to give opinion about the reason for failure. The damaged parts are made of cast steel SG60/SE300. Many types of investigation was performed in order to solve this problem. As first visual control was done. After that, radiographic control was made. Investigations continued with determination of chemical composition and macro and micro metallography and determination of non-metallic inclusions. Finally mechanical testing like tensile testing, hardness measurement and impact toughness were performed too. Performed research confirmed that typical casting defects in the investigated part like the hot tears, slag inclusions, shrinkage porosity and segregation are the main reasons for failure of the delivered parts, holder of breaking shoes i.e. appearing of cracks or their completely fracture.

KEYWORD: HOLDER OF BREAKING SHOE BEAM, SG60/SE300, STEEL CAST, HOT TEARS, SLAG INCLUSIONS, FRACTURE, MICROSTRUCTURE,

Introduction

This technical report was prepared on the request of company for production of parts for railways vehicles. Subject of investigation is holder of breaking shoe beam as a part of assembly mounted in railway wagons. Because of accident, which happened to some of these parts in exploitation conditions, the purchaser of parts submit complaint to the producer in order to explain the reason for the failure. According obtained information's, about sixty parts were delivered to the purchaser. Six of them were failed. More concretely in few parts was noticed cracks and few parts were completely fractured.

One of the rejected parts was returned to the supplier in order to be performed investigations and to find a reason for appearing of defects – cracks. Producer of assembly asked Prof Cvetkovski to make investigations and find a reason for occurred accident.

It has to be point out that casting parts were produced by subcontractor i.e. casting company. Damage of parts happened in exploitation conditions. During routine control was detected that some parts have cracks but some of them were completely broken. Investigated part is one of the few parts in which cracks appeared in exploitation period. It was clearly confirmed that casting technology is base reason for failure of parts [1, 2].

1 Material for investigation

Investigated part was produced by steel casting GS60 (GE300) with material number 1.0558. It is defined as steel cast for general engineering purposes. Designation C60 of this of steel cast is according DIN EN 1681 while designation CE300 is according EN 10293. After casting heat treatment i.e. normalization was performed [3]. Once cast, steel alloys will often have a non-homogeneous microstructure, which includes large grains as well as other unwanted structural components normalizing the casting will deliver a uniform, fine-grained structure with greater mechanical predictability and improved machining qualities [4, 5].

This cast has a fairly low ductility and a moderately high tensile strength among cast carbon, non-alloyed steels. Delivered steel holder for investigation is presented in the figure 1. This part is obtain by send casting process.



Figure 1 Received holder for investigation

2 Performed investigations

2.1 Visual inspection

Visual inspection of the holder (figure 2) was done by necked eye and magnifying lens. Inspection confirmed that one macro crack was formed in the holder. On the top of the part the crack is much wider. Propagating into interior crack become thinner and stop to propagate in the material. It is quite normal to expect that crack will continue to grow if part continue to work. Other cracks or some other defects was not detected in the holder by visual inspection. It can be seen too that part is painted after production.



Figure 2 Crack on the specimen

2.2 Radiographic testing (RT)

Radiographic testing was performed using x-ray tube XXG-2005 and Kodak T500 films with Pb foils. The seven expositions of the investigated specimen was made. Besides macro crack, noted during visual inspection, no other significant casting defects were detected Figure 3 (a-c).

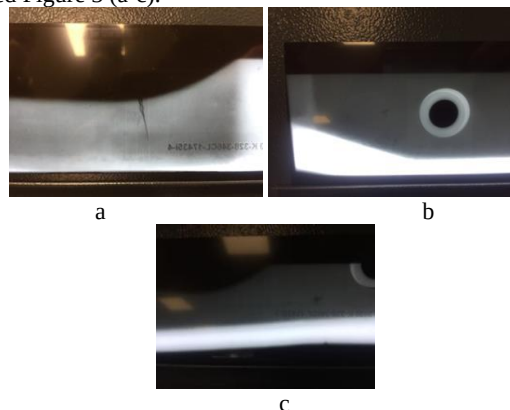


Figure 3 Radiographic films

2.3 Determination of the chemical composition of the holder

For determination of the chemical composition of the investigated holder, piece with dimension 30x30 was cut. The emission spectrometer type SPECTRO was used for chemical analysis.

Obtained concentration of chemical elements were compared with the values prescribed in previously mentioned standards (tables 1 and 2).

Table 1 Chemical composition of the analyzed steel casting compared compared with DIN 1681 prescribed values

Element %	C	Si	Mn	P	S	Cu
Measured (SPECTRO)	0.44	0.32	0.724	0.019	0.05	0.15
Standard DIN 1681)	0.27-0.32	0.456	0.75-0.90	0.04	0.04	0.3

Table 2 Maximum concentration of unspecified elements in analyzed specimen is given in DIN EN 10293 standard

Element %	Cr	Ni	Mo
Measured values (SPECTRO)	0.349	0.182	0.08
Standard EN 10293)	0.3	0.4	0.12

2.4 Metallography

For the metallographic investigations was prepared specimen cut from the holder containing the macro crack (figure 4). Standard metallographic preparation of the specimen was performed. After grinding and polishing with diamond powder, Nital (3%) etching of the specimens was done. Macro and microanalysis were made on the specimen. Polished specimen was used for the analysis of the material cleanliness (non-metallic inclusions) or any others type casting defects. Optical microscope Meiji Techno was used for metallographic investigation.

2.4.1 Macro metallography

Figure 5 presents prepared specimen for macro metallographic investigation. Macro inspection confirmed that one macro crack was formed in the holder. On the top (origin, Point A) the crack is much wider. Propagating into interior crack become thinner and stop to propagate in the material point B. Other cracks was not detected in the holder by macro metallography.

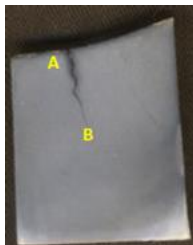


Figure 5 Metallographic specimen with crack cut from the holder

2.4.2 Analysis of the non-metallic inclusions

Non-metallic inclusions were analyzed on polished metallographic specimens using optical microscope Meiji Techno. Magnification of x100 was used for this analysis. As can be seen from the metallographic pictures, material is pretty clean concerning non-metallic inclusions. The presented inclusions are small mainly rounded, randomly distributed (figure 6 (a-c)).

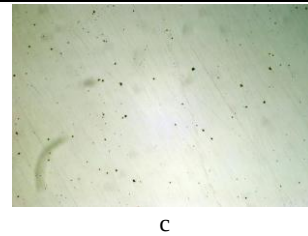
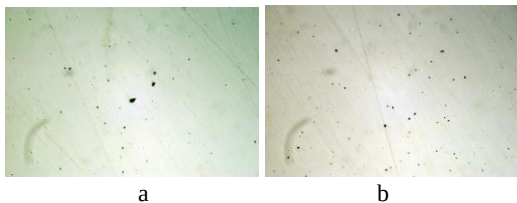


Figure 6 (a-c) Nonmetallic inclusions in casting x100

2.3.3 Analysis of defects on the polished surface

Figure 7 (a and b) present beginning and end of the macro crack. It can be seen from the figure 7a that crack origin is pretty wide, but it must be point out that very big defect so call slag inclusion is detected on the left side of the crack. End of the crack is shown on the figure 7b. It is important to say that propagation of crack is forced by presence of the of the defects in the material like shrinkage cavities.

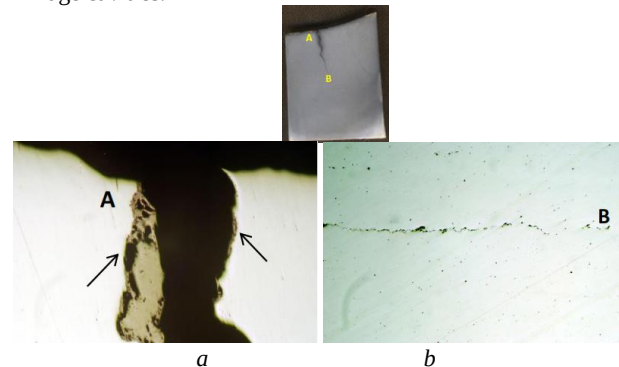


Figure 7 (a and b) a. beginning b. end of crack

Figure 8 presents end of this central crack magnified x500. Shrinkage cavities are clearly noticed during this magnification.

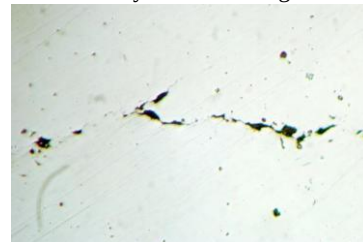


Figure 8 End of the crack x500 - shrinkage cavity

Figure 9 shows polished surface of the specimen. It is clearly seen crack formed beneath the surface, which start from the some impurity, and it's propagate almost parallel with the surface of the specimen.



Figure 9 Crack beneath the surface x100 (on the left side of the macro crack)

Figure 10 presents cracks, which are, formed on the surface of the specimen. Their orientation is different.

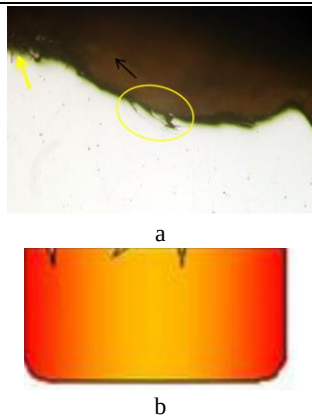


Figure 10 a. Formed cracks on the surface of the specimen with different orientation, x100 b. hot tears schematic presentation (right side from macro crack)

2.4.3 Micro metallography

Figure 11(a and b) presents microstructure of the investigated, casted part (holder) after normalization. It is clearly seen that microstructure consists of ferrite and pearlite. It can be concluded that ferrite delineate former austenite grains. Segregation in the part can be seen too.

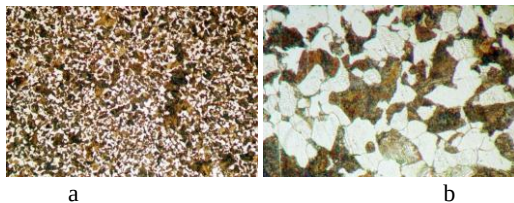


Figure 11 Microstructure of the normalized specimen etched with Nital
a. x100 b. x500

Figure 12 (a-d) shows microstructure of the specimen in the neighbourhood of the crack. With black arrows are shown slag inclusions.

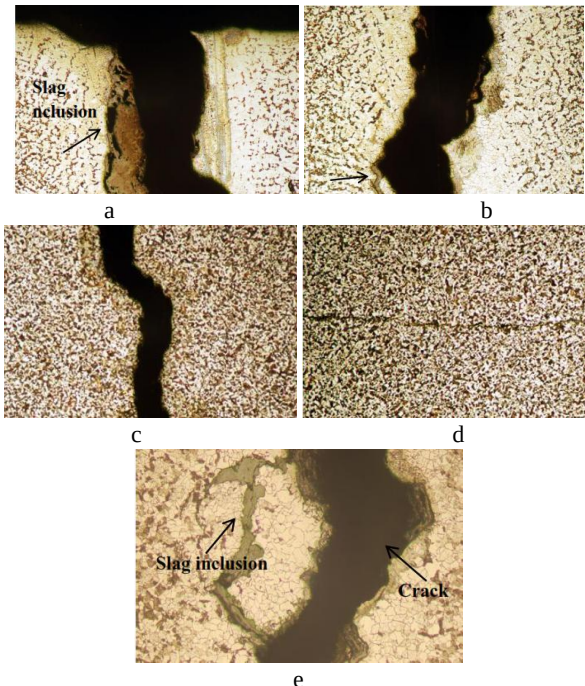


Figure 12 Present defects in the specimen i.e. slag inclusions near the crack

2.5 Tensile testing

For determining tensile properties of casted part, one round specimen was machined. Obtained results from testing probe are

given in the table 3. Diagram stress-deformation is given in the figure 13, and fractured surfaces of the specimen are shown in figure 14.

Table 3 Tensile properties of the material – holder

Tensile properties	RP _{0.2}	Rm, MPa	A
Measured values	660	750	17
Standard EN 1293	300	600-750	15

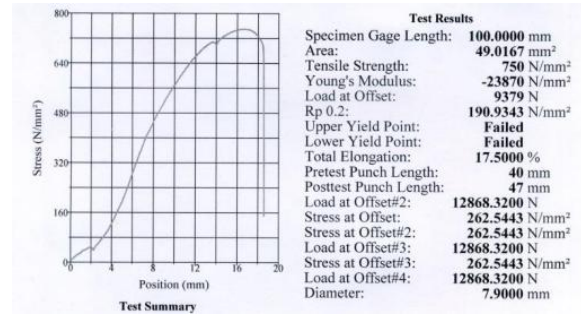


Figure 13 stress-strain diagram



Figure 14 Fractured surface of tensile specimen

2.6 Impact toughness

Impact toughness testing was performed at ambient temperature i.e. 20 °C as is standard requirement for this material. Three specimens with V notch were prepared. Because of lower thickness of the part nonstandard specimens with dimension is 10x8x55. According standard for material with thickness beneath 13 mm the value of impact toughness should be 27J. It is clear that specimens with proper dimensions should fulfill requirements. Fractured surfaces of Charpy specimen is given in figure 15, and obtained toughness value is given in the table 4.



Figure 15 Fractured surface of impact specimen

Table 4 Impact toughness value for tested Charpy specimens

Specimen no	1	2	3
Impact value	25	24	20

2.6 Hardness measurement

Hardness measurement was made using HRB method. According with standard requirement for normalized steel cast (SG60) DIN 1681 hardness values should be in range 165/215 HB. Hardness was measured from the top of the specimen toward its interior. As can be seen from the figure 16, the highest hardness value is measured at the top of the specimen i.e. 185HB. But the hardness in the interior is 163HB. It means that difference of 20HRB units. Because of that additional measurement's was made on the top of the specimen, and the same values were obtained. In order to explain such situation metallographic analyze was made figure 16b. It can be seen that at the top of the specimen microstructure is deformed and consist of fine grains. Microstructure in the interior consists of ferrite and pearlite. Microstructure have to be normalized ferrite pearlite like in the lower part of the figure 16b. Anyhow, hardness values in the range of standard requirement.

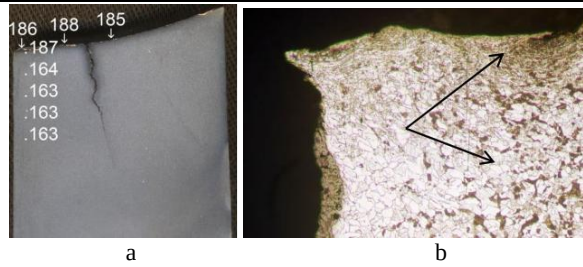


Figure 16 (a and b)

a. Measured hardness values

b. microstructure near the top of the specimen and in the interior

Discussion

Chemical composition of the holder is in accordance with standard requirement, only carbon content is over upper limit prescribed with standard 0.44 %C, and required values should be 0.27-0.32%C. In order to determine mechanical properties of the casting, specimens were prepared from the investigated holder near the crack. Hardness values were measured on the metallographic specimen. It was decided for this option because we did not have testing coupons. Generally, it can be concluded that mechanical properties fulfil requirement. More concretely mechanical properties of the investigated specimens correspond with values prescribed by standard.

It was found from metallographic analysis that few types of casting defects directly influence the quality of the casting holder i.e. formation of macro crack [6-8]. One of them are hot tears and another slag inclusions, besides shrinkage cavity and segregation contribute for defects formation in the investigated part too [9]. It can be concluded from the metallographic analysis that besides main crack and another crack were detected; some of them starts from surface and some appear and propagate beneath the surface these type of cracks are known as a hot tears or hot cracks [10]. Another detected defects are slag inclusions. Slag inclusions located immediately near to the macro crack. Both types of defects belong to the metallurgical casting defects [11,12]

Description and reasons for the appearing of hot tears in casting:

- hot tears are intercrystalline discontinuity (cracks),
- cracks run along the grain boundaries,
- the risk of cracks at alloys with a high freezing range is higher than with a small freezing range,
- the reason are stresses during solidification because of hindered a small freezing range contraction (residual stress)
- the main reason for formation of hot tears are the geometry of casting.

Prevention:

- design appropriate to casting, prevention of residual stresses, wide difference in the wall thickness and hot spots)
- prevention of hot sand effects .

The main reasons for appearing of slag inclusions are the following:

Slag inclusions are divided in two main groups - endogenous and exogenous inclusions

Endogenous inclusions are caused by the reaction products during the melting process (especially during deoxidation). Exogenous inclusion are caused by other materials in the melt e.g. refractory lining.

Prevention of slag inclusion appearing in casting are the following: use of clean charge,

optimization of gating and feeding system (lamellar flow), decrease of the dissolved oxygen, decrease of the overheating temperature

Shrinkage cavities were detected on the metallographic specimen too. Nevertheless, they are pretty small and propagate along the imagine line, figure 8.

Metallographic specimen with macro crack was broken after performed investigation. Our idea was to perform visual inspection on the fractured surface (figure 17). It is clear that fractured surface is coarser in the upper half. With arrows and circles are denoted locations with impurities. Besides crack and impurities were detected on the fractured surfaces.

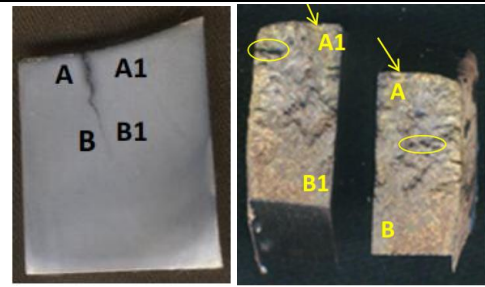


Figure 17 Fractured surface of metallographic specimen

Additionally pictures from other damaged holders were required from purchaser in order to compare the location and types of defects. It was concluded that macro cracks were detected in all cases, and its location is almost at the same for all specimens. It is another confirmation that casting technology is the main reason for the accident.



Conclusion

From the performed investigation was concluded that formation of macro cracks in the investigated holder is influenced by few types of casting defects i.e. hot tears and slag inclusion. Besides shrinkage cavities, (porosity) and segregation were detected on the metallographic pictures too. It is well known what are the reason for their appearing. So our opinion is that these defects are results of unappropriated casting technogy like mold design, too high or too low casting temperature, deformation during cooling and many other. If producer did not undertake necessary precautionary these crack should not appear. As most important for appearing of this metallurgical reason could be slag in the molten metal, very high temperature of molten metal, stress of the casting during cooling, improper design of casted part and similar.

Although mechanical properties of the part are in accordance with standard requirement, casting technology is the main reason for cracks appearing.

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Possible energy savings in passenger elevators

Svilen Rachev

Technical University – Gabrovo, Republic of Bulgaria
sratchev@mail.com

Abstract: Paper deals with determining the possible savings of electrical energy in a passenger elevator. After carrying out calculations with a set number of floors of an administrative building and number of passengers according to a proven and widely used methodology in Bulgaria, an appropriate three-phase squirrel-cage induction motor has been selected to drive the considered elevator system. Calculations have been also carried out on the possible recovery, i.e. returning electrical energy back to the supply power grid when the driving rotating electrical machine is switched to generator mode. Variants with different number of passengers and movement of the cabin in upward and downward directions were theoretically studied. The active power, time to work in recovery mode and the active energy returned to the power grid are defined for each specific case. Calculations of possible electrical energy return in generator mode would be of interest to specialists dealing with these technical facilities.

Keywords: INDUCTION MOTORS, ELECTRIC DRIVE, ENERGY CONSUMPTION, POWER GENERATION, POWER GRID

1. Introduction

Lifting and transport equipment plays a key role in the processes of mechanization and automation of specific activities related to lifting, lowering, transportation, loading, unloading and other manipulation actions of different size, mass and type of cargo in the industry [1, 2].

Elevators are stationary lifting devices with periodic action, intended for raising or lowering people or various loads in a cabin or platform moving between two or several permanent stops in a specially constructed shaft. If there is no such shaft, and the stairwell is small and does not allow the construction, then in the mass case, an external elevator is made along one of the walls.

Elevators save us the endless and tiresome climbing of stairs in tall buildings. They were used as early as 2600 years ago, but of course they were quite different from modern ones. The first electric passenger elevator was made by the German company *SIEMENS* in 1888. It rose to 22 m in just 11 seconds. The first *OTIS* electric elevator was installed in a skyscraper in New York in 1889.

Currently, the situation in Bulgaria regarding elevators is as follows. As of 16 September 2024, according to the information system of the State Agency for Metrological and Technical Surveillance (SAMTS) for the facilities with increased danger, which also includes information about the elevators registered by the technical supervision authorities, their number is as follows: registered 90905 elevators, of which 80905 are in operation, and licensed persons have registered 69873 elevators, of which 64117 are in operation. There are 11,122 units in public buildings, which are under the supervision of SAMTS, and 69,873 units are in residential and industrial buildings and they are under the supervision of companies with a license issued by SAMTS to inspect them [3].

A large part of the elevators that left the factories count them as being in service. But there are many buildings in which there are 3 or 4 elevators, but only one is actually functioning. The technical condition of the old elevators is getting worse every year. They are becoming more and more dangerous and still not maintained according to European safety requirements and standards. The average age of elevators that were manufactured before 1992 is now almost 40-45 years. Periodic repairs must be carried out, which are necessary and stipulated by the manufacturers of the respective lifts. All who maintain elevators are obliged to comply with the instructions of the factories that produced them and to carry out functional inspections, technical services: small, medium and capital repairs.

An elevator is a means of transport like a car. It has even been proven that globally, elevators carry the most people in the world, even more than cars. Because many people today will travel by car, by subway, by bus, but they will also take an elevator in a building. So this is an extremely important facility that the owner

must manage properly so that its safety is not compromised. Just as if a car fails technical inspection, its owner is penalized, so if an elevator in an apartment or administrative building fails technical inspection, the owner of the building is penalized [3].

By purpose, elevators are divided into the following types: passenger, hospital, cargo. Elevators are divided by the size of the nominal speed also: low-speed - with nominal speed up to 1 m/s for buildings up to 15 floors; speed - with a nominal speed up to 2.5 m/s for buildings with a height of up to 24 floors; high-speed - with a nominal speed above 2.5 m/s for buildings with a very high height and with a large flow of passengers.

The main parameters that characterize the qualities of individual elevators are: speed, load capacity (the maximum weight of payload or passengers), lift height (the distance from the lowest to the highest service level of the elevator) and number of stops (usually the number of stops overlaps with the number of floors).

Most often, induction motors (IMs) - single-speed and two-speed - are used to drive elevators. Two-speed IMs provide motion at rated and reduced speed. The nominal (high) speed is used for transport between floors, and the low (reduced) speed is used for positioning and precisely stopping the cabin relative to the set floor. Unlike general-purpose IMs, those for elevators have an increased starting torque.

It has been estimated that IMs are used in seventy to eighty per cent of all industrial drive applications [2, 4]. In turn, IMs owe their wide distribution for solving various engineering tasks to their relatively simple construction, the small number of moving parts and the high wear resistance of the motor elements. It is primarily due to the absence of a collector and the associated friction, sparking, wear of the brushes and contact elements. An important advantage of these machines is their direct power supply from an alternating current (AC) mains.

The electrical control schemes for passenger elevators that are still widely used are relay-contactor control systems. To improve the operation of elevators and to improve the automation of their management, control systems based on programmable logic controllers (PLC) can be used.

The development of technology leads to rapid progress in elevator technology. A modern solution is to include more elevators in a common system. The market demands are small size, high speed and higher heights, quick stopping and low noise level. In recent years, the elevator market has witnessed a significant technological evolution towards systems with gearless traction, which allows the construction of reliable, quiet and comfortable installations, overcoming the limitations of traction with traditional gearing [1, 2].

There has been a huge interest in the purchase and installation of elevators in recent years. Until recently, the largest number of orders came from hotels, new business buildings, but more and

more customers are those who have old cooperatives without an elevator or small new blocks for which this service is saved. The prices move in a very wide range, depending on three main factors – local or imported production, size and load capacity, luxurious interior design, etc.

2. Details according to the passenger elevator under consideration

The elevator, the subject of this paper, has been designed for an office building with 10 floors. The flow of passengers in the morning is high, up direction, boarding a full cabin and descending an empty cabin, and in the late afternoon it is the opposite – ascending an empty cabin and disembarking passengers afterwards.

When choosing the power of electric motors (EMs) for elevators, the method of successive approximations is used. It consists in the following – on the basis of static loads or statistical data for similar mechanisms, a preliminary power of the EM is determined. With the static load data and the data of the pre-selected motor, calculations have been made and a static and dynamic load diagram has been drawn out for a full cycle. This chart checks the pre-selected motor for warm-up and short-term overheat conditions.

The average power loss method or equivalent quantity methods are used to check the EM for heating. If these checks are not passed, the next higher power motor from the standard power range is selected and the checks are carried out again.

In order to dimension the EMs correctly it is extremely important to specify the kind of operation the EM is to perform. Regulation CEI 2-3, dossier 8284, in accordance with European (European Committee for Electrotechnical Standardization – CENELEC EN 60034-1) and international standards (IEC 60034-1), distinguishes 10 types of duties, whose operating criteria are specified below [5, 6]. The first three modes (S1, S2 S3) are adopted as the main operating modes of EMs: continuous, short-time and periodic duty. Modes S4 – S10 are introduced to simplify the puzzle of random mode equivalents by rated load, by expanding the nomenclature of the latter. The heating conditions of EMs are different, which is why different methods of power selection are needed. For each mode, specially designed EMs are used.

The duty cycle type of the elevators is Intermittent Periodic Duty (S3). This mode is characterized by a cyclical change in the state of the EM – after work, there is a pause for a short time and then the process is repeated. The temperature does not have time to reach a constant value, and during shutdown the machine does not have time to cool down to the ambient temperature. The duty cycle is too short for thermal equilibrium to be reached. The starting current does not significantly affect temperature rise. Recommended values for the *cyclic duration factor* are 15, 25, 40, and 60%. The duration of one duty cycle is limited to 10 min. Induction motors, driving lifting equipment (cranes, hoists, elevators), electric tools, as well as punching and drilling machines, etc., are specifically designed and work most often in this mode [2, 7].

Selected and successfully passed the checks is an EM with specific output data, some of them are:

- ✓ Rated load capacity $G_{RATED} = 3200 \text{ N}$ – i.e. 4 passengers weighing 80 kg ($\approx 800 \text{ N}$) each
- ✓ Cabin travel speed $V = 1 \text{ m/s}$
- ✓ Cabin weight $G_{CABIN} = 5100 \text{ N}$;
- ✓ Guide wheel diameter $D = 0.58 \text{ m}$
- ✓ Transmission ratio of the gear $i_g = 27.32$
- ✓ Number of floors – 10;
- ✓ Floor height $h = 3.6 \text{ m}$;
- ✓ Nominal efficiency of the system $\eta = 0.75$.

Some technical data of the drive EM are given in the Appendix.

In elevators with electric drive, a feature of the mechanical system is the presence of the so-called a counterweight that balances the weight of the cabin plus part of the load.

The weight of the counterweight is determined by the formula:

$$G_{CW} = G_{CABIN} + \alpha G_{RATED}, N \quad (1)$$

where

G_{CW} – weight of the counterweight

α – equalization coefficient, takes values from 0.3 to 0.6, i.e. balancing 30-60% of the rated load capacity. We accept $\alpha = 0.5$.

$$G_{CW} = 6700 \text{ N}$$

The acting resistance forces F_i and their corresponding moments of resistance are determined for each of the possible stops, as well as the travel times and the acting accelerations.

In terms of resistance forces, they are greatest when a loaded cabin with a nominal load starts up from the lowest floor and when an empty cabin descends from the top floor.

The determination of the resistance moments acting on the individual stops is as follows:

$$M_i = \frac{F_i \cdot D}{2i_g \eta_i} = \frac{1600 \times 0.58}{2 \times 27.32 \times 0.75}, Nm \quad (2)$$

where

η_i – efficiency for the respective stop.

In terms of accelerations, the two most severe cases with the largest values in elevator operation are lowering a full cabin and raising a single passenger. When starting and stopping the elevator, the accelerations must be less than the permissible value 1.5 m/s^2 . If the accelerations in the mentioned cases are greater than the permissible value, with an already selected EM, they can enter the norm by changing the flywheel moment of the system with the addition of a flywheel.

Both the torque of an EM and its speed can be in different directions. Since in mathematical formulations the direction of velocity and torque are represented by their signs, both quantities are sign-variable. The polarity of angular velocity and torque determines the direction of power transmission between the motor and the mechanism connected to it (this mechanism is considered as a mechanical load). When the shaft power of the electric motor is $P > 0$, the EM motor operates in motor mode. In this mode, the EM converts electrical energy to mechanical energy. Electrical energy is drawn from the supply power grid, converted to mechanical energy in the EM and given to the load, i.e. the mechanism. When $P < 0$ the EM is said to be operating in braking mode.

There are three types of braking modes:

✓ generator braking (with release of electrical energy into the power grid)

In this stop, the rotor is spun by an external mechanical source. The angular speed becomes greater than the synchronous speed: $\omega > \omega_0$. The slip s becomes negative, the signs of the induced voltage and current in the rotor change and the IM becomes an induction generator (IG). This method of stopping is used in micro-hydroelectric power plants and in mechanisms with a potential active moment of resistance (elevating transport mechanisms - cranes, hoists and elevators).

✓ dynamic braking

It is used for squirrel-cage IMs in flywheel mechanisms. The stator winding is disconnected from the mains and to two of the phases voltage is applied from a direct current (DC) source which creates a constant stationary field. The interaction of the rotating magnetic field of the rotor and the stationary magnetic field of the

stator produces a braking effect. In this mode IM becomes a generator, which is loaded with the resistance in the rotor circuit. Mechanical energy is converted into thermal energy, which is dissipated in the air space.

- ✓ braking by counter-locking: exclusively for IMs with a wound rotor.

As a summary – in the generator modes, the mechanical energy coming from the working machine is converted in the EM to electrical energy. In regenerative braking, electrical energy is fed back into the power grid. In practice, rotation frequencies much higher than synchronous are not allowed due to increased losses and heating and reduced efficiency. That is why, even as a generator, the asynchronous machine works with slips that are the same in absolute value as those of a motor.

3. Results obtained

In connection with the set goal, calculations were carried out for the possible recovery, i.e. returning electrical energy back to the supply power grid when the driving rotating electrical machine is switched to generator mode.

Two sets of calculations have been performed. First group of calculations have been carried out in the case that there is no previously selected EM and only the output data is used – 10-floor building (each floor with a certain height and floor slab thickness) with a lift for a maximum of 4 people. A second group of calculations have been carried out in a different way - with an already selected EM – and taking into account its nominal data (mainly rated power and rated rotational frequency).

For both sets of calculations, results have been obtained for the movement of the cabin with passengers in it in the UP and DOWN directions. The results for moving the cabin with passengers in it in the DOWN direction are assuming it moves from the top floor to the ground floor.

The obtained results are presented in tabular form below.

Table 1: Results of preliminary calculations for an electric motor for an upward direction

Number of passengers	Forces at the stops, N	Efficiency at the stops	Torques at the stops, Nm	Active power, kW	Working time, s	Active energy, $\times 10^{-3}$ kWh
4 passengers	$F_0=1600$	0.75	$M_0=22.65$	2.134	8.33	4.938
	$F_1=800$	0.72	$M_1=11.79$	1.111	8.33	2.571
	$F_2=0$		$M_2=0$	0	8.33	0
	$F_3=-800$	0.48 (load downward)	$M_3=-4.08$	-0.384	8.33	0.890
3 passengers	$F_0=800$	0.687	$M_0=800$	1.164	11.1	3.589
	$F_1=0$	0.114	$M_1=0$	0	11.1	0
	$F_2=-800$	0.596 (load downward)	$M_2=-800$	-0.477	11.1	1.471
2 passengers	$F_0=0$	0.114	$M_0=0$	0	16.65	0
	$F_1=-800$	0.596 (load downward)	$M_1=-800$	-0.477	16.65	2.206
1 passenger	$F_0=-800$	0.596 (load downward)	$M_0=-800$	-0.477	33.3	4.412

Table 2: Upward direction results with electric motor selected

Number of passengers	Active power, 6.8 kW	Working time, s	Active energy, $\times 10^{-3}$ kWh
4 passengers	Between stop 3 and stop 4	8.33	15.734
3 passengers	Between stop 2 and stop 3	11.1	20.967
2 passengers	Between stop 1 and stop 2	16.65	31.450
1 passenger	To stop 1 (we accept the last floor)	33.3	62.900

Table 3: Results of preliminary calculations for an electric motor for a downward direction

Number of passengers	Forces, N	Efficiency	Torque, Nm	Active power, kW	Working time, s	Active energy, $\times 10^{-3}$ kWh
4 passengers	$F_f=1600$	0.66	$M_f=11.21$	1.056	33.3	0.010
3 passengers	$F_f=800$	0.59	$M_f=5.01$	0.480	33.3	0.004

Table 4: Downward results with electric motor selected

Number of passengers	Active power, kW	Working time, s	Active energy, $\times 10^{-3}$ kWh
4 passengers	5.8	33.3	62.9
3 passengers	5.8	33.3	62.9

It can be seen from Table 2 and Table 4 that the greatest savings in electrical energy are achieved in the cases of raising 1 passenger from the ground floor to the top floor and when lowering 3 or 4 passengers from the top floor to the ground floor.

Other scenarios are also possible, but the ones studied so far show certain trends.

4. Conclusions

The treated topic is actual, as the results of some developments in this area have not yet been put into practice.

With the availability of smart electricity meters in recent years, the electricity generated by the elevators could be counted and deducted from the monthly bills of consumers. If this energy is not taken into account, it is immediately consumed (and recorded on another electricity meter) by the nearest consumer.

Regardless of the specific case - whether it is a new elevator or an existing one - it would be good to take into account the possible savings in electrical energy. They directly affect the monthly and annual electricity costs of administrative and domestic buildings.

Among the leading technological trends in drives, summarized by the analysts, is the increasingly targeted market demand for specialized solutions for specific applications. Typical examples are drinking and wastewater pumping equipment, HVAC systems, elevators, and faucets. Investing in a purpose-built solution creates greater confidence for users, who are convinced that they can rely on optimized hardware, firmware and technical documentation that precisely matches the application area.

Leading EM and ED manufacturers are united around the proposition that key *Industry 4.0* technologies such as artificial intelligence and machine self-learning will play a fundamental role in the development of modern drives as well. Consumers already expect every device to have smart functions, but their self-serving integration alone does not lead to serious technological progress, experts believe. The real winners in the race will be those manufacturing companies that succeed in harnessing innovations such as machine learning to collect performance data from ED in real time. The possibilities for automated adaptation of work parameters and processes "on the fly" based on the collected information will prove to be the real winning advantage over the competition.

5. Acknowledgments

The implementation of this paper is thanks to the support from:

- the University Project 2206S 'Applied mathematical investigations in electric power supply and electrical equipment focused on energy and economic efficiency', financed by the Ministry of Education and Science of the Republic of Bulgaria.
- the European Regional Development Fund under the Operational Program "Scientific Research, Innovation and Digitization for Smart Transformation 2021-2027", Project CoC "Smart Mechatronics, Eco- and Energy Saving Systems and Technologies", BG16RFPR002-1.014-0005.

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Appendix

INDUCTION MOTOR DATA

Type AC 200-1-6/24 – elevator two-speed induction motor

Rated power – $P_H = 6.8 / 1.4$ kW

Cyclic duration factor – CDF = 50/10 %

Number of switches on per hour – SF = 180 h⁻¹

Rated voltage – U = 380 V

Rated rotational frequency – $n_r = 897 / 193$ min⁻¹

Rated current – $I_n = 17.0 / 13.8$ A

Multiplicity of starting torque – 2.55/1.86

Multiplicity of starting current – 63.5/19.0

Rotor moment of gyration – 1.07 kgm²

Weight – 160 kg

Управление на битови електроуреди чрез кабелна и Wi-Fi мрежа

Control of household electrical appliances via cable and Wi-Fi network

Управление бытовыми электроприборами по кабелю и сети Wi-Fi

Доц. д-р Жейнов, Ж. Ив.¹, Инж. Гелдиев Е.²
 Технически Университет-Варна, България
 e-mail: zh_viv@tu-varna.bg¹, rahe@abv.bg²

Abstract: The article analyzes some solutions for remote control of household electrical appliances, through which electricity consumption is monitored. A historical overview and classification of technologies for remote control of consumption is made. The hardware and software features of the control are discussed. An example implementation of an accessible Arduino microcomputer control system is shown via cable and Wi-Fi network. The system sends data about electricity consumption and switches electrical consumers on and off according to a schedule.

Keywords: ELECTRICAL APPLIANCES MONITORING AND CONTROL, ARDUINO, MICROCOMPUTER, WI-FI MODULE, ELECTRICAL CONSUMPTION

1. Увод

Автоматизацията в домакинството предоставя значително удобство на потребителите, като им позволява да контролират и управляват различни уреди дистанционно. Това дава следните предимства:

- Енергийна ефективност: Чрез автоматизацията могат да се оптимизират разходите за енергия, като уредите се включват и изключват според нуждите и времевите графици.
- Подобряване на безопасността: Системите за дистанционно управление могат да включват функции за мониторинг и предупреждения, което повишава нивото на безопасност в дома.
- По-лесно управление на дома: Автоматизацията улеснява управлението на различни аспекти от домакинството, като осветление, отопление, охранителни системи и др.

Развитието на Интернет на нещата (IoT) и смарт технологиите прави автоматизацията все по-достъпна и популярна.

Потребителите могат да контролират уредите у дома си от всяка точка на света чрез смартфони или компютри. Възможно е предварително задаване на графици и автоматизации на задачите, като включване и изключване на отопление или осветление преди пристигане у дома. Оптимизацията на потреблението на енергия намалява месечните сметки за ток и други услуги.

Дистанционното управление позволява интеграция с други смарт системи като охранителни камери, датчици за движение и др.. Повишеното удобство и контрол върху домашната среда подобрява качеството на живот на обитателите.

2. Предпоставки и начини за решаване на проблема

Дистанционното управление позволява потребителите да контролират уредите в дома си от всяка точка на света чрез смартфони или компютри. С него се постига управление по време. Това е възможност за предварително задаване на графици и автоматизация на задачите, като включване на отопление или осветление преди пристигане у дома. Оптимизацията на потреблението на енергия води до намаляване на месечните сметки за ток и реализация на други услуги.

Първите опити за дистанционно управление на уреди са базирани на механични таймери и електромеханични релейни системи. В края на 20-ти век, инфрачервените

технологии стават популярни за управление на устройства като телевизори и аудио системи. В началото на 21 век Radio Frequency (RF) дистанционните управления позволяват управление на уреди без пряка видимост, разширявайки възможностите за дистанционно управление [2]. С развитието на персоналните компютри и интернет, започват да се разработват първите системи за дистанционно управление чрез компютърни мрежи [3].

- Възходът на Wi-Fi технологиите и смартфоните прави възможно управлението на уреди чрез интернет и мобилни приложения [1]. Появата на IoT платформи като Amazon Alexa, Google Home и Apple HomeKit създава нови възможности за интеграция и автоматизация на домакинските уреди. Wi-Fi имат широка достъпност, лесна интеграция със съществуващите мрежи, висока скорост на предаване на данни, обаче имат по-високо енергопотребление и са възможни проблеми със сигурността.

- Bluetooth предлага ниско енергопотребление, добра съвместимост с мобилни устройства. Bluetooth има обаче ограничен обхват и ограничена скорост на предаване на данни.

- Zigbee има ниско енергопотребление, мрежова топология (mesh network), висока надеждност. Zigbee има по-ниска скорост на предаване на данни, необходимост от специални хъбове за управление.

- Z-Wave има ниско енергопотребление, сигурна и надеждна комуникация, мрежова топология (mesh network). Недостатъци са по-високи разходи за хардуер, по-малка база от съвместими устройства в сравнение с други технологии.

- Radio Frequency Identification (RFID) и Near Field Communication (NFC) се ползват най-вече за контрол на достъпа и идентификация на обекта.

Предимствата на RFID и NFC технологиите са лесното и бързото им взаимодействие на къси разстояния. Недостатъците им са в ограничения обхват. Те не са подходящи за всички видове уреди.

Съществуват няколко решения и продукти, предлагани на пазара за дистанционно управление:

- Интегрирани IoT платформи: Amazon Alexa, Google Home, Apple HomeKit. Това са системи, които предлагат централизирано управление на разнообразни уреди чрез гласови команди и мобилни приложения, напр. Смарт крушки, термостати, охранителни системи, смарт – розетки [4].

- Специализирани системи за управление: Philips Hue, Nest Thermostat. Продукти, които се фокусират върху

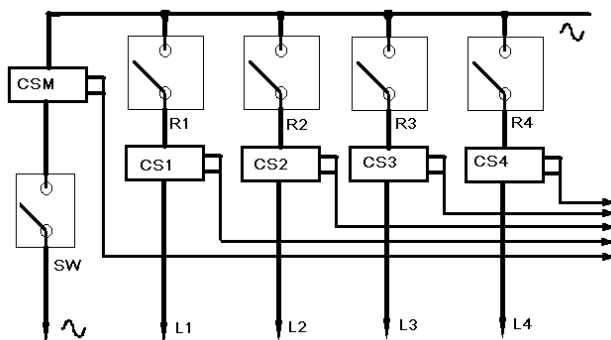
специфични аспекти на домакинството, като осветление и климатизация. Те предлагат лесна инсталация, интуитивни интерфейси, съвместимост с други IoT платформи [5].

- Отворени платформи и „Направи си сам” /Do It Yourself/ решения: OpenHAB, Home Assistant. Това са платформи с отворен код, които позволяват на потребителите да създават и персонализират свои собствени системи за дистанционно управление. Те са гъвкави, осигуряват поддръжка на широка гама от устройства и активни потребителски общности. Те имат по-сложна конфигурация, изискваща технически познания.
- Модулни системи: Samsung SmartThings. Това е система, която поддържа множество модули и устройства, предоставяйки гъвкавост и мащабируемост. Позволява лесно разширяване с нови модули и интеграция с различни технологии (Wi-Fi, Zigbee, Z-Wave).

3. Резултати и дискусия

Ще реализираме макет на проста система за дистанционно управление на битови електроуреди с управляващ микрокомпютър и периферия. Чрез него ще бъдат демонстрирани предимствата и възможностите на такава система. Системата позволява управление на различни уреди в домакинството на къси разстояния като изпраща данни за потреблението на електричество и включва и изключва по график дистанционно електрическите консуматори.

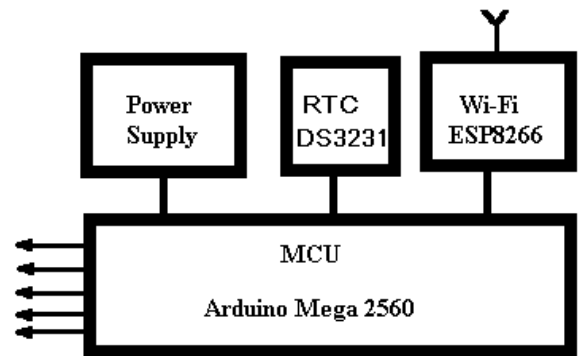
Примерна реализация на електрическо табло за дома е показано на фиг. 1. Към таблото са свързани електрическите консуматори.



Фиг. 1. Блокова схема на главното разпределително електрическо табло

На фиг. 1 с R1-R4 са означени релетата, комутиращи тока през товарите L1-L4. CS1-CS4 са токови сензори, измерващи тока през товарите. CSM е токов сензор за общото потребление. Към главния прекъсвач SW на електрическото табло е добавен датчик на Хол (ACS724 50A), с който ще се измерва консумирания ток, респективно енергията и мощността на главното разпределително табло. Като прекъсвачи за електричеството за помещенията (хол, спалня, кухня, баня...) са използвани Solid State Relay (SSR) релета, монтирани на отделна печатна платка. Чрез тях се комутира съответната токова верига.

Информацията от петте токови датчици се подава за обработка към микрокомпютъра на управляващия модул. Тази информация се визуализира на локален LCD дисплей и се подава към WEB браузър – фиг. 2.

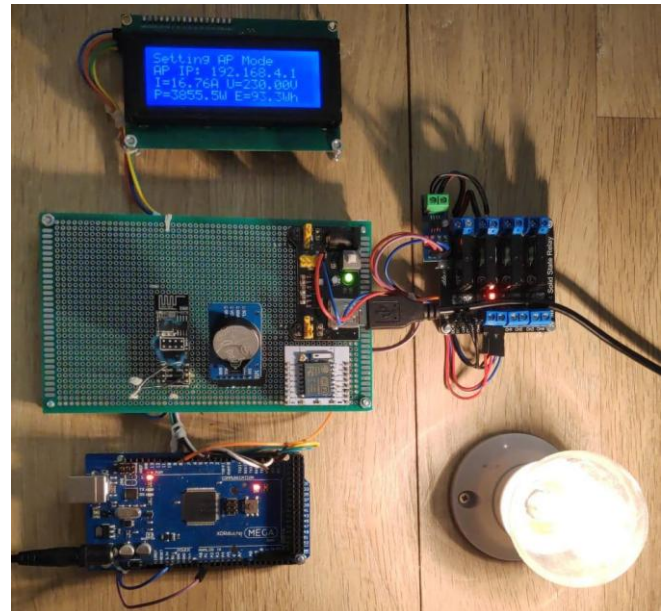


Фиг. 2. Блокова схема на модула за управление на електрически консуматори

Управляващият модул осъществява включване и изключване на електрическото захранване. Той съдържа микроконтролерен модул Arduino Mega 2560, часовник за реално време (RTC) DS3231 и модулът ESP8266 за безжична комуникация и свързване към Wi-Fi мрежа.

За целта към апартаментното електрическо табло са добавени елементите по проекта. Непосредствено до него се поставя таблото с модула за управление.

На фиг. 3 е показана фотография на реализирания макет за управление на електрически консуматори в малък апартамент.



Фиг. 3. Макет за електронно управление на електрически консуматори

Arduino Mega2560 е развойна платка с 8-битов микроконтролер ATmega2560, работещ с тактова честота 16 MHz, 4KB EEPROM, 8KB вътрешна SRAM. Предимство на този модел е голямата му флеш памет, която може да достига до 256 KB. Микрокомпютърът има 54 цифрови входно-изходни крачета, 15 от които може да се използват като аналогови 8-битови изходи за PWM (Power Wide Modulation) и 16 като аналогови входове. Моделът Mega има 4 програмируеми серийни комуникационни порта (USART), SPI комуникационен порт и 6 хардуерни прекъсвания. Платката може да се захранва през USB конектор или външен жак с постоянно напрежение 7-12V.

Към управляващия микрокомпютър са свързани с кабели четирите SSR релета и петте токови датчика.

За измерване на големината на тока се ползва аналогов токов сензор, използващ ефекта на Хол. Сензорът преобразува измерената стойност на тока в напрежение. Измереното

напрежение се подава на аналоговите входове A0 и A1 на АЦП на Arduino микрокомпютъра. Измереният ток се пресмята по формулата (1):

$$I = \frac{5000 * Sens * (Ir - Io)}{1024} \quad (1)$$

където I – аналогова стойност на измерения ток във веригата [A], а Sens – константа на преобразуването. Sens е напрежението [mV], давано от сензора за единица измерен ток. Ir е получена измерена цифрова стойност на напрежението от ADC /0-1023/. Io е получена измерена цифрова стойност на напрежението 2.5[V] от ADC при ток I=0[A]. Imax е максимална измервана стойност на тока от сензора. Ако I=Imax, изходното напрежение на датчика е 5[V].

Използвани са интегрални схеми на токови сензори тип ACS712 за ток Imax=30[A] и ACS724 за Imax=50 [A].

За локално измерване и визуализация се добавя LCD дисплей с 4 реда и 20 символа/ред. Този дисплей използва шина I2C за данни за връзка с микрокомпютъра. На LCD дисплея се извежда текущото време от регистрите на часовника за реално време, текущата консумация от всеки канал, свързан към сензора за ток.

Часовникът за реално време DS3231 поддържа информация за секунди, минути, часове, ден, месец, година. Той автоматично коригира датата в края на месеца при месеци с по-малко от 31 дни. Работи в 24 или 12 часов формат на времето. Часовникът има 3V батерия, така че точно отчита времето и когато липсва захранване от микрокомпютъра. DS3231 е свързан към Arduino посредством I2C интерфейс, който използва крачетата SDA и SCL на Arduino модула.

ESP8266-01S е компактен модул с вградена Wi-Fi комуникация. Той позволява свързване с 802.11 b/g/n мрежи, работейки в режими Wi-Fi Direct (P2P) и Soft-AP. Чрез него вашето устройство може да споделя данни в мрежата или да бъде управлявано от разстояние. Вграденият в модула 32-битов микроконтролер се програмира чрез сериен интерфейс с допълнителен USB-сериен конвертор. Модулът може да комуникира посредством AT команди или да се използва самостоятелно програмиран чрез софтуера на Arduino IDE.

Токовите сензори са свързани към аналоговите входове на Arduino Mega 2560 за отчитане на напрежението, пропорционално на измерения ток. LCD дисплей е свързан към Arduino чрез I2C интерфейс за визуализация на данните.

Изготвено е демонстрационно табло, на което са монтирани всички компоненти. Таблото е използвано за реална функционална проверка на отделните елементи и на цялата система като цяло.

Написаният софтуер включва следните основни програмни елементи:

1. Инициализация:
 - Инициализиране на сериен монитор и ESP8266 модул за Wi-Fi връзка.
 - Инициализиране на LCD дисплей и RTC.
 - Конфигуриране на ESP8266 като точка за достъп (AP).
 - Стартиране на сървър.
 - Конфигуриране на крачетата за управление на релетата и за измерване на ток и напрежение като изходи и входове.
2. Основен цикъл (loop):
 - Проверка за налични клиентски заявки към сървър.
 - Обработка на GET заявки от клиента.
 - Измерване на ток и напрежение.
 - Изчисляване на мощност и енергия.
 - Обновяване на LCD дисплей.
3. Обработка на клиентски заявки:
 - Обработка на заявки за управление на релета.

- Обработка на заявки за задаване на време за включване и изключване на релета.

- Изпращане на данни за измервания към клиента чрез генериране и изпращане на основната HTML страница.

4. Заключение

При производството и потреблението на електроенергия е нужен баланс между произведената и консумираната електроенергия. Във всеки момент генерираната електроенергия трябва да покрие потреблението. Мерките, които предприема държавата за осигуряване на баланс на енергопотреблението стимулират и ограничават потребителите на електрическа енергия като я заплащат по различни тарифи. Резките климатични промени също налагат въвеждане на редица регулации. Това налага всеки един битов потребител да е в състояние сам да може да планира, следи и контролира потреблението на електрическа енергия.

Основните предимства на разработеното решение са, че то има лесен достъп до данните от консумацията. Чрез WEB интерфейса данните са достъпни в реално време, което улеснява мониторинга и управлението на системата. Системата е модулна и гъвкава. Тя може лесно да бъде разширена или модифицирана за различни приложения.

Заради използването на модула за безжична комуникация, системата може да има забавяне при обработката на данни. Освен това тя консумира значително количество енергия, особено при активна Wi-Fi комуникация.

Тези недостатъци могат да бъдат избегнати чрез оптимизация на софтуера и използване на енергийно ефективни компоненти.

Разгледаната система може да бъде използвана в разнообразни приложения като:

- Домашна автоматизация за мониторинг на енергопотреблението.
- Научни изследвания и образователни проекти, свързани с електроника и IoT.

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УПРАВЛЯЮЩЕЕ ВОЗДЕЙСТВИЕ ДОПОЛНИТЕЛЬНЫХ НАПРЯЖЕНИЙ НА ПРОЦЕСС ПРОКАТКИ

CONTROLLING EFFECT OF ADDITIONAL STRESSES ON THE ROLLING PROCESS

Valery Chigirinsky¹, Sergey Melentyev¹, Irina Volokitina²

¹Rudny Industrial University, Rudny, Kazakhstan

²Karaganda Industrial University, Temirtau, Kazakhstan

e-mail: melentev.98@inbox.ru

Abstract: As it is known, the manufacturing process of complex long products is accompanied by significant uneven deformations. Accordingly, as a result of the equalizing action of the compressions in height and width of the produced varietal profile, undesirable additional stresses arise in it at the inlet and outlet of the deformation zone. But at the same time, these additional stresses can act as a controlling effect on the deformation zone. This work is devoted to the consideration of realization factor of additional stresses as a control action factor. During the work, both theoretical research in this area of research and a physical experiment were carried out. The conducted studies have shown that in order to make sure how effective and efficient the loading is when regulating the stress-strain state of the plastic medium with the help of additional stresses, it is always necessary to assess the additional impact on the deformation zone. It has been proved that the effectiveness of the control effect of additional stresses on the rolling process takes place if its implementation under force loading is less than the main deformation effect.

KEYWORDS: ROLLING, ADDITIONAL STRESSES, UNEVEN DEFORMATION, ADDITIONAL IMPACT, PHYSICAL MODEL

1. Введение

Изготовление сортового проката имеет отличительную особенность, что процесс производства сопровождается значительными неравномерными деформациями. В результате уравнивающего действия вытяжек по высоте и ширине профиля на входе и на выходе из очага деформаций возникает дополнительное напряжение [1]. Дополнительное напряжение воспринимается как отрицательный фактор, однако есть варианты при которых дополнительные напряжения могут выступать как управляющее воздействие на очаг деформации. В значительной степени изменяется напряженное и деформированное состояние в зоне формоизменения. Если будет доказано что это дополнительное воздействие будет меньше основного нагружения, тогда можно считать что это дополнительное нагружение может быть управляющим. Рассмотрим величины дополнительных напряжений и сопоставим их с основным нагружением в очаге деформации. С этой целью был спланирован и осуществлен эксперимент по замеру моментов со стороны боковых линеек с неравномерным ассиметричным обжатием.

На рисунке 1 показано совмещение шаблонов чистового и предчистового калибров в последнем проходе при прокатке профиля обода колеса грузового автомобиля. В данном случае реализуется технология прокатки особо тонкостенного профиля в центральной части при помощи управляющего воздействия, характеризуемого скорректированной формой (волнообразной) сильно обжимаемого участка [2].



Рис. 1. Чистовой и предчистовой шаблоны при прокатке обода с центральной волнообразной частью

Следует отметить, что в работе [2] обобщены теоретические, экспериментальные исследования, приведены свидетельства внедрения высокоэффективных профилей проката.

Неоднородность пластической деформации присутствует во всех процессах обработки металлов давлением, что

негативно сказывается на технологических процессах изготовления изделий. Это влияние очевидно.

Целью данной работы является разработка физической модели эффекта дополнительного воздействия на очаг деформации, как управляющего фактора процесса пластической деформации.

2. Материалы и методы

Дополнительные напряжения, как результат взаимодействия различно обжимаемых элементов в условиях неравномерной деформации определяется либо теоретически [2], [3] либо экспериментально [5]. В соответствии с работой [2]:

$$\sigma_0 = 2 \frac{\sigma_i}{\varepsilon_i} \cdot \frac{a_i}{1 + a_i} \cdot \ln \frac{\mu_{cp}}{\mu_i}, \quad \sigma_1 = 2 \frac{\sigma_i}{\varepsilon_i} \cdot \frac{1}{1 + a_i} \cdot \ln \frac{\mu_{cp}}{\mu_i}, \quad (1)$$

где σ_0 , σ_1 – дополнительные напряжения на входе и выходе из очага деформации для i -го элемента; σ_i – интенсивность нормальных напряжений; ε_i – интенсивность деформаций; a_i – коэффициент, определяющий соотношение между дополнительными напряжениями на входе и выходе из очага деформации; $\ln \frac{\mu_{cp}}{\mu_i}$ – продольная деформация взаимодействия между смежными участками полосы с разными обжатиями; μ_{cp} – средняя вытяжка в очаге деформации при прокатке профиля с разными по ширине деформациями; μ_i – частная вытяжка i -го элемента полосы.

Дополнительные напряжения на основании экспериментальных данных работы [5]:

$$\sigma_0 = \beta \sigma_u (k_1 - 1), \quad \sigma_1 = \beta \sigma_u (1 - k_2), \quad (2)$$

где $k_1 = n_1$ – экспериментальный коэффициент напряженного состояния металла сильно обжимаемого элемента (1), (подпор); $k_2 = n_2$ – экспериментальный коэффициент напряженного состояния металла слабо обжимаемого элемента (1), (растяжение).

Подставляя выражения (1), (2) в уравнение равновесия для моментов, получим для входа в очаг деформации и выхода следующие выражения:

$$M_{вх} = \sum 2 \frac{\sigma_i}{\varepsilon_i} \cdot \frac{a_i}{1 + a_i} \cdot \ln \frac{\mu_{cp}}{\mu_i} F_{0i} y_{0i},$$

$$M_{\text{вых}} = \sum 2 \frac{\sigma_i}{\varepsilon_i} \cdot \frac{1}{1+a_i} \cdot \ln \frac{\mu_{cp}}{\mu_i} F_{1i} y_{1i}. \quad (3)$$

Выражения (3) сложно использовать в расчетах т.к. в структуре дополнительных напряжений (1), (2) и в выражениях для моментов (3) присутствует нелинейность отношений σ_i/ε_i . Очевидно моменты (3) необходимо экспериментально проработать как функции:

$$M_{\text{вх}} = f \left(\sum 2 \frac{\sigma_i}{\varepsilon_i} \cdot \frac{a_i}{1+a_i} \cdot \ln \frac{\mu_{cp}}{\mu_i} F_{0i} y_{0i} \right), \quad (4)$$

$$M_{\text{вых}} = f \left(\sum 2 \frac{\sigma_i}{\varepsilon_i} \cdot \frac{1}{1+a_i} \cdot \ln \frac{\mu_{cp}}{\mu_i} F_{1i} y_{1i} \right). \quad (5)$$

Представляет интерес использовать экспериментальные данные работы [5], выражения (2), для определения моментов сил со стороны внешних зон:

со стороны входа

$$M_{\text{вх}} = \beta \sigma_u \cdot \frac{F_0}{2H} \cdot \frac{(k_1 - 1) \cdot (1 - k_2)}{k_1 - k_2}, \quad (6)$$

со стороны выхода

$$M_{\text{вх}} = \beta \sigma_u \cdot \frac{F_1}{2h} \cdot \frac{(k_1 - 1) \cdot (1 - k_2)}{k_1 - k_2}. \quad (7)$$

Использование выражений (4), (5) и (6), (7) и сопоставление результатов расчетов усиливает достоверность или не достоверность физической и математической модели используемой при решении поставленной задачи.

Следует отметить, что для обоснования достоверности результата появилась необходимость в проведении работы [4]. В этом исследовании прокатывался аналогичный образец с тем отличием, что форма образца была асимметричной. На осциллограмме (б) показано изменение величины боковой силы P в процессе прокатки полосы на выходе из очага деформации. Имеет место резкое увеличение давления на линейку в период выхода переднего конца полосы из валков. Выравнивание изогнутого короткого конца полосы происходит с большими пиковыми нагрузками. В этот момент давление на линейку на входе в очаг деформации происходит по нарастающей схеме, а затем наступает установившийся процесс.

3. Результаты

На рисунке 1 представлены осциллограммы сил со стороны полосы на боковые линейки со стороны входа и выхода.



Рис. 2. Осциллограммы сил со стороны полосы на боковые линейки со стороны входа (а) и выхода (б)

Из сопоставления данных видно, что при установившемся процессе выравнивающие силы на входе в очаг деформации больше, чем на выходе из очага деформации.

Таким образом, удалось привязать разные работы [5] и [2], через неравномерность деформации, к общему фактору влияния, который характеризует дополнительное воздействие на очаг деформации. Таким обобщенным фактором, с учетом физического и математического моделирования, выступают внешние поперечные силы или моменты со стороны боковых линеек.

Оценка дополнительного воздействия на очаг деформации необходима для того, чтобы убедиться насколько это нагружение эффективно и дееспособно при регулировании напряженно-деформированного состояния пластической среды. Эффективность этого воздействия будет иметь место в том случае, если будет показано, что его реализация при силовом нагружении будет меньше основного деформационного воздействия. Это один из основных показателей управляющего воздействия на очаг деформации.

Если напряжения входящие в момент принимаются равными напряжениям пластической текучести, следовательно, эти напряжения максимальные, а нагружение от данных моментов является основным. В дальнейшем следует производить анализ и оценку относительно этого основного нагружения.

Для подтверждения этого факта на стане 150 прокатывались ступенчатые несимметричные образцы, с разным отношением B_1/B_0 и H_1/H_0 . Для измерения давления полосы на линейки применялись роликовые линейки специальной конструкции, рисунок 3.

Прокатывалось 8 партий свинцовых образцов с разными размерами заготовки B_1/B_0 и H_1/H_0 , которые находились в пределах 0,5...0,93 и 0,65...0,91 соответственно.

Параметры H_1/H_0 и B_1/B_0 в определенной степени характеризуют неравномерность пластической деформации по ширине профиля. Соотношение H_1/H_0 определяет в количественном отношении неравномерность деформации между двумя смежными элементами. Соотношение B_1/B_0 - весомость каждого элемента при неравномерной деформации.

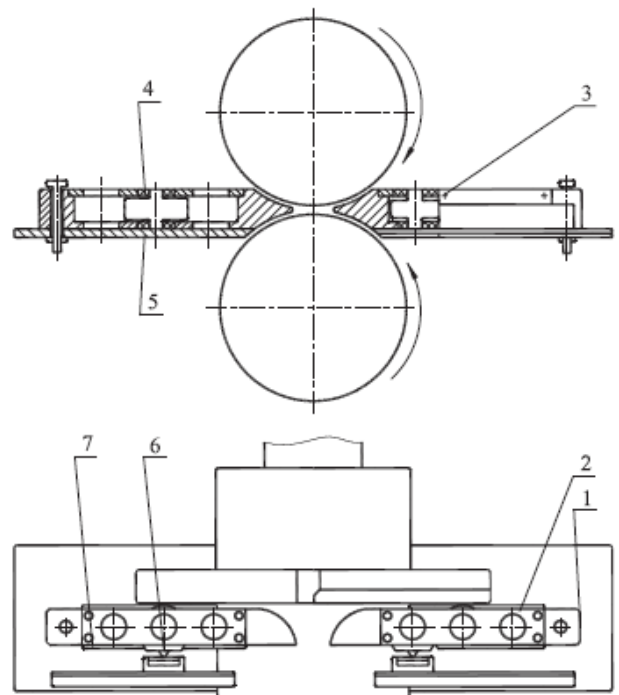


Рис. 3. Схема установки для измерения давления раската на боковые линейки

Действительно, чем больше неравномерность, следовательно, меньше отношение H_1/H_0 тем больше усилие на линейки. При значениях $B_1/B_0 = 0,62$ и значений отношений $H_1/H_0 = 0,87; 0,83; 0,75; 0,72$ моменты со стороны входа увеличиваются соответственно, $M_{\text{вх}} = 1115; 1210; 1805,0; 1952,0$ Н со стороны выхода из очага деформации соответственно $M_{\text{вых}} = 487,0; 563,0; 786,0; 780,0$ Н. Чем ближе отношение B_1/B_0 к единице, тем прямолинейней выходит полоса из валков, тем меньше ее стремление к искривлению, тем меньше сила со стороны линеек. При значениях отношений $H_1/H_0 = 0,65...0,67$ близких к друг другу, и значениях отношений $B_1/B_0 = 0,93; 0,77; 0,63$, моменты сил со стороны

входа металла в валки равны $M_{вх}=680,0; 1255,0; 1290,0$ Н со стороны выхода из очага деформации соответственно $M_{вых}=257,0; 505,0; 520,0$ Н.

Параметры B_1/B_0 и H_1/H_0 в определенной степени способны оценить процесс неравномерности, когда количество элементов минимальное. Но они не дают полного представления об асимметрии нагружения для профилей сложной конструкции, когда их количество больше двух и с другими качественными показателями.

Фрагментами таких показателей могут быть статические моменты данного сечения, далее факторы, учитывающие продольное взаимодействие в очаге деформации $\ln \mu_{cp}/\mu_i$, и т.д. Для более полной характеристики параметров неравномерной деформации следует воспользоваться математической моделью (4) и (5) приведенной к безразмерному показателю, полученные на основании уравнений равновесия внешних частей полосы. Выражения, стоящие в скобках, определяющие моменты со стороны линеек, показаны параметрами δ , со стороны входа и выхода:

вход

$$\delta_{вх} = \frac{\sum 2 \cdot \frac{a_i}{1+a_i} \cdot \ln \frac{\mu_{cp}}{\mu_i} F_{0i} y_{0i}}{W_{пл.вх}}, \quad (8)$$

выход

$$\delta_{вых} = \frac{\sum 2 \cdot \frac{1}{1+a_i} \cdot \ln \frac{\mu_{cp}}{\mu_i} F_{1i} y_{1i}}{W_{пл.вых}}, \quad (9)$$

где $W_{пл}$ – момент пластического сопротивления на входе и выходе из очага деформации.

Математическая обработка экспериментальных результатов методом наименьших квадратов для степенной функции, позволила получить выражения вида:

на входе

$$M_{вх} = 1.938 \cdot M_{пл.вх} \cdot \left[\frac{\sum 2 \cdot \frac{a_i}{1+a_i} \cdot \ln \frac{\mu_{cp}}{\mu_i} F_{0i} y_{0i}}{W_{пл.вх}} \right]^{0.443}, \quad (10)$$

на выходе

$$M_{вых} = 1.827 \cdot M_{пл.вых} \cdot \left[\frac{\sum 2 \cdot \frac{1}{1+a_i} \cdot \ln \frac{\mu_{cp}}{\mu_i} F_{1i} y_{1i}}{W_{пл.вых}} \right]^{0.485}. \quad (11)$$

Теснота связей исследуемых параметров соответственно для входа и выхода равна 0,946 и 0,937. Выражения (10) и (11) позволяют рассчитывать значения моментов при асимметричной прокатке разных профилей любых размеров и с любым количеством элементов.

Следует обратить внимание на разницу значений основного и дополнительного нагружений, которые можно объяснить разными физическими процессами происходящих при пластической деформации. При пластическом изгибе напряжения последнего достигают максимальных значений равных пределу текучести, что характеризует основное нагружение. При прокатке с неравномерным обжатием в очаге деформации появляются силы продольного взаимодействия, определяемые дополнительными напряжениями. Величина дополнительных напряжений, как это видно из проведенных исследований, меньше предела текучести. Оно характеризуется не пластическим нагружением, а разными вытяжками в очаге деформации, подчиняющиеся закономерностям математических моделей (10), (11).

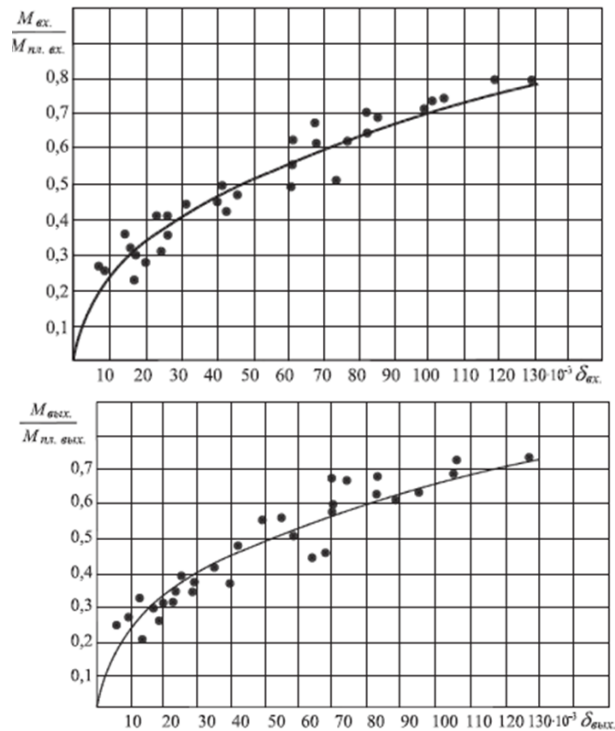


Рис. 4. Зависимости отношений моментов $M_{экс}/M_{пл}$ на входе и на выходе из очага деформации от параметров δ .

3. Заключение

В данной работе:

- рассмотрен фактор реализации дополнительных напряжений как фактор управляющего воздействия;
- поставлен эксперимент по замеру сил со стороны боковых линеек при асимметричном нагружении по ширине;
- показано, что дополнительное нагружение изменяется к основному нагружению в зависимости от сложного деформационного геометрического параметра $\delta_{вх}, \delta_{вых}$;
- отношение дополнительного нагружения к основному находится в пределах 0,2-0,8.

Данное исследование финансировалось Комитетом науки Министерства науки и высшего образования Республики Казахстан (Грант № AP23488953).

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ИССЛЕДОВАНИЕ И АНАЛИЗ ПОТЕРИ УСТОЙЧИВОСТИ ПРОЦЕССА ПРОКАТКИ В УСЛОВИЯХ СЛОЖНОГО АСИММЕТРИЧЕСКОГО НАГРУЖЕНИЯ

INVESTIGATION AND ANALYSIS OF THE STABILITY LOSS OF THE ROLLING PROCESS AT COMPLEX ASYMMETRIC LOADING

Valery Chigirinsky¹, Irina Volokitina², Abdrakhman Naizabekov³, Sergey Kuzmin¹, Evgeniy Panin², Andrey Tolkushkin¹, Sergey Melentyev¹

¹Rudny Industrial University, Rudny, Kazakhstan

²Karaganda Industrial University, Temirtau, Kazakhstan

³Innovative University of Eurasia, Pavlodar, Kazakhstan

e-mail: decan_2008@mail.ru

Abstract: This work is devoted to the study and analysis of the stability loss of the rolling process at complex asymmetric loading during deformation of thin and extra thin products. To solve this practical problem, a physical and mathematical model of the rolling process at complex asymmetric loading was developed. The analysis of the obtained results showed that the physical and mathematical modeling of asymmetric rolling of thin and extra thin strips allows to fully assess the impact of loading on the stability of this process.

KEYWORDS: ROLLING, DEFORMATION ZONE, COMPLEX ASYMMETRIC LOADING, EXTRA THIN-WALLED STRIPS, CONTACT STRESSES

1. Введение

С учетом последних теоретических достижений в области механики сплошной среды происходит усиление в прогнозировании эффектов и особенностей пластической среды в условиях сложного асимметричного нагружения при прокатке тонких и особо тонких изделий. Для реализации известных подходов [1-4] рассматриваются режимы прокатки особотонкостенных полос на грани потери устойчивости процессов, которые позволяют решить ряд высокоэффективных прикладных задач.

2. Материалы и методы

Для решения данной практической задачи была рассмотрена постановочная система уравнений теории пластичности [5]. Исходная система уравнений:

$$\frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} = 0; \quad \frac{\partial \tau_{yx}}{\partial x} + \frac{\partial \sigma_y}{\partial y} = 0; \quad (\sigma_x - \sigma_y) + 4\tau_{xy}^2 = 4k^2, \quad (1)$$

граничные условия:

$$\tau_n = - \left[\frac{\sigma_x - \sigma_y}{2} \sin(2\phi) - \tau_{xy} \cos(2\phi) \right]. \quad (2)$$

Начало решения свелось к упрощению граничных условий (2) с использованием выражения для определения интенсивности касательных напряжений, [5]:

$$T_i = \frac{1}{2} \sqrt{(\sigma_x - \sigma_y)^2 + 4\tau_{xy}^2}. \quad (3)$$

Используя выражения (3), можно записать разность нормальных напряжений и отсюда, с учетом (1), получить обобщенное уравнение равновесия:

$$\sigma_x - \sigma_y = 2\sqrt{T_i^2 - \tau_{xy}^2}, \quad (4)$$

$$\frac{\partial^2 \tau_{xy}}{\partial x^2} - \frac{\partial^2 \tau_{xy}}{\partial y^2} = \pm 2 \frac{\partial^2}{\partial x \partial y} T_i \sqrt{1 - \left(\frac{\tau_{xy}}{T_i} \right)^2}. \quad (5)$$

Следующим этапом является определение касательного напряжения с учетом (5). Для этого вводятся в рассмотрение две аргумент функции:

$$\frac{\tau_{xy}}{T_i} = \sin A \Phi, \quad T_i = H_\sigma \exp \theta, \quad (6)$$

Тогда касательные напряжения, с учетом (6), можно записать в виде:

$$\tau_{xy} = H_\sigma \exp \theta \sin A \Phi. \quad (7)$$

С учетом (6) и (7) уравнение (5) можно переписать следующим образом:

$$\begin{aligned} & \frac{1}{2i} \exp(\theta + iA\Phi) \cdot \{ [(H_\sigma)_{xx} - (H_\sigma)_{yy} - 2i(H_\sigma)_{xy}] + \\ & + 2(H_\sigma)_x [(\theta_x + A\Phi_y) - i(\theta_y - A\Phi_x)] - 2(H_\sigma)_y [i(\theta_x + A\Phi_y) - (\theta_y - A\Phi_x)] \\ & + H_\sigma [(\theta_{xx} - \theta_{yy} + 2A\Phi_{xy}) + i(A\Phi_{xx} - A\Phi_{yy} - 2\theta_{xy})] + H_\sigma [(\theta_x + A\Phi_y) - i(\theta_y - A\Phi_x)]^2 \} - \\ & - \frac{1}{2i} \exp(\theta - iA\Phi) \{ [(H_\sigma)_{xx} - (H_\sigma)_{yy} + 2i(H_\sigma)_{xy}] + \\ & + 2(H_\sigma)_x [(\theta_x + A\Phi_y) + i(\theta_y - A\Phi_x)] - 2(H_\sigma)_y [(\theta_y - A\Phi_x) - i(\theta_x + A\Phi_y)] \\ & + H_\sigma [(\theta_{xx} - \theta_{yy} + 2A\Phi_{xy}) - i(A\Phi_{xx} - A\Phi_{yy} - 2\theta_{xy})] + H_\sigma [(\theta_x + A\Phi_y) + i(\theta_y - A\Phi_x)]^2 \} = 0. \end{aligned} \quad (8)$$

Уравнение (8) в значительной степени упрощается, если воспользоваться соотношениями Коши-Римана:

$$(\theta_x = -A\Phi_y), \quad (\theta_y = A\Phi_x). \quad (9)$$

После подстановки (9) в (8), имеем:

$$\begin{aligned} & \frac{1}{2i} \exp(\theta + iA\Phi) \{ [(H_\sigma)_{xx} - (H_\sigma)_{yy} - 2i(H_\sigma)_{xy}] + \\ & + H_\sigma [(\theta_{xx} - \theta_{yy} + 2A\Phi_{xy}) + i(A\Phi_{xx} - A\Phi_{yy} - 2\theta_{xy})] \} - \\ & - \frac{1}{2i} \exp(\theta - iA\Phi) \{ [(H_\sigma)_{xx} - (H_\sigma)_{yy} + 2i(H_\sigma)_{xy}] + \\ & + H_\sigma [(\theta_{xx} - \theta_{yy} + 2A\Phi_{xy}) - i(A\Phi_{xx} - A\Phi_{yy} - 2\theta_{xy})] \} = 0. \end{aligned}$$

Можно показать, что операторы в квадратных скобках равны нулю, отсюда:

$$\frac{1}{2i} \exp(\theta + iA\Phi) \{[(H_\sigma)_{xx} - (H_\sigma)_{yy} - 2i(H_\sigma)_{xy}] - \frac{1}{2i} \exp(\theta - iA\Phi) \{[(H_\sigma)_{xx} - (H_\sigma)_{yy} + 2i(H_\sigma)_{xy}] = 0. \quad (10)$$

С учетом дифференциального уравнения (10) определяется параметр:

$$H_\sigma = \frac{C_0\left(\frac{l}{2}-x\right) + C_1\left(\frac{l}{2}+x\right)}{l}.$$

Подставляя функцию (7), с учетом (9), в дифференциальные уравнения (1), после интегрирования, имеем:

$$\begin{aligned} \sigma_x &= -\frac{\frac{k_0}{\cos A\Phi_0}\left(\frac{l}{2}-x\right)\exp(\theta-\theta_0) + \frac{k_1}{\cos A\Phi_1}\left(\frac{l}{2}+x\right)\exp(\theta-\theta_1)}{l} \cos A\Phi + k_0, \\ \sigma_y &= -3\frac{\frac{k_0}{\cos A\Phi_0}\left(\frac{l}{2}-x\right)\exp(\theta-\theta_0) + \frac{k_1}{\cos A\Phi_1}\left(\frac{l}{2}+x\right)\exp(\theta-\theta_1)}{l} \cos A\Phi + k_0, \\ \tau_{xy} &= \frac{\frac{k_0}{\cos A\Phi_0}\left(\frac{l}{2}-x\right)\exp(\theta-\theta_0) + \frac{k_1}{\cos A\Phi_1}\left(\frac{l}{2}+x\right)\exp(\theta-\theta_1)}{l} \sin A\Phi, \\ \sigma_0 &= -2\frac{C_0\left(\frac{l}{2}-x\right) + C_1\left(\frac{l}{2}+x\right)}{l} \exp\theta \cos A\Phi, \end{aligned} \quad (11)$$

при

$$\theta_x = -A\Phi_y, \theta_y = A\Phi_x. \theta_{xx} + \theta_{yy} = 0, A\Phi_{xx} + A\Phi_{yy} = 0.$$

После подстановки граничных условий и упрощений получим:

$$C_0 = \frac{k_0 \xi_0}{\exp \theta_0 \cos A\Phi_0}, C_1 = \frac{k_1 \xi_1}{\exp \theta_1 \cos A\Phi_1},$$

Используя соотношения (9) и уравнения Лапласа (11) запишем аргумент функции:

$$\begin{aligned} A\Phi' &= AA'_6 \left(\frac{l}{2}+x\right)y - AA''_6 \left(\frac{l}{2}-x\right)y - 2\phi = \\ &= AA'_6 \left[(x-X_0) + \left(\frac{l}{2}+X_0\right)\right]y + AA''_6 \left[(x-X_0) - \left(\frac{l}{2}-X_0\right)\right]y - 2\phi, \end{aligned}$$

$$\theta = -\frac{1}{2}(AA'_6 + AA''_6)[(x+X_0)^2 - y^2] - (AA'_6 l_{om} - AA''_6 l_{on})(x - X_0), \quad (12)$$

где $\phi = (l-x)/R$ – угол наклона площадки контакта;

X_0 – положение нейтрального сечения относительно начала координат;

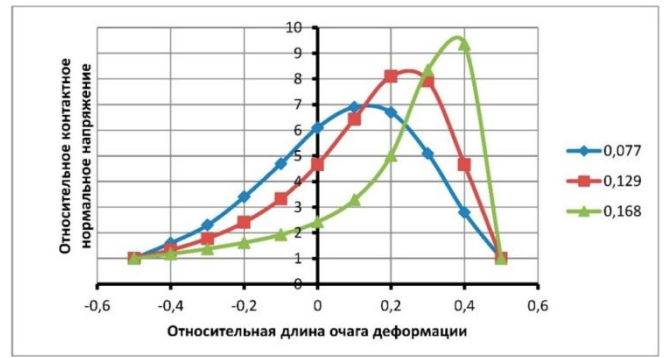
AA'_6, AA''_6 – постоянные, определяющие значения тригонометрических функций по краям очага деформации.

С учетом граничных условий определяется нейтральный угол, показывающий положение нейтрального сечения на контакте в очаге деформации:

$$\gamma = \frac{\alpha}{2} \frac{A\Phi_1 - \alpha}{(A\Phi_0 + 2\alpha)\left(1 - \frac{1}{2}\varepsilon\right)}. \quad (13)$$

3. Результаты

На рисунке 1 представлены эпюры распределения контактных напряжений в зависимости от угла захвата при одинаковых значениях коэффициента трения и фактора формы. Полученный результат представляется, как устойчивый процесс прокатки.



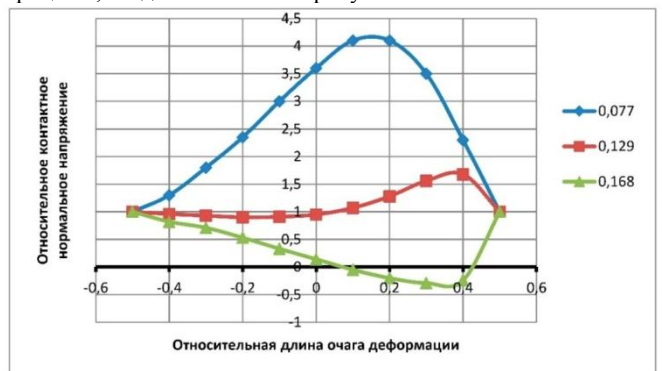
а)



б)

Рис. 1. Распределение контактных напряжений по длине очага деформации в зависимости от угла захвата, при: при $l/h=11.04$, $\alpha=0.077; 0.129; 0.168$, $f=0.4$: а – распределение нормальных напряжений; б – распределение касательных напряжений

На рисунке 2 представлены эпюры контактных нормальных и касательных напряжений в условиях потери устойчивости процесса, когда имеет место пробуксовка полосы в вальцах.



а)



б)

Рис. 2. Распределение контактных напряжений по длине очага деформации в зависимости от угла захвата, при: $l/h=11.04$; $\alpha=0.077; 0.129; 0.168$; $f=0.2$: а – распределение нормальных напряжений; б – распределение касательных напряжений

Видно, что максимальным обжатиям соответствует вогнутая эпюра распределения нормальных напряжений, а касательные напряжения определяют однозонный очаг деформации, зона опережения отсутствует. В сопоставлении с минимальными обжатиями очаг деформации двухзонный, эпюра нормальных напряжений выпуклая. Из этого следует,

что данные математические построения улавливают потерю устойчивости процесса и по нормальным и по касательным напряжениям. Такие критерии оценки напряженного состояния позволяют изучать и управлять параметрами процесса прокатки при разработке оптимальной технологии производства.

3. Заключение

1. Разработана физическая и математическая модель процесса прокатки в условиях сложного асимметричного нагружения.

2. Анализ результатов расчета показал, что моделирование асимметричной прокатки позволяет оценить влияние нагружения на устойчивость процесса.

3. Показаны критерии потери устойчивости, базирующиеся на оценке напряженного состояния пластической среды, определяющей фактор пробуксовки валков.

Данное исследование финансировалось Комитетом науки Министерства науки и высшего образования Республики Казахстан (Грант № AP19678682).

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Energy and exergy analysis of steam generator from nuclear power plant at four operating regimes

Mrzljak Vedran¹, Prpić-Oršić Jasna¹, Jelić Maro², Medica-Viola Vedran¹

¹Faculty of Engineering, University of Rijeka, Vukovarska 58, 51000 Rijeka, Croatia

²Maritime Department, University of Dubrovnik, Ćira Carića 4, 20000 Dubrovnik, Croatia

E-mail: vedran.mrzljak@riteh.uniri.hr, jasna.prpic.orsic@riteh.uniri.hr, maro.jelic@unidu.hr, vedran.medica@riteh.uniri.hr

Abstract: In this paper are presented results of the energy and exergy analyses related to the steam generator from nuclear power plant at four observed operating regimes. It is shown how the optimization processes and algorithms influence observed steam generator operation. The highest steam generator energy outlet is equal to 3012.17 MW and the lowest energy loss is 0.07 MW – both of them are obtained by using Genetic Algorithm (GA). Whale Optimization Algorithm (WOA) gives fluid operating parameters which will result with the lowest steam generator exergy destruction (107.05 MW) and the highest exergy efficiency (92.709%) in comparison to all other operating regimes. During the increase in ambient temperature from 5 °C up to 45 °C the lowest decrease in steam generator exergy efficiency (equal to 2.0136%) is obtained in the second operating regime which operating parameters are defined by using WOA. Final conclusion which can be derived from the observed research is that WOA has the most beneficial influence on the steam generator operation.

KEYWORDS: ENERGY ANALYSIS, EXERGY ANALYSIS, STEAM GENERATOR, NUCLEAR POWER PLANT, VARIOUS OPERATING REGIMES, THE AMBIENT TEMPERATURE CHANGE

1. Introduction

In recent years, many technologies and processes are developed with an aim to reduce fossil fuel consumption and to decrease the emission of harmful elements from the fossil fuel combustion gases [1, 2]. However, the dominant part of the electricity nowadays is still produced by the combustion of various fossil fuel types [3].

Nuclear energy is one of the solutions how the harmful emissions can be notably reduced, while the electricity production can be maintained (or even increased if required) [4]. Nuclear power plants nowadays operate on the nuclear fission principle, while the nuclear fusion is currently under investigation [5, 6]. Many researchers and scientists performed various analyses and improvements related to nuclear power plants [7, 8]. Regardless of the potential problems and challenges, nuclear power plants are surely promising solution in electricity production worldwide in the future.

Operating medium used in nuclear power plants is water which is transferred to almost saturated steam in steam generators. Such steam is delivered to the steam turbine through which expands. Steam generator in a nuclear power plant is a highly important component, because it uses heat produced in nuclear reactors and transfer that heat to the operating medium (water) which will expand in the turbine [9]. Therefore, steam generator in nuclear power plant actually connects reactor and turbine cycles [10].

In this paper are performed energy and exergy analyses of a steam generator which operates in a nuclear power plant. Both analyses are performed at four different operating regimes. Research in this paper will not present the operating characteristics of steam generator only (during the various operating regimes), it will also show how optimization algorithms and procedures can influence the steam generator operation and which improvements can be expected. In addition, it will be presented that optimization algorithms and procedures can help to reduce sensitivity of steam generator exergy parameters during the ambient temperature change.

2. Description of the analyzed steam generator from nuclear power plant

Simplified scheme of the steam generator from nuclear power plant analyzed in this paper is presented in Fig. 1. In Fig. 1 are also presented operating points (from 1 to 4) required for the steam generator energy and exergy analyses.

Steam generator in nuclear power plant is a completely different component in comparison to steam generators from conventional steam power plants. In conventional steam power plants, steam generators are composed or at least three (or more) heat exchangers - water heater, evaporator and superheater mounted in the same housing. All steam generator components in conventional steam power plants are using heat from combustion gases (combustion gases are obtained by fossil fuel combustion) for increasing water temperature, for the evaporation and finally for obtained saturated

steam superheating [11]. In nuclear power plants, fossil fuel combustion did not occur, so the steam generators cannot be composed in a same manner as in conventional steam power plants.

In nuclear power plants, steam generators are heat exchangers in which occur heat transfer from the warmer water (from a nuclear reactor) to colder water (from condensate/feedwater heating system). During the heat transfer, the temperature of warmer water decreases (from operating point 1 to operating point 2, Fig. 1) and the heat is transferred to water from condensate/feedwater heating system (operating point 3, Fig. 1) which temperature firstly increases after which it evaporates. Obtained steam contains many water droplets (wet steam) which are dominantly removed in the steam separator (gray rectangle in Fig. 1). After the steam separator, steam is very close to the dry saturated state and that steam is delivered to the steam turbine (operating point 4, Fig. 1). After heat transfer, warmer water (operating point 2, Fig. 1) is delivered back to the nuclear reactor which increases its temperature. The entire heat exchange in steam generator from nuclear power plant occurs through the walls of U-pipes (through U-pipes passes warmer water, while around U-pipes passes the colder water which will be transferred to steam). It should be highlighted that nowadays, each nuclear reactor has several identical steam generators (not only one) [12], but the heat transfer and operating fluid parameters are identical in all of them.

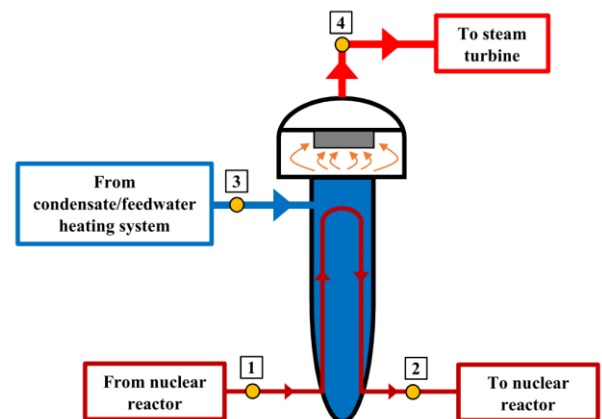


Fig. 1. Simplified scheme of the analyzed steam generator from nuclear power plant along with operating points required for energy and exergy analyses

Observed steam generator from nuclear power plant is a counter-flow heat exchanger [13]. Fluid streams temperature change diagram of the analyzed steam generator is presented in Fig. 2. Operating point numeration in Fig. 2 is in relation to operating point numeration from Fig. 1.

From Fig. 2 can clearly be seen that warmer water transfers heat to the colder water and its temperature decreases (from operating

point 1 to operating point 2, Fig. 2), while due to the heat transfer, colder water temperature increases (from operating point 3 to operating point 4, Fig. 2). Fluid streams temperature change diagram of any heat exchanger (as well as of the analyzed steam generator) is a very useful tool for overall visualization of the heat transfer process. Temperature change curves of both fluid streams must not touch or intersect – touching or intersection of the curves in Fig. 2 will denote an impossible heat transfer process. Temperatures presented in Fig. 2 in each operating point are related to the data from Table 1 (in Table 1 are presented data required for the steam generator energy and exergy analyses in all four observed operating regimes).

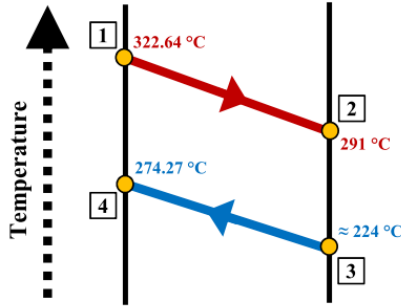


Fig. 2. Fluid streams temperature change diagram of the analyzed steam generator from nuclear power plant (steam generator is a counter-flow heat exchanger)

3. Equations for the energy and exergy analyses

3.1. Overall equations and balances

In comparison to the exergy analysis of any system or component which is based on the second law of thermodynamics and consider ambient conditions, the energy analysis is based on the first law of thermodynamics and it did not consider the ambient conditions [14]. Therefore, in the observation of any system or component exergy analysis offer additional possibilities related to the ambient conditions change (which cannot be considered in the energy analysis) [15]. Both energy and exergy analyses comprise some general equations and balances which must be satisfied, regardless of the observed system, component as well as operating or ambient conditions.

The main energy and exergy balance equations can be found in the variety of literature [16]:

$$\dot{Q} - P = \sum \dot{E}n_{out} - \sum \dot{E}n_{in}, \quad (1)$$

$$\dot{X}_{heat} - P = \sum \dot{E}x_{out} - \sum \dot{E}x_{in} + \dot{E}x_D. \quad (2)$$

In two equations above, $\dot{Q}$ is heat energy transfer, P is mechanical power, index in denote inlet (input), index out denote outlet (output) and index D denotes destruction (exergy loss). Energy and exergy flows of any fluid stream ($\dot{E}n$ and $\dot{E}x$) can be defined as [17]:

$$\dot{E}n = \dot{m} \cdot h, \quad (3)$$

$$\dot{E}x = \dot{m} \cdot \varepsilon, \quad (4)$$

where $\dot{m}$ is fluid mass flow rate, h is fluid stream specific enthalpy and ε is fluid stream specific exergy which can be defined by an equation [18]:

$$\varepsilon = (h - h_0) - T_0 \cdot (s - s_0). \quad (5)$$

In Eq. 5, index 0 denotes the ambient (environment) state, T is temperature and s is fluid stream specific entropy. The last undefined variable from Eq. 2 is a heat exergy transfer at the temperature T ($\dot{X}_{heat}$), which can be calculated as [19]:

$$\dot{X}_{heat} = \sum (1 - \frac{T_0}{T}) \cdot \dot{Q}. \quad (6)$$

In standard operation of any system or component fluid leakage did not occur, therefore the mass flow rate balance is:

$$\sum \dot{m}_{in} = \sum \dot{m}_{out}. \quad (7)$$

General energy and exergy efficiency equation, valid for any system or component can be written as [20]:

$$\eta_{en(ex)} = \frac{\text{cumulative energy (exergy) output}}{\text{cumulative energy (exergy) input}}. \quad (8)$$

It must be highlighted that exact energy and exergy efficiency equations of any system or component can be notably different than presented in Eq. 8. The exact energy and exergy efficiency equations are dependable on system or component operation characteristics.

3.2. Energy and exergy analyses equations of the observed steam generator from nuclear power plant

Steam generator energy and exergy analysis equations are composed according to recommendations and guidelines from the literature [21]. In all equations from this subsection, numbers in the indexes are related to operating points from Fig. 1 and Fig. 2.

Steam generator cumulative energy (exergy) inlet is:

$$\dot{E}n_{SG,in} (\dot{E}x_{SG,in}) = \dot{m}_1 \cdot Z_1 - \dot{m}_2 \cdot Z_2. \quad (9)$$

Steam generator cumulative energy (exergy) outlet is:

$$\dot{E}n_{SG,out} (\dot{E}x_{SG,out}) = \dot{m}_4 \cdot Z_4 - \dot{m}_3 \cdot Z_3. \quad (10)$$

In Eq. 9 and Eq. 10 during the calculation of energy inlet and outlet, Z is fluid stream specific enthalpy (h), while during the calculation of exergy inlet and outlet Z is fluid stream specific exergy (ε). Steam generator energy loss and exergy destruction are:

$$\dot{E}n_{SG,L} = \dot{E}n_{SG,in} - \dot{E}n_{SG,out}, \quad (11)$$

$$\dot{E}x_{SG,D} = \dot{E}x_{SG,in} - \dot{E}x_{SG,out}. \quad (12)$$

Steam generator energy and exergy efficiencies are:

$$\eta_{SG,en} = \frac{\dot{E}n_{SG,out}}{\dot{E}n_{SG,in}}, \quad (13)$$

$$\eta_{SG,ex} = \frac{\dot{E}x_{SG,out}}{\dot{E}x_{SG,in}}. \quad (14)$$

All equations (from Eq. 9 up to Eq. 14) remain identical as presented, regardless of the observed operating regime. In each steam generator operating regime, variables which change their values are fluid mass flow rates ($\dot{m}$), fluid specific enthalpies (h) and fluid specific exergies (ε), but the equations remain as presented.

4. Fluid operating parameters required for the steam generator energy and exergy analyses

The operating parameters of all fluid streams related to the analyzed steam generator (in each operating point from Fig. 1 and Fig. 2) at all four operating regimes are found in [22] and presented in Table 1.

First of all, it should be highlighted that four observed operating regimes include base plant operating regime (BASE) which involves operating parameters measured during the nuclear power plant operation. Second, third and fourth operating regimes are related to operating parameters obtained by using three different optimization algorithms and procedures (WOA = Whale Optimization Algorithm, GA = Genetic Algorithm and PSO = Particle Swarm Optimization). The main goal in [22] was to perform whole nuclear power plant optimization through overall plant efficiency increase, while in this paper is observed how applied optimization algorithms influence steam generator operation only (and steam generator energy and exergy parameters).

Secondly, it should be highlighted that in [22] are found fluid temperature, pressure and mass flow rate in each operating point and at each operation regime – other operating parameters presented

in Table 1 are obtained from the previous ones by using NIST-Refprop 9.0 software [23].

In regards to energy analysis, in the exergy analysis is required to define the base ambient state for which the calculations will be performed. In this paper, the base ambient state is defined by the ambient temperature of 25 °C (298.15 K) and ambient pressure of 1 bar (0.1 MPa).

Table 1. Steam operating parameters required for the steam generator energy and exergy analyses – all four operating regimes

Base plant (BASE)							
O. P. *	Temp. (°C)	Pressure (bar)	Mass flow rate (kg/s)	Specific enthalpy (kJ/kg)	Specific entropy (kJ/kg·K)	Quality **	Specific exergy (kJ/kg) ***
1	322.64	157.0	16800	1469.0	3.4498	Sub.	445.02
2	291.00	154.0	16800	1289.7	3.1415	Sub.	357.63
3	223.82	59.2	1660	962.1	2.5465	Sub.	207.46
4	274.27	58.8	1660	2776.2	5.8820	0.9939	1027.00
WOA							
O. P. *	Temp. (°C)	Pressure (bar)	Mass flow rate (kg/s)	Specific enthalpy (kJ/kg)	Specific entropy (kJ/kg·K)	Quality **	Specific exergy (kJ/kg) ***
1	322.64	157.0	16800	1469.0	3.4498	Sub.	445.02
2	291.00	154.0	16800	1289.7	3.1415	Sub.	357.63
3	224.48	59.6	1664	965.2	2.5526	Sub.	208.73
4	274.27	58.8	1664	2775.4	5.8805	0.9934	1026.70
GA							
O. P. *	Temp. (°C)	Pressure (bar)	Mass flow rate (kg/s)	Specific enthalpy (kJ/kg)	Specific entropy (kJ/kg·K)	Quality **	Specific exergy (kJ/kg) ***
1	322.64	157.0	16800	1469.0	3.4498	Sub.	445.02
2	291.00	154.0	16800	1289.7	3.1415	Sub.	357.63
3	224.45	59.7	1664	965.1	2.5523	Sub.	208.68
4	274.27	58.8	1664	2775.3	5.8803	0.9933	1026.60
PSO							
O. P. *	Temp. (°C)	Pressure (bar)	Mass flow rate (kg/s)	Specific enthalpy (kJ/kg)	Specific entropy (kJ/kg·K)	Quality **	Specific exergy (kJ/kg) ***
1	322.64	157.0	16800	1469.0	3.4498	Sub.	445.02
2	291.00	154.0	16800	1289.7	3.1415	Sub.	357.63
3	224.40	60.0	1664	964.8	2.5517	Sub.	208.60
4	274.27	58.8	1664	2775.0	5.8798	0.9931	1026.50

* O. P. = Operating Point (in accordance to Fig. 1 and Fig. 2)

** Sub. = Subcooled; 0 = water; 1 = dry saturated steam

*** At the base ambient state

5. Results and discussion

Energy analysis results for the observed steam generator at all four operating regimes are presented in Fig. 3.

In all operating regimes steam generator energy inlet is the same and equal to 3012.24 MW, due to the same fluid temperature, pressure and mass flow rate in operating points 1 and 2 (Fig. 1 and Fig. 2). However, the steam generator energy outlet varies in all operating regimes due to the change in fluid operating parameters in operating point 3. In addition, each used optimization process and algorithm increases the mass flow rate of fluid which enters in the steam generator from the condensate/feedwater heating system. Such change in fluid operating parameters resulted in a fact that the steam generator energy outlet is higher for all operating regimes where the optimization is performed (in comparison to the base plant process). The highest steam generator energy outlet is equal to 3012.17 MW and is obtained by using GA.

Steam generator energy loss is the highest at the base plant process (equal to 0.90 MW) and is notably reduced in all optimized operating regimes. The lowest steam generator energy loss is obtained by using GA (equal to 0.07 MW), while other optimization algorithms and processes results with the highest steam generator energy loss equal to 0.13 MW. The energy efficiency of the observed steam generator is very high, higher than 99.95% in all

observed operating regimes. Such high energy efficiency and low heat losses in all operating regimes of various heat exchangers (not only of the observed steam generator) are the reason why energy analysis cannot be recommended for the heat exchangers operation observation [24].

Presented energy analysis results lead to conclusion that optimization algorithms and processes increase the steam mass flow rate which will be delivered to the turbine, what increases produced mechanical power and overall plant efficiency. Simultaneously, an increase in the steam mass flow rate results with a notable decrease in steam generator energy losses. GA has the most beneficial impact on the steam generator energy analysis parameters – it results in the lowest steam generator energy loss and the highest energy outlet.

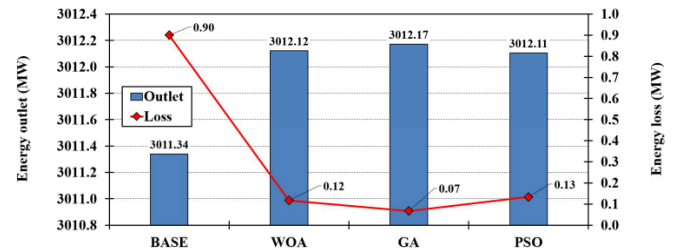


Fig. 3. Steam generator energy outlet and energy loss for all four observed operating regimes

The positive influence of optimization algorithms and processes is also clear when observing steam generator exergy parameters, Fig. 4.

Increase in steam mass flow rate which will be delivered to the turbine (in comparison to the base plant process) reduces steam generator exergy destruction and increases its exergy efficiency. All optimization algorithms and processes decrease steam generator exergy destruction and increases its exergy efficiency in comparison to the base plant process. However, WOA gives fluid operating parameters which will result with the lowest steam generator exergy destruction (equal to 107.05 MW) and the highest exergy efficiency (equal to 92.709%) in comparison to all other operating regimes.

Due to the additional losses considered in exergy analysis of any heat exchanger (not only the observed steam generator), in comparison to energy analysis, exergy analysis can be recommended for any heat exchanger operation observation.

Final conclusion from the steam generator exergy analysis results is that WOA has the most beneficial influence on the steam generator operating parameters. Therefore, for the analyzed steam generator, energy and exergy analyses gives different optimization algorithms and procedures as the most beneficial ones, Fig. 3 and Fig. 4.

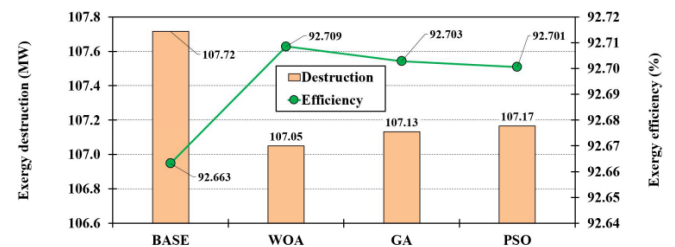


Fig. 4. Steam generator exergy destruction and exergy efficiency at the base ambient state for all four observed operating regimes

At the end of this analysis is performed investigation related to the ambient temperature change influence on the observed steam generator exergy parameters in all four operating regimes. The ambient temperature is varied from 5 °C up to 45 °C, while the ambient pressure remains the same as at the base state (1 bar).

An increase in the ambient temperature results with an increase in steam generator exergy destruction and simultaneously with a decrease of its exergy efficiency in all operating regimes. However, the decrease intensity of steam generator exergy efficiency is not the same in all operating regimes.

Fig. 5 shows that during the increase in ambient temperature from 5 °C up to 45 °C the lowest decrease in steam generator exergy efficiency (equal to 2.0136%) is obtained in the second operating regime which operating parameters are defined by using WOA. It is interesting that operating parameters obtained by the GA are more sensitive to the ambient temperature change (in regards to steam generator exergy efficiency) than operating parameters of the base plant process.

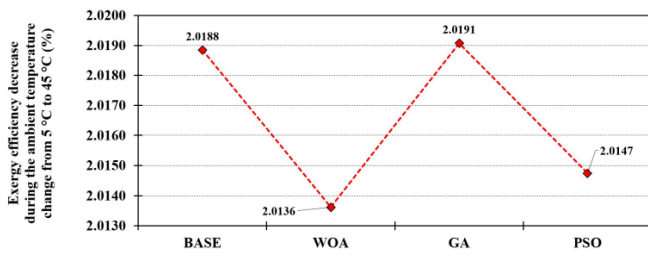


Fig. 5. Steam generator exergy efficiency decrease during the ambient temperature change from 5 °C to 45 °C for all four observed operating regimes

Final conclusion which can be derived from the observed research is that WOA has the most beneficial influence also on the steam generator operation (as well as on the overall plant efficiency and produced mechanical power [22]).

6. Conclusions

This paper presents results of the energy and exergy analyses related to the steam generator from nuclear power plant at four observed operating regimes. The most important conclusions are:

- The highest steam generator energy outlet is equal to 3012.17 MW and is obtained by using GA. The lowest steam generator energy loss is obtained by using GA (equal to 0.07 MW), while other optimization algorithms and processes results with the highest steam generator energy loss equal to 0.13 MW. It is obvious that GA has the most beneficial impact on the steam generator energy parameters.
- Very high energy efficiency and low heat losses in all operating regimes of various heat exchangers (not only of the observed steam generator) are the reason why energy analysis cannot be recommended for the heat exchangers operation observation.
- WOA gives fluid operating parameters which will result with the lowest steam generator exergy destruction (equal to 107.05 MW) and the highest exergy efficiency (equal to 92.709%) in comparison to all other operating regimes. WOA has the most beneficial influence on the steam generator exergy parameters.
- During the increase in ambient temperature from 5 °C up to 45 °C the lowest decrease in steam generator exergy efficiency (equal to 2.0136%) is obtained in the second operating regime which operating parameters are defined by using WOA.
- Final conclusion derived from the observed research is that WOA has the most beneficial influence on the steam generator operation.

7. Acknowledgment

This research has been fully supported by the Croatian Science Foundation under the project IP-2022-10-2821.

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Sustainable Heat Exchanger Design for Natural Gas Savings in Industrial Dryers

Oğulcan Söğüt^{1,*}, Y. Yağız Şimşek², Onur Çimen³, M. Barış Yıldız⁴
KANSAN R&D Center, Izmir, Turkey^{1,2,3,4}
*ogulcansogut@kansanmak.com

Abstract: There are many different models and types of heat exchangers depending on the area of use. The type of fluids involved in heat transfer and their temperature play a critical role in selecting the appropriate model. Common heat exchangers include plate exchangers, tube-type exchangers, air-cooled exchangers, and graphite exchangers. In this study, a sustainable and original heat exchanger system was designed to increase energy efficiency and reduce natural gas consumption by utilizing the waste heat from natural gas. The design prioritizes ease of maintenance and cleaning. Detailed engineering analyses were conducted, and critical engineering errors identified in previous heat exchanger designs were resolved. The developed designs were validated through test studies and experiments, leading to the final design after an optimization process.

As a result of the study, a high-capacity, energy-efficient, and sustainable heat exchanger integrated with modern technology was developed.

Keywords: HEAT EXCHANGER, NATURAL GAS, ENERGY EFFICIENCY, SUSTAINABILITY, INDUSTRIAL DRYERS

1. Introduction

Industrial dryers play a crucial role in various sectors by removing moisture from materials such as food, textiles, and chemicals. However, the energy consumption of these dryers, particularly in terms of natural gas usage, is substantial, contributing to high operational costs and significant environmental impact. As industries strive to reduce their carbon footprint and operating expenses, energy-efficient technologies have become essential. Among these, heat exchangers offer a promising solution by recycling heat within the system, reducing the need for additional energy input.

Heat exchangers play a critical role in energy recovery, making them invaluable in applications aimed at reducing overall energy consumption and optimizing operating costs. These devices work by capturing waste heat from exhaust gases or other sources within the system and transferring it back to the incoming air or process fluid. This process not only recycles energy, but also reduces the amount of additional heating required, thus saving fuel and reducing emissions.

Conventional heat exchangers such as plate and tube models are widely used in industries for this purpose. However, their efficiency can be limited, especially when large amounts of energy recovery are required over long periods of time. In such cases, factors such as heat exchanger contamination, flow resistance, and maintenance requirements can affect their performance, limiting their effectiveness and increasing operating costs. To address these limitations, more sustainable and highly efficient heat exchanger designs are needed that can withstand the demands of continuous operation in industrial environments while maximizing energy recovery potential.

This paper presents a sustainable heat exchanger design specifically aimed at improving the natural gas efficiency of industrial dryers. By focusing on energy recovery, material optimization, and system integration, the proposed design seeks to enhance both the economic and environmental performance of industrial drying processes.

2. Literature Review

The performance of heat exchangers in industrial drying systems plays a crucial role in enhancing energy efficiency, reducing operational costs, and minimizing environmental impact. As drying processes often account for a significant portion of energy consumption in industrial facilities, advancements in heat exchanger design are critical for achieving sustainable and cost-effective operations. This review explores the challenges associated with traditional systems, recent innovations in heat exchanger design, energy conservation strategies, renewable energy integration, and existing research gaps.

Traditional heat exchangers, such as shell-and-tube and plate designs, are widely used in industrial drying applications, but they

face significant limitations. Shell-and-tube heat exchangers, for example, often experience substantial heat losses due to inefficient insulation and suboptimal heat transfer surfaces. Plate heat exchangers, although more compact, are prone to fouling, which reduces their efficiency over time and increases maintenance costs. Both types are characterized by their inability to maximize heat transfer efficiency without incurring significant pressure drops or requiring larger installations. This trade-off between performance and practicality often results in higher energy consumption, increased fuel usage, and elevated operational costs for drying systems.

To overcome the limitations of traditional systems, researchers have developed advanced heat exchanger designs that optimize heat transfer performance while addressing space and operational constraints. Spiral heat exchangers, for instance, utilize a coiled structure that creates higher surface area for heat transfer while maintaining compactness. Their design minimizes pressure drops and is effective at handling viscous fluids, making them ideal for certain industrial processes. Heat pipes, which leverage the phase-change properties of working fluids, offer another promising solution. These systems excel in applications with significant temperature gradients, providing high thermal efficiency. However, their application in drying systems is limited by challenges in scaling up for large industrial operations.

Microchannel heat exchangers have garnered considerable attention for their high thermal performance and compact design. These exchangers feature extremely narrow channels, increasing the heat transfer coefficient while reducing the size and weight of the system. [1] This design offers significant advantages, including reduced energy consumption, lower material costs, and easier integration into space-constrained environments, making them particularly well-suited for industrial drying applications.

Energy conservation techniques, such as waste heat recovery and heat integration, have proven effective in reducing energy demand and improving overall system efficiency [2,3]. Waste heat recovery systems capture excess thermal energy from exhaust streams and repurpose it to preheat incoming air or other working fluids. This approach not only reduces fuel consumption but also enhances sustainability by decreasing greenhouse gas emissions. Research has shown that properly designed waste heat recovery systems can achieve significant reductions in fuel usage. Heat integration, which optimizes internal heat distribution within the drying system, reduces energy losses and enhances thermal efficiency without additional energy inputs. Advanced control systems and process simulations are often employed to maximize the effectiveness of heat integration strategies.

Renewable energy integration has emerged as a complementary solution for industrial drying systems. Solar thermal systems, for example, can capture solar energy and convert it into thermal energy for use in drying processes. These systems are particularly advantageous in regions with abundant solar radiation, as they reduce dependence on fossil fuels. However, challenges such as

intermittent solar energy availability, the need for large-scale storage systems, and high initial investment costs have limited their widespread adoption. Other renewable energy technologies, such as biomass-based heating and geothermal energy systems, are also being explored as alternatives to conventional heating methods. While these systems offer carbon-neutral operation, their implementation is often dependent on regional resource availability and economic feasibility.

Despite these advancements, significant research gaps remain in the design and application of heat exchangers that address both energy efficiency and sustainability. Many existing designs prioritize thermal performance but often overlook other critical factors such as the use of sustainable materials, long-term durability, and environmental impacts over the system's lifecycle. Moreover, the integration of advanced heat exchangers and renewable energy systems into large-scale industrial drying operations presents challenges in system optimization and control. The development of robust simulation tools and real-time monitoring and predictive maintenance systems could improve the performance and reliability of these technologies, ensuring optimal efficiency.

Hybrid systems that combine advanced heat exchanger designs with renewable energy sources and waste heat recovery are a promising avenue for future research. These integrated systems could achieve unprecedented levels of efficiency and sustainability by leveraging the strengths of multiple technologies. Further studies focusing on material innovation, system integration, and advanced control mechanisms are essential to optimize heat exchangers for industrial drying applications. Addressing these challenges will allow the next generation of heat exchangers to play a transformative role in achieving sustainable industrial operations.

3. Heat Exchanger Design Principles

The design of a sustainable heat exchanger for industrial dryers requires a meticulous approach to balance several critical factors, including maximizing heat transfer efficiency, ensuring material durability, and minimizing environmental impact. The goal is to develop systems that enhance energy recovery, lower operational costs, and reduce the carbon footprint associated with the drying process. By integrating various design principles, the heat exchanger can achieve high performance and sustainability.

Maximizing heat transfer efficiency is the central aim of any heat exchanger. Effective heat transfer can be achieved by optimizing fluid flow arrangements and enhancing heat transfer surfaces. Counter-current flow, where hot and cold fluids flow in opposite directions, is one of the most efficient designs as it maintains a large temperature gradient across the entire heat exchanger, ensuring that the heat is transferred efficiently throughout the system. In industrial drying processes, where large volumes of hot air or gas are involved, maintaining this gradient is crucial for ensuring that the system operates with high thermal efficiency.

The design of heat transfer surfaces plays a pivotal role in improving efficiency. Finned tubes, which increase surface area, and turbulators, which disrupt fluid flow to increase turbulence, are commonly employed. These design features enhance the contact between the heat transfer surface and the fluid, promoting more efficient heat exchange. Another emerging design involves the use of advanced microchannel systems that allow for highly compact and efficient heat exchangers [4,5]. By reducing the size of the heat exchanger while maintaining or even improving heat transfer rates, these systems are ideal for industrial dryers where space constraints are common, and high thermal performance is essential.

In industrial dryers, the importance of managing pressure drop cannot be overstated. While enhancing heat transfer is crucial, the increased flow resistance can lead to higher pumping power requirements, which may offset the energy savings achieved through improved heat exchange. Therefore, achieving an optimal

balance between heat transfer and hydraulic performance is necessary to ensure that the system operates efficiently without excessive energy consumption. Innovative designs, such as using low-resistance heat transfer surfaces or optimizing the geometry of flow paths, can help reduce pressure drop while maintaining high heat transfer performance.

Material selection is another critical factor in sustainable heat exchanger design. The materials used must have high thermal conductivity to ensure efficient heat transfer while being resistant to corrosion and wear, as industrial dryers often operate in environments with high humidity, temperature fluctuations, and potentially corrosive substances. Copper and aluminum are commonly used for their excellent thermal properties, but advanced alloys, such as stainless steel and titanium, are often chosen for their durability in harsh conditions. Materials must also be selected with environmental sustainability in mind. Low embodied energy materials, which require less energy to produce, are preferable for reducing the carbon footprint of the heat exchanger. Additionally, recyclable materials should be prioritized to enable the reuse of the heat exchanger at the end of its operational life, contributing to a circular economy.

Long-term durability is a major concern for industrial systems that operate continuously over extended periods. Heat exchangers are often exposed to high thermal stresses, chemical exposure, and mechanical wear. Therefore, selecting materials with high fatigue resistance and the ability to withstand these extreme conditions can help prolong the life of the heat exchanger, reducing maintenance costs and extending its operational lifespan [5]. Furthermore, material selection should align with sustainability goals by focusing on materials that are locally available, reducing transportation emissions, and lowering overall environmental impact.

Heat recovery integration is a cornerstone of designing sustainable heat exchangers. By capturing waste heat from the drying process and reintroducing it into the system, energy consumption can be significantly reduced. Air-to-air and liquid-to-liquid heat exchangers are common systems used for this purpose. For example, an air-to-air heat exchanger recovers heat from exhaust air and transfers it to incoming air, reducing the amount of energy required to heat fresh air. Liquid-to-liquid heat exchangers work similarly by transferring waste heat from hot water or other fluids to preheat the incoming fluids used in the drying process. These heat recovery systems can reduce overall fuel consumption, making the drying process more energy-efficient and cost-effective.

The integration of real-time monitoring and control systems can further enhance the effectiveness of heat recovery systems. By continuously monitoring process variables such as temperature, flow rates, and energy consumption, these systems can adjust operations dynamically to maximize energy recovery. For example, when waste heat is abundant, the system can optimize heat recovery, while during periods of lower waste heat, it can adjust to ensure that energy use is minimized. This adaptive approach ensures that the heat exchanger operates at optimal efficiency, reducing energy consumption and operational costs.

Renewable energy integration is an essential strategy for further reducing reliance on conventional fossil fuels, such as natural gas, and lowering the carbon footprint of industrial drying systems. Solar thermal energy and geothermal heat are two renewable energy sources that can be incorporated into heat exchanger systems. Solar thermal collectors harness the sun's energy to heat fluids used in the drying process, while geothermal heat pumps exploit the earth's natural temperature for heating or cooling. These renewable sources can reduce or eliminate the need for fossil fuels, making the drying process more sustainable.

However, the integration of renewable energy systems presents challenges, including intermittency in the case of solar energy and the initial capital costs associated with implementing geothermal systems. To address these challenges, hybrid systems that combine renewable energy with conventional heating methods can be

employed. For instance, solar thermal systems can be used to preheat incoming air or water, while natural gas or electricity can be used as a backup during periods of low sunlight or high demand. This approach can optimize energy use and reduce reliance on non-renewable energy sources.

In conclusion, designing a sustainable heat exchanger for industrial dryers involves several integrated principles that focus on improving heat transfer efficiency, selecting durable and environmentally responsible materials, incorporating waste heat recovery, and integrating renewable energy sources. By developing systems that balance these elements, industrial drying processes can operate more efficiently, reduce energy consumption, and minimize their environmental impact. As industrial sectors continue to prioritize sustainability, innovative heat exchanger technologies will play an essential role in achieving energy efficiency, lowering operational costs, and reducing the carbon footprint of industrial processes. [6,7]

4. Design Proposal

The proposed heat exchanger design for industrial dryers incorporates several innovative features to improve natural gas efficiency:

Enhanced Heat Transfer Surfaces: The design employs multi-layered, finned surfaces within the heat exchanger tubes to increase heat transfer rates and minimize heat loss. [8,9]

Heat Recovery System: A dual-loop heat recovery system captures exhaust air from the dryer and uses it to preheat incoming air, thereby reducing the energy required to reach the desired drying temperature.

Advanced Materials: The heat exchanger is made from corrosion-resistant alloys that reduce maintenance costs and extend the life cycle of the system. Table 1 lists mechanical properties of selected heat exchanger materials.

Table 1: Mechanical properties of materials

	Stainless steel AISI 316	Stainless steel AISI 304
Yield strength R _m [MPa]	270	205
Tensile strength	690	515
Modulus of elasticity [GPa]	190	193
Max. working temp. [°C]	500	500

Optimized Flow Arrangement: A counter-current flow arrangement is used to ensure maximum temperature gradient and efficient heat transfer.

Initial simulations suggest that this design could reduce the natural gas consumption of industrial dryers by up to 30%, depending on the specific application and operating conditions.

The design process (Fig.2) consisted of several stages: initial concept development, detailed engineering analysis, optimization and validation through physical testing. Each phase is meticulously structured to address overall goals such as sustainability and efficiency; ensuring that the final product not only reduces energy consumption but also complies with modern environmental standards.

In the first phase, the primary focus was to identify the difficulties and inefficiencies present in existing heat exchanger systems. General problems such as high flow resistance, material degradation due to corrosion, and contamination caused by

particulates in exhaust gases were analyzed to determine design priorities. The goal was to create a heat exchanger that could overcome these challenges while maintaining ease of maintenance and a long working life [10].

After the basic concept was defined, detailed engineering calculations were performed to determine the specific dimensions, material requirements and performance parameters of the heat exchanger [11]. At this stage, it was largely based on thermodynamic principles to calculate heat transfer rates, surface area requirements and the overall efficiency of the system. For example, the following basic heat transfer equation was used in the design:

$$Q = U \cdot A \cdot \Delta T_{lm}$$

Q: Heat transfer rate (W)

U: Overall heat transfer coefficient (W/m²·K)

A: Heat transfer surface area (m²)

ΔT_{lm} : Log mean temperature difference (K)

The new design developed by taking these basic approaches into account is shown in Figure 1. Detailed views of the heat exchanger are given in Figures 2a and 2b.

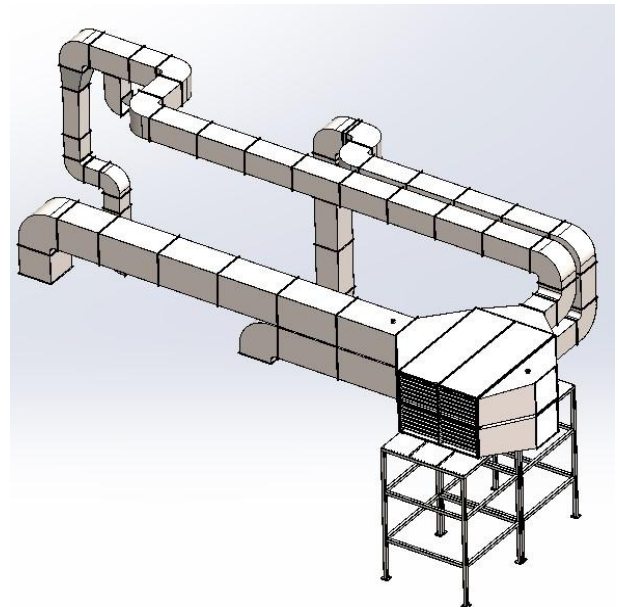


Fig. 1. 3D model of Heat Exchanger

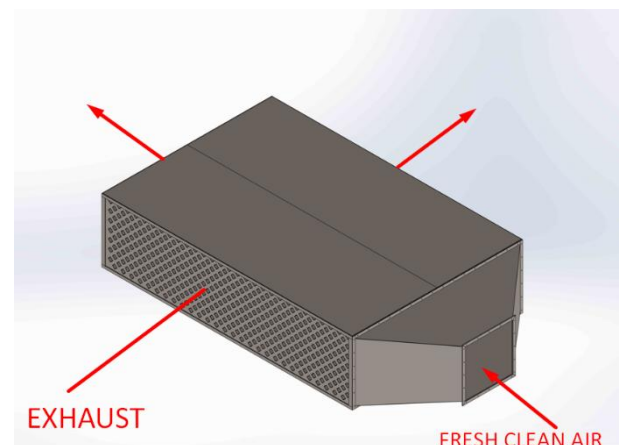


Fig. 2a. General design of the developed heat exchanger

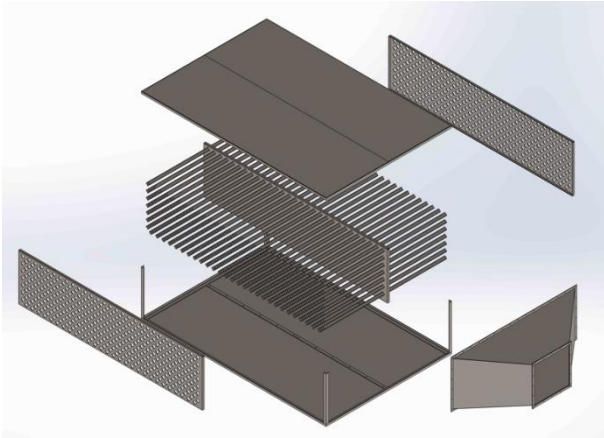


Fig. 2b. Inside design of the heat exchanger

5. Implementation and Case Study

To evaluate the effectiveness of the proposed heat exchanger design, a case study was conducted in a wetlaid textile processing facility. The existing drying system was retrofitted with the new heat exchanger design, and performance data was collected over a six-month period. The test results showed that the new design (Fig. 1) provides a significant reduction in natural gas consumption without compromising drying performance. The modular structure of the system allows for easy integration into existing industrial installations, and the sustainable design approach ensures that both operating costs and environmental impact are minimized.

The results showed a 25% reduction in natural gas consumption, with a significant decrease in operational costs and environmental emissions. The system's payback period was calculated to be 12 months, demonstrating both economic and environmental benefits. These findings highlight the potential for wide-scale adoption of this heat exchanger design across various industrial sectors seeking to improve their energy efficiency and sustainability.

6. Results and Discussion

The proposed sustainable heat exchanger design offers substantial energy savings and a clear pathway toward reducing natural gas usage in industrial dryers. Key findings include:

- * A 25% reduction in natural gas consumption.
- * Significant cost savings, particularly for large-scale industrial operations.
- * A positive environmental impact due to reduced carbon emissions and energy consumption.

The integration of waste heat recovery and sustainable materials further enhances the system's overall efficiency and sustainability.[12]

Moreover, to protect the innovative aspects of the design and ensure its commercial viability, a patent application has been filed and is currently pending. This underscores the novelty and potential of the technology, which could offer a significant advancement in energy-saving solutions for industrial drying systems [13,14]

7. Conclusion

This paper presents a sustainable heat exchanger design aimed at reducing natural gas usage in industrial dryers. By incorporating enhanced heat transfer surfaces, heat recovery systems, and advanced materials, the design offers both economic and environmental advantages. The case study demonstrates its feasibility and potential impact, providing a model for industries seeking to improve energy efficiency and sustainability in drying operations. Further research and development are recommended to

optimize this design for broader applications and explore the integration of renewable energy sources.

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Numerical results of CFD simulations for full-scale ship-shape body motion in deep and shallow water

Pavel Ivanov

Nikola Vapsarov Naval Academy, Varna, 9026 Bulgaria

p.ivanov@nvna.eu

Abstract: The objective of the simulations is to calculate the total resistance and visualize the flow around a bare hull of a boat motion in deep and shallow water. Ship resistance is an important issue for ensuring smooth propulsion in various speeds in open sea and especially in the increasing influence of shallowness. Subcritical speed range in open shallow water is the main interest regime. A limited number of cases in critical and supercritical speed regions are applied in computations for comparison. For the full-scale bare ship-shape body resistance tests, computational fluid dynamics techniques and SST k - ω turbulence viscous model were employed. All calculations were carried out considering the influence of the free surface effect in a fluid. For convenience of mesh generation, an automated structured polyhedral meshing was adopted for the delicate curved surface and the domain. CFD solver interFoam – OpenFOAM, is applied to execute all computations in this article. The numerical model was initially built in FreeCAD, an open computer aided design (CAD) software and discretized in the cfMesh, a library implemented on top of the OpenFOAM framework. Post-processing is performed within ParaView, an application for scientific visualization. All software is free.

Keywords: SIMULATION, FREE SOFTWARE, CFD, FREECAD, OPENFOAM, PARAVIEW

1. Introduction

Maneuverability is a key component in performance. There are standards for ship maneuverability that are promulgated by the International Maritime Organization (IMO), but these standards cannot ensure absolute navigation safety. For this purpose, ITTC Maneuvering Technical Committee take responsibility for the prediction of the hydrodynamic performance of ships and marine installations based on the results of physical and numerical experiments. The test process is complex and the distribution information of the flow field around the ship obtained from the test is limited. Compared with traditional methods, computational fluid dynamics (CFD) method can provide more detailed information for naval architecture and ocean engineering, Yang et al [1].

CFD simulations not only minimize physical testing which is expensive but also reduce time spent for field tests. More importantly it is achievable to test the models in environments and situations that are hard to experiment within real life. Simulations can recreate critical moments or incidents cases virtually and this may increase understanding and decrease the chance of such.

Obtaining data from CFD models for shallow waters, gathering information and visualizations about hull behavior can be helpful for seamen.

The behavior of the ship in real sailing conditions is important for safety, where the total resistance gives us the proper speed to optimize the voyage. Therefore, use of numerical methods to predict the hydrodynamic phenomena during maneuverability in shallow waters can help navigators to optimize their decisions, consent within review'24 [2].

It is noticeable that there is a relatively small amount of research papers that considered the free surface effect of flow around the vessel, which is closely related to resistance and maneuverability. In the present study, the flow field around ship-shaped body is simulated.

2. General Setup

A hydrodynamic coefficient must be determined to predict the maneuvering motion of the ship. The methods used for this purpose are the captive model test, system identification techniques applied to the results of free-running model tests, and computational fluid dynamics (CFD).

CFD simulations became popular with the advancement of computer technology. The results obtained with the CFD method are very reliable and provide a detailed picture of surface elevations as well as velocity and pressure fields. This lead to a better understanding of the hydrodynamic phenomena of a ship maneuvering in shallow waters. CFD calculations are an alternative to physical methods because they provide reliable data at a much lower cost [3].

In the basis of all models is momentum, mass, and energy balance which are PDEs (Partial Differential Equations). They require Boundary and Initial conditions to be defined in the solver before calculations.

The final system of differential, integral and algebraic equations is complex to be solved analytically and for this reason, numerical solutions are applied based on appropriate algorithms, where the initial mathematical model is reduced to a system of linear algebraic equations giving an approximate solution.

Finite Volume Method (FVM) is the common approach that is applied for discretization of the space under study. OpenFOAM implements a cell-centered FVM.

2.1 Case formulation

The precise formulation is a fluid mechanics of a ship-shape body with surge motion in deep and shallow waters, representing a straight flow around a static body (captive model).

The test model simulates forward motion with a speed $U = 2, 3.2, 4$ and 5.2 m/s with drift angles of $0^\circ, 3^\circ, 6^\circ, 9^\circ$ and 12° in calm water.

The Froude number, for hull resistance indication (F_n) and for shallow waters (F_{nh}):

$$F_n = \frac{U}{\sqrt{gL}}$$

where U is the ship velocity, L is the ship length, g is acceleration due to gravity. A general rule is that $F_n < 0.4$ indicate a pre-planing hull, also known as displacement hull, and $F_n > 1.0$ indicate a fully planing hull.

$$F_{nh} = \frac{U}{\sqrt{gh}}$$

where h is depth of water basin. Setting relative depths for h/d to 4.0 (deep water), 1.8 (moderate shallow water), 1.5 (shallow water) and 1.2 (marginal shallow water) are specified by Vantorre et al [4].

For $F_{nh} < 1$ the flow is called a subcritical flow, further for $F_{nh} > 1$ the flow is characterized as supercritical flow. When $F_{nh} \approx 1$ the flow is denoted as critical flow.

The numerical study considers F_n of 0.10, 0.16, 0.20, 0.26 for speed in deep water and F_{nh} from 0.17 to 0.84 for shallow water.

2.2 Mathematical models

The mathematical model of ship maneuvering motions is a key component in marine simulators. The numerical results presented in this paper are used to improve understanding of hydrodynamic phenomena acting upon hull in shallow waters with seawater free surface effect.

Therefore:

- RANS method is used to predict the hydrodynamic forces and moments to obtain a more accurate fluid flow equation since it capable to capture turbulent effects [5].
- Turbulence model 'SST k-Omega' is used in OpenFOAM [6]. The Menter [7] Shear Stress Transport model (SST) k- ω turbulence model which the transport equations are solved for two variables: turbulent kinetic energy k and specific dissipation rate ω .

The maneuvering derivatives of CFD data from such settings help to improve the accuracy of mathematical models for ships maneuvering motions and enable maneuvering motions to be predicted, confirmed by Yang et al [1].

❖ General assumptions:

Mathematical models describing ship manoeuvrability and seakeeping are based on six equations of motion according to the six degrees of freedom (6DOF) of a ship and an equation of equilibrium for ship propulsion.

A model motivated by Newton's second law: $F = \Delta a$, where F represents force, Δ the mass of the vessel and a - the acceleration of ship dynamics, can be described by means of strongly nonlinear dimensional equations from figure 1.

$$\Delta(\dot{u} + qw - rv) = X$$

$$\Delta(\dot{v} + ru - pw) = Y$$

$$I_z \dot{r} + (I_y - I_x)pq = N$$

where Δ - mass of the ship, u, v, w - linear velocity and angular velocity p, q, r . Moments of inertia I_x, I_y, I_z around X-Y-Z axis which are ship-fixed reference frame and $X_0-Y_0-Z_0$ are the Earth-fixed reference frame. Note here that X and Y are total forces acting along appropriate axes and N is total moments acting to the hull.

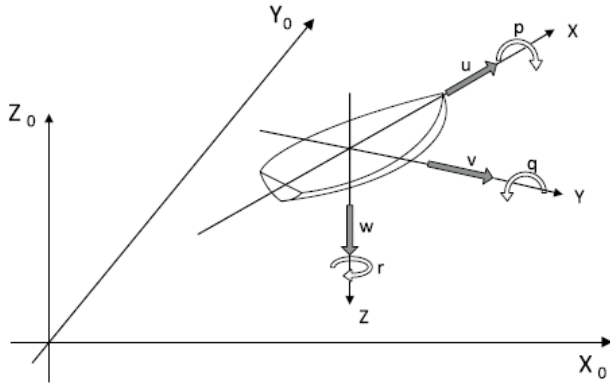


Fig.1 6DOF for a ship-shape body with centre of rotation at the ship gravity center exactly in the mid-section.

For many control applications like the heading, speed and/or trajectory stabilization it is a common practice to neglect pitch, roll and heave motion with assuming that $p = q = w = 0$. That lead to change of the 6 DOF model to the 3 DOF model:

$$\Delta(\dot{u} - rv) = X$$

$$\Delta(\dot{v} + ru) = Y$$

$$I_z \dot{r} = N$$

❖ Formal models:

The equations of motion in the horizontal plane, introduced by Abkowitz in the 1960s [8], are based on a third order Taylor-series development of the hydrodynamic forces. Unfortunately, a 3rd order Taylor-series expansion results in a large number of terms. By applying some physical insight, the complexity of these expressions can be reduced. Abkowitz (1964) makes the following assumptions:

1. Most ship maneuvers can be described by a 3rd-order truncated Taylor expansion about the steady state condition $u = u_0$
2. Only 1st-order acceleration terms are considered.
3. Standard port/starboard symmetry simplifications except terms describing the constant force and moment arising from single-screw propellers.
4. The coupling between the acceleration and velocity terms is negligible.

Simulations of standard ship maneuvers show that these assumptions are quite good, Fossen (2011) [9]. The force of hydrodynamic phenomena related to the hull movement through the water can be expressed as follow:

$$X = X_0 + X_{vv}v^2 + X_{vr}vr + X_{rr}r^2$$

$$Y = Y_vv + Y_r r + Y_{vvv}v^3 + Y_{vv}vr^2 + Y_{vrr}vr^2 + Y_{rrr}r^3$$

$$N = N_vv + N_r r + N_{vvv}v^3 + N_{vv}vr^2 + N_{vrr}vr^2 + N_{rrr}r^3$$

here X_0 is direct navigation resistance and we can *note also that equation N is as same as Y .

During direct navigation, the ship-shape body moves at constant speed along the X direction, and the hull resistance coefficient X_0 is measured.

When the ship moves obliquely at a certain drift angle β , the velocity components u and v in the body-fixed coordinate system can be expressed as:

$$u = U \cos \beta$$

$$v = -U \sin \beta$$

where hull has longitudinal velocity u and transverse velocity v , and the other disturbances ($\dot{v} = \dot{r} = r = 0$) are zero, than Taylor expansion can be simplified (regressed) as follows:

$$X = X_0 + X_{vv}v^2$$

$$Y = Y_vv + Y_{vvv}v^3$$

Here X_{vv} , Y_v , Y_{vvv} , N_v and N_{vvv} are transverse velocity dependent damping coefficients (*equation for Y is same as N). The coefficients Y_v and N_v are the linear coefficients and the rest are nonlinear ones. Simulation at various drift angle β provides the forces X , Y and N moment (Fig.2).

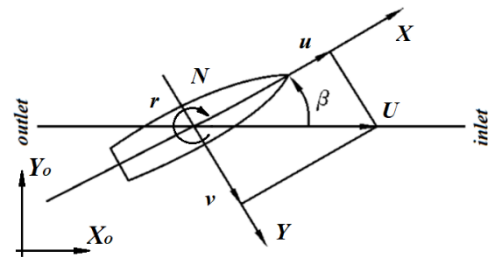


Fig.2 3DOF Diagram of oblique towing test.

Considering the port- and starboard symmetry, the mathematical model relating Y , N , and v can be expressed as:

$$Y = Y_0 + Y_vv + \frac{1}{6}Y_{vvv}v^3$$

$$N = N_0 + N_vv + \frac{1}{2}N_{vvv}v^3$$

where Y_v , Y_{vvv} , N_v , N_{vvv} are the maneuvering hydrodynamic derivatives, and Y_0 , N_0 are the lateral force and moment at the initial steady state of forward motion.

The variables are transferred to non-dimensional values based on the ship length L , ship speed U , and water density ρ . They are distinguished by putting the sign of ' (prime) as follows:

$$Y' = Y'_0 + Y'_v v' + \frac{1}{6} Y'_{vvv} v'^3$$

$$N' = N'_0 + N'_v v' + \frac{1}{2} N'_{vvv} v'^3$$

The dimensionless forms for wetted surface:

$$v' = \frac{v}{U} \quad F' = \frac{F}{0.5\rho L d U^2} \quad M' = \frac{M}{0.5\rho L^2 d U^2}$$

❖ Modular mathematical models:

In the 1980s the ‘concept of modularity based on a separate representation of elements of the manoeuvring model’ has been fully recognized among the world, MARSIM '93 [10]. The principal structural form of a modular manoeuvring model neglecting the external forces is based on Newton's equations:

$$\begin{aligned} \Delta(\dot{u} - vr - x_G \dot{r}^2) &= X \\ \Delta(\dot{v} + ur + x_G \dot{r}) &= Y \\ I_{zz} \dot{r} + \Delta x_G(\dot{v} + ur) &= N \end{aligned}$$

There are a lot of expressions of this mathematical model comment a research group called Maneuvering Modeling Group (MMG) in Japan [11]. Nowadays, a lot of simulation methods based on MMG model exist and many simulation methods sometimes harm the adaptability of hydrodynamic force data for the maneuvering simulations since one method may be not applicable to other methods in general.

To avoid this, the basic part of the method should be common. The test procedure and the data analysis to determine the hydrodynamic force coefficients for the simulations should be also common since those often involve the quantitative value of the hydrodynamic coefficients (*next equation Δ sign will substitute mass symbol m used in MMG model for synchronous purposes and other reasons):

$$\begin{aligned} (\Delta + \Delta_x)\dot{u} - (\Delta + \Delta_y)v_m r - x_G \Delta r^2 &= X \\ (\Delta + \Delta_y)\dot{v}_m + (\Delta + \Delta_x)ur + x_G \Delta \dot{r} &= Y \\ (I_{zG} + x_G^2 \Delta + J_z)\dot{r} + x_G \Delta(\dot{v}_m + ur) &= N_m \end{aligned}$$

where Δ_x, Δ_y is added mass, v_m is lateral velocity at midship. x_G longitudinal coordinate of center of gravity of ship, I_{zG} is moment of inertia of ship around center of gravity and J_z added moment of inertia.

❖ Mathematical model describing manoeuvring motion:

The research work published by authors during the last and this century is of great value for the prediction of ship manoeuvrability. However, none of the existing methods is sufficiently broad and accurate at present to be raised up to a general, standardized manoeuvring model, Kose (1995) [12].

The preference is given to a modular manoeuvring model. In contrast with the formal or regression models, ship/fluid interaction is no longer treated as a black box and the hydrodynamic forces are linked to the three modules of a manoeuvring ship: hull, propeller and rudder, Eloit (2006) [13].

3. CFD Simulation

The physical model of environment domain was created in FreeCAD version 0.21.1. Analyses were performed using the software product OpenFOAM version 2212. Post-processing and images are extracted from ParaView version 5.12.0.

3.1 OpenFOAM Solver

The multiphase solver *interFoam* is designed for transient simulations for two incompressible, isothermal, and immiscible fluids. It can handle laminar and turbulent, accommodating both Newtonian and non-Newtonian fluids. It utilizes the Volume of Fluid (VOF) approach for capturing the interface between the fluids

accurately.

The solver uses the PIMPLE (merged PISO and SIMPLE) algorithm for pressure-momentum coupling. This algorithm leverages the strengths of both PISO and SIMPLE methods for pressure-velocity coupling, ensuring robustness in handling transient flows with large time steps. This approach is supplemented by under-relaxation techniques to secure convergence stability.

interFoam uses the multidimensional universal limiter for explicit solution (MULES) method to maintain boundedness of the phase fraction independent of underlying numerical scheme, mesh structure [14]. So, the choice of schemes for convection are not restricted to those that are strongly stable or bound.

The ability to capture complex fluid interactions together with dynamic mesh capabilities makes it very versatile and useful in the marine industry, where complex ship-waves interactions can be studied. For the transportation industry, mixing stirring tanks can be analyzed and tank sloshing phenomena. Wave loading or offshore structure loads can be predicted.

As a validation of *interFoam* solver, it is proposed to recreate a Sloshing Problem. As an example, a 2D and 3D Dam Break problem are applied.

3.2 Sloshing Problem: Dam break problem

The 2D dam break case is represented by OpenFOAM tutorials in software package after installation the product or from official website [15]. A coarse mesh with the same domain dimensions was created for comparison, figure 3a.

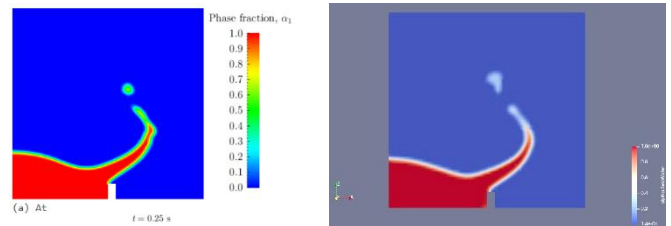


Fig.3a 2D breaking of a dam compared with experiment (time=0.25 sec)

where the sample is taken from *OpenFOAM Tutorial number 4.1*.

The 3D dambreaking problem developed by Kleefsman et al [16]. A coarse mesh with the same domain dimensions was created for comparison, figure 3b.

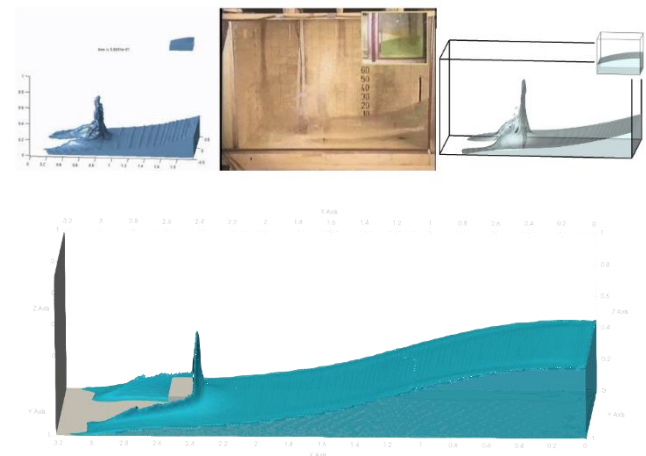


Fig.3b 3D coarse mesh snapshots of a dambreak simulation with a box in the flow compared with experiment (t=0.56 sec)

It is visible and we can say for the used approach of CFD method is correct and reproduces the test case very well, which is a guarantee for the authenticity (verification) of further research on the ship-shape body.

4. Ship-shape body and Simulation design

4.1 Physical shape of the studied body

The physical model used in the simulation is in figure 4.

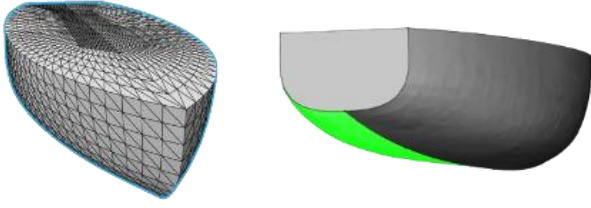


Fig. 4 Body shape evolution

All simulations are performed with the bare boat design model with following dimensions (Tab. 1)

Table 1. Boat model particulars, Full-scale

Design		
Length of waterline	L_{WL}	41.21 m
Breadth	B	15.74 m
Draft	d	3.27 m
Wetted Surface Area	S_0	577.19 m ²

The scale is one to one, full scale because of viscous forces (ITTC, 1978) [17].

4.2 Domain numerical set-up

A 3D rectangular computation domain representing a numerical towing tank is used in the simulations. Due to the vertical plane symmetry of the ship hull and domain, the task is symmetrical so to facilitate memory and computation time, the simulation can be done for half of the experiment. The half domain will have length of 255 m, close to 2L in front and 3L behind the hull, 156 m wide and 26 m above water line. Depending on the case, there is a free surface at distance of 3.924 m from domain bottom for marginal shallow water (Fig. 5a).

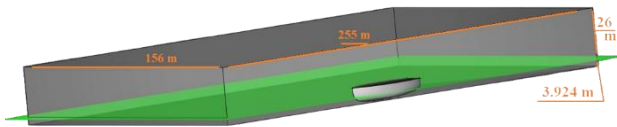


Fig.5a View of half-model

Both domains' dimensions are selected sufficiently large to avoid back flow at high drift angles. For full model distance of the inlet and outlet boundary from ship center is considered to be more than 2L and 4L, respectively. The side boundaries are located at around 3.5L and the top is at 1L from the free surface (Fig. 5b) while bottom distance depends on cases.

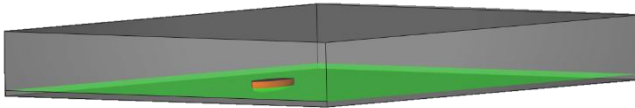


Fig.5b The domain

Full model dimensions are tailored considering ITTC recommendations (75-03-04-01: Guideline on Use of RANS Tools for Manoeuvring Prediction, 2017).

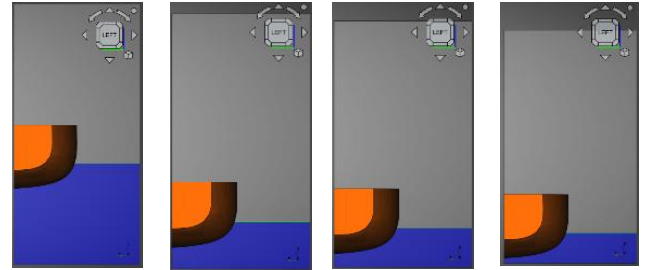
The model is prepared for calm water surface, no wind effects. It is achievable by dividing the inlet wall of physical domain to two zones, one for water inlet and the other zone for air inlet, which condition is added to top boundary. BCs are on table 2.

Table 2. OpenFOAM built-in boundary conditions

Boundary	alpha.SeaWater	p_rgh	U
inlet	fixedValue	fixedFlux Pressure	fixedValue
outlet	variableHeight FlowRate	zero Gradient	outletPhase MeanVelocity
top	inletOutlet	total Pressure	pressureInlet OutletVelocity
side	symmetry	symmetry	symmetry
bottom	zeroGradient	fixedFlux Pressure	movingWall Velocity
hull	zeroGradient	fixedFlux Pressure	fixedValue

The hull is a *no-slip wall* allowing for boundary layer around the ship-shape body to be developed. So y^+ wall treatment with 10 layers is used for the hull with expansion ratio 1.2 (ITTC 2017, Recommended Procedures and Guidelines). Bottom and side boundaries are modelled as *symmetry* for deep water case, while top is *open* boundary. As for shallow water only, the bottom is changed to a *no-slip wall*.

Different model cases of depth can be seen in figure 6.



$h_1=13.080\text{m}$ $h_2=5.886\text{m}$ $h_3=4.905\text{m}$ $h_4=3.924\text{m}$
Fig. 6 Four depths: from deep to optimal shallow water models

4.3 Mesh generation

Mesh is of highest importance in CFD simulations and the process of creating optimal mesh for any case is a hard and time-consuming process. Having this in mind, the quality metrics must be checked with an OK mesh Check Test for topological errors or orthogonality, skewness, aspect ratio and smoothness for obtaining accurate results.

Table 3. Grid Quality Check for $h = 1.2d$, drift 12°

Mesh: OK	Values:
Cells	6 164 509
Max Aspect Ratio	41.897
Max non-orthogonality [deg]	81.304
* faces > 70 [deg]	5 859
Avg non-orthogonality [deg]	8.058
Max Cell Skewness	3.798

Should be aware that numerical results can be considered precise and valid if its solution is independent of the grid. Nevertheless, validation and verification are mandatory.

5. Numerical results

- Resistance test

Drag coefficient, C_T can be calculated by the formula:

$$C_T = \frac{F_x}{0.5\rho S_0 U^2}$$

at different water depths, which gradually increases as the ship manoeuvring in shallower basin due to the effect of the sea bottom.

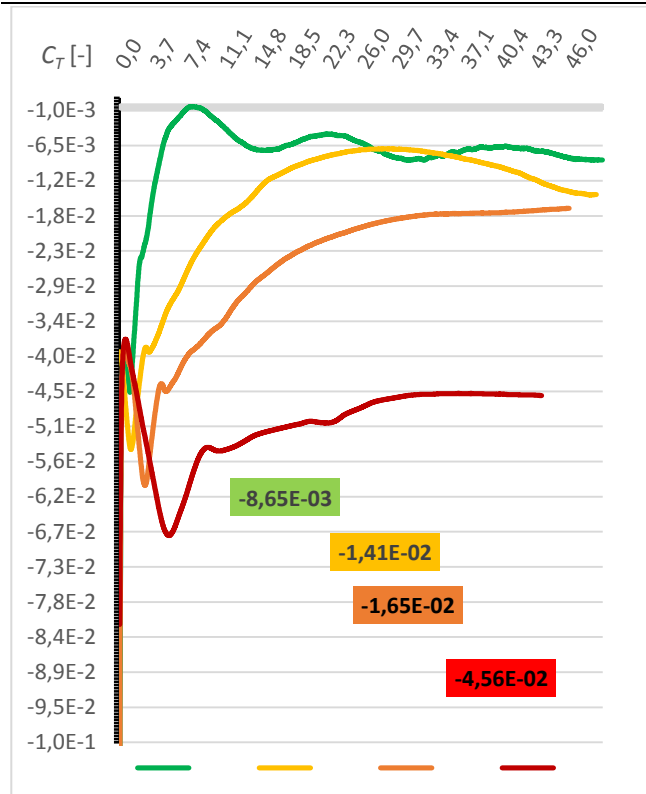


Fig.7 Force coefficient C_T against time, within four depths at same ship speed $U=5.2$ m/s.

Only for deep water with different speeds is drawn at figure 8:

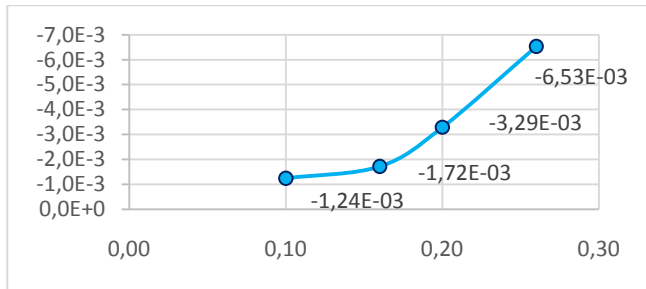


Fig.8 Results of resistance at various ship speeds in deep water. here horizontally is Frude numbers (Fn) and vertically are the values of ship resistance coefficient in straight motion (C_T), which in FreeCAD coefficients.dat reporting function file correspond to C_d .

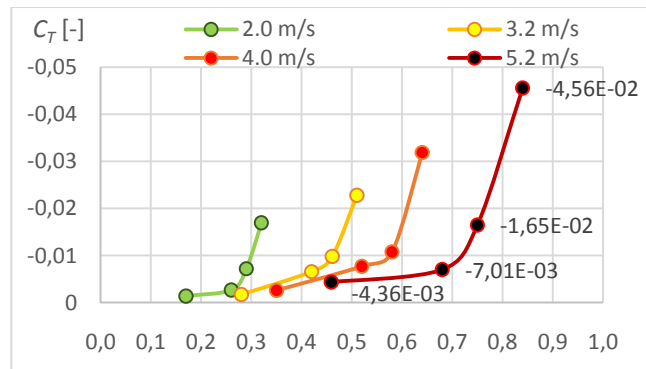


Fig.9a Results of resistance F_{n_h} in shallow water for dif. speed.

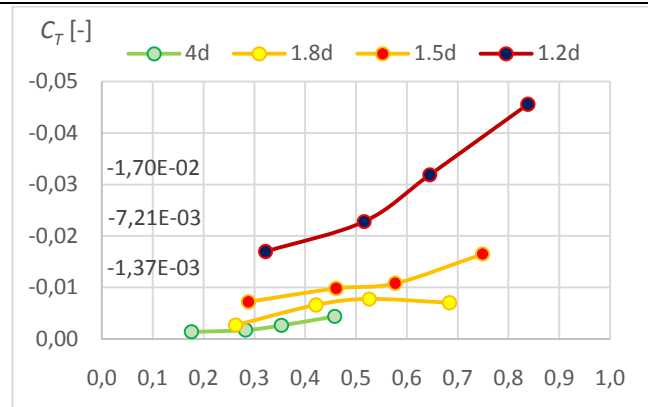


Fig.9b Results of resistance F_{n_h} at dif. speed for shallow waters.

Figure 10, gives us information about the values of force and moment for the whole period simulation time:

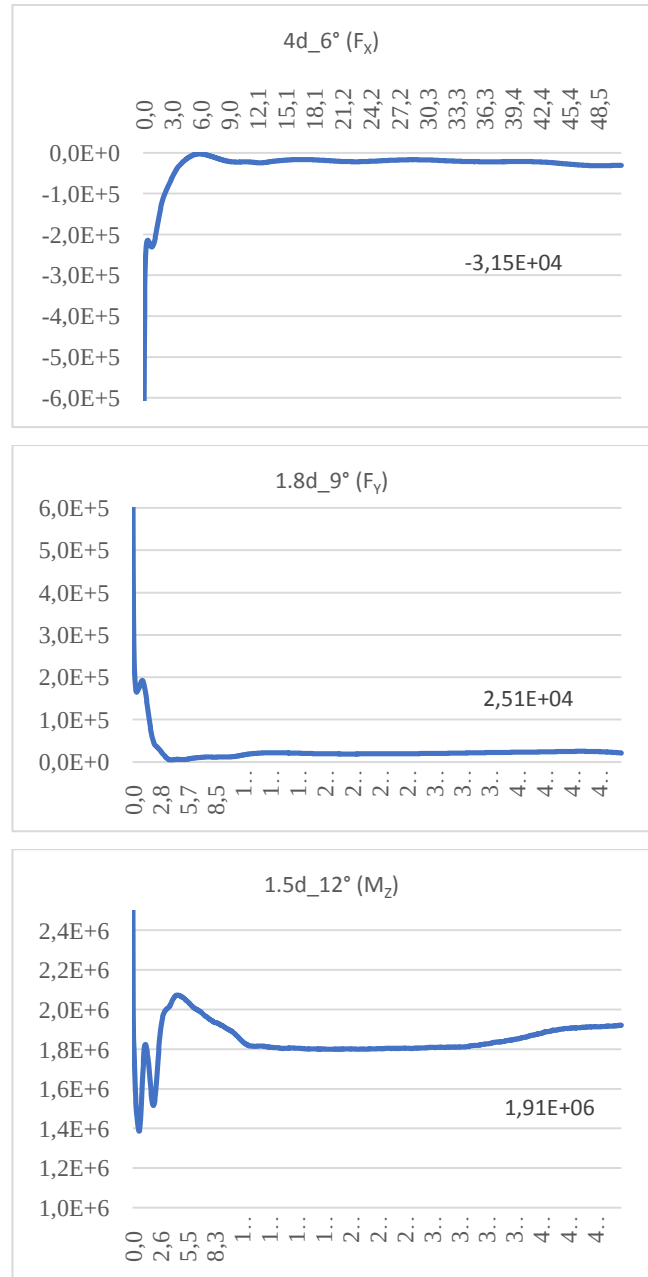


Fig.10 Report of functions (t=51 sec.)

- Static drift test

In the static drift test, the ship moves in oblique flow due to a given drift angle β . The hydrodynamic forces are a function of sway velocity, $v = -U \sin \beta$. Figure 11 illustrates the results of the static drift test at various water depths.

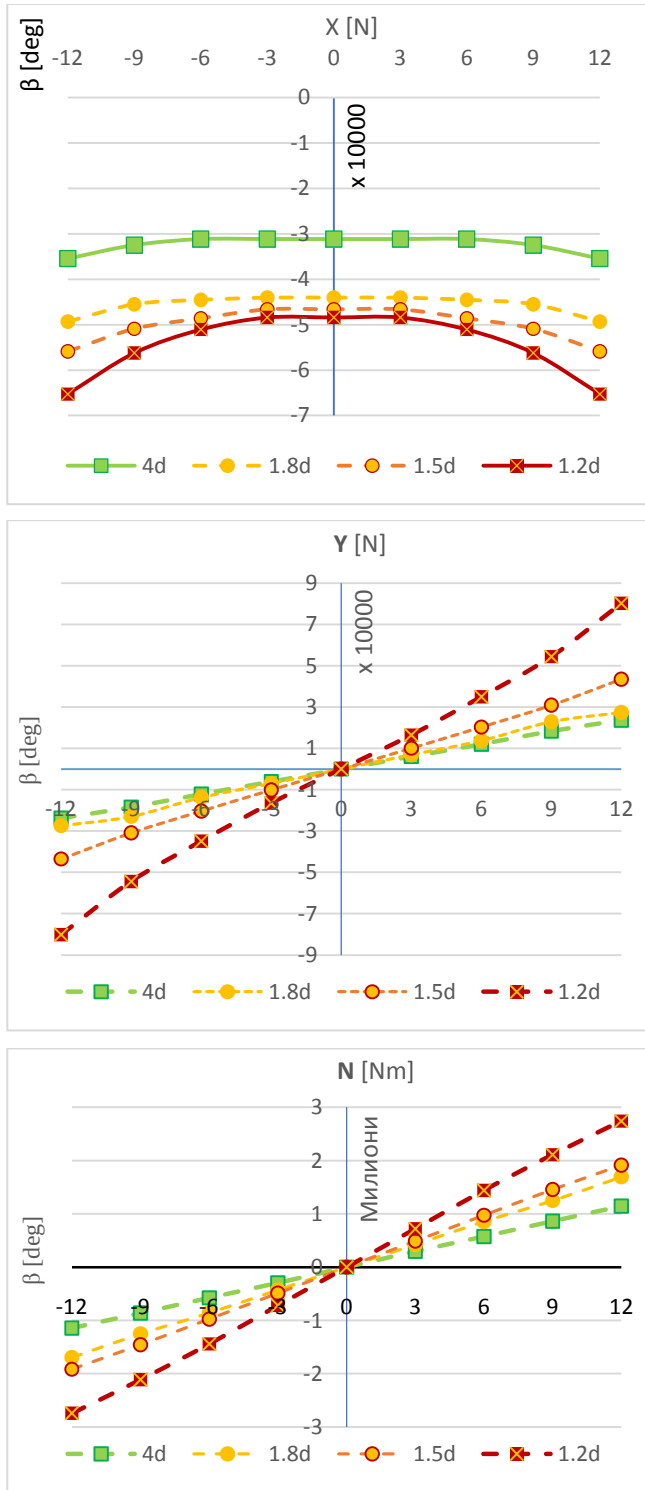


Fig.11 Results of static drift at various water depths: Surge force, Sway force, and Yaw moment. Hydrodynamic forces acting on hull.

The hydrodynamic forces are higher when the water shallowness increases. Diagram slope has a significant change at $h=1.2d$, as the hydrodynamic force are equal to double (2 times) of $h=1.5d$. The increase in hydrodynamic forces and moments in shallow water was caused by the increased in flow velocity and decrease in pressure through the limited space between ship bottom and seabed. This proves that shallow water affects considerably hydrodynamic forces generated by sway velocity.

5.1 Numerical post-processing (data visualization)

Free surface related patterns performance for different depths are shown on these figures, except figure 13 and 16.

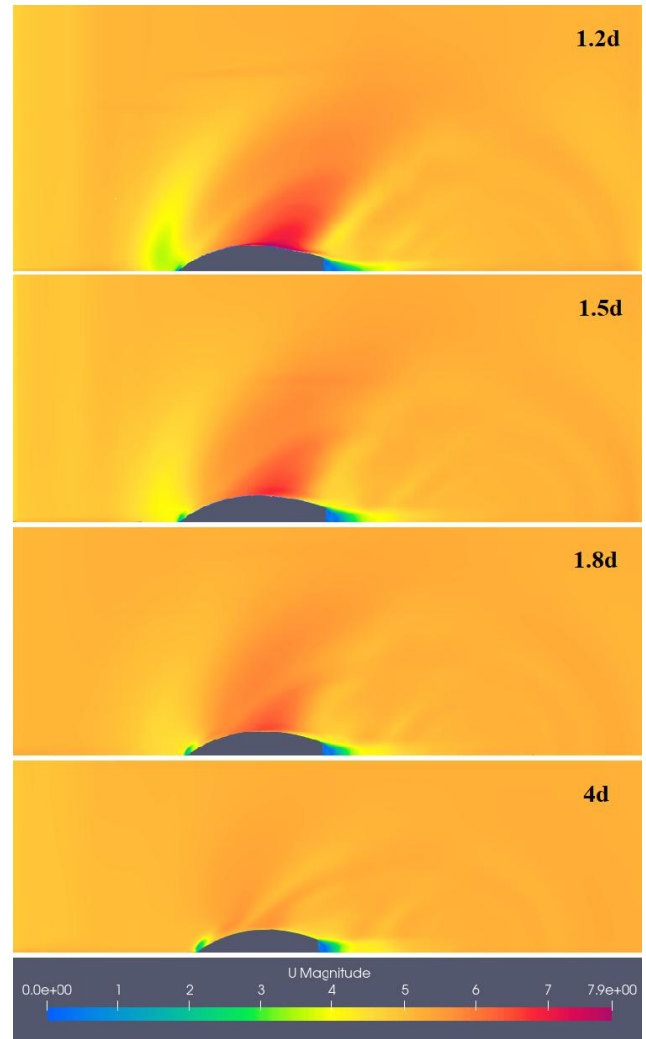
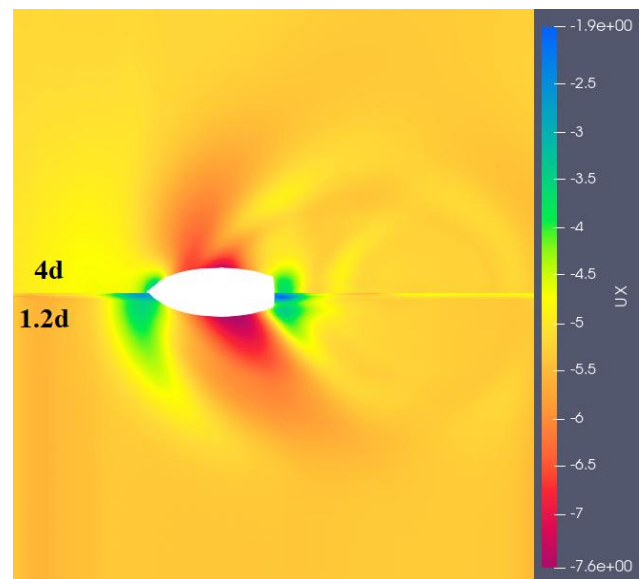


Fig.12 Velocity field on interface-free surface

Images of keel plane with top view are presented in figure 13.



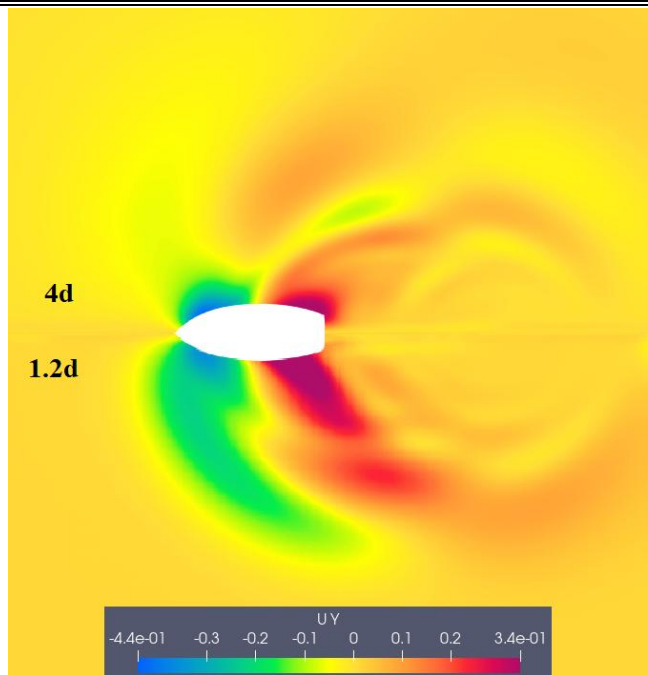


Fig.13 Keel plane, velocity field at X and Y direction.

here ‘keel plane’ means, that in ParaView a flat plane to Z axis is placed at the lowest construction point of ship hull.

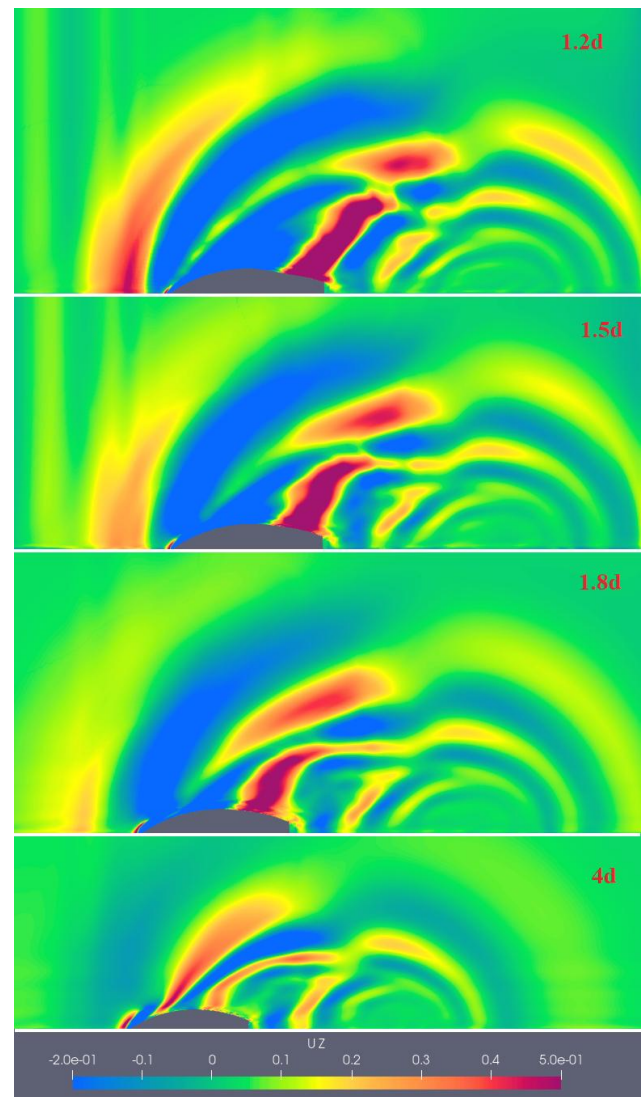


Fig.14 Wave pattern, free surface U field at Z axis.

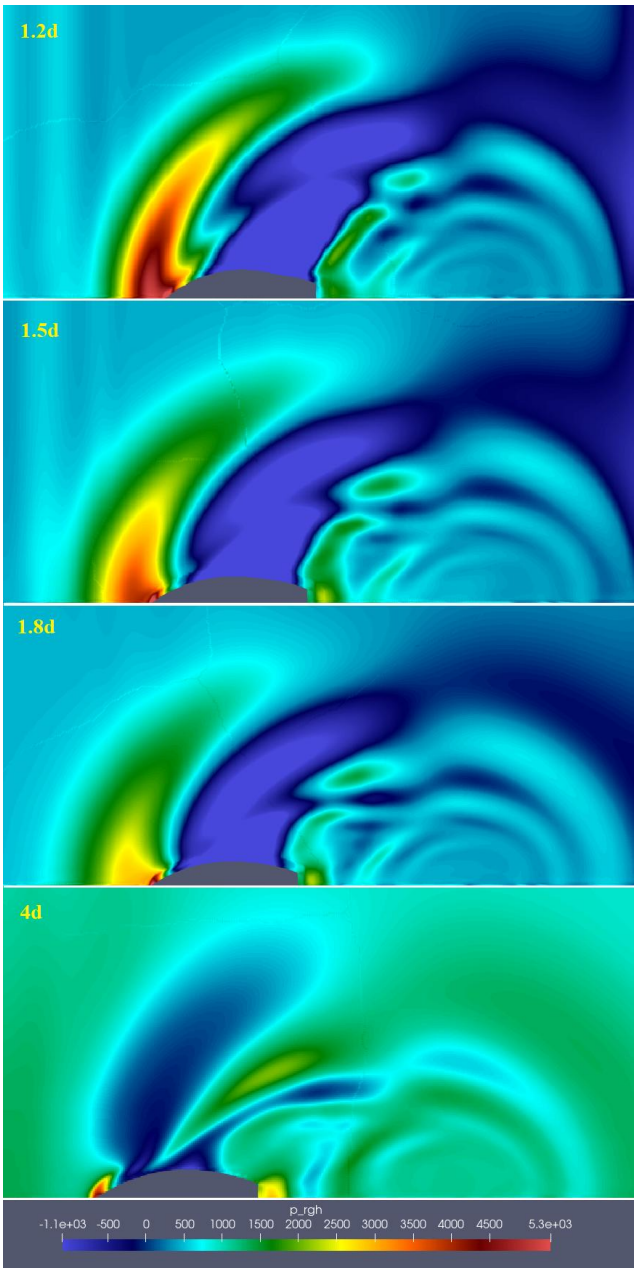
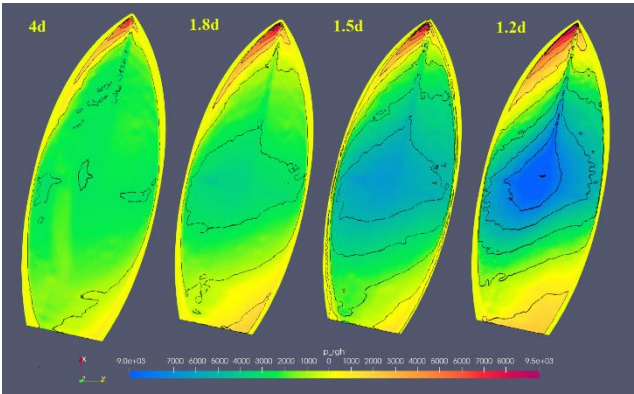


Fig.15 Pressure field at free surface

Images of pressure field at hull wetted surface on figure 13:



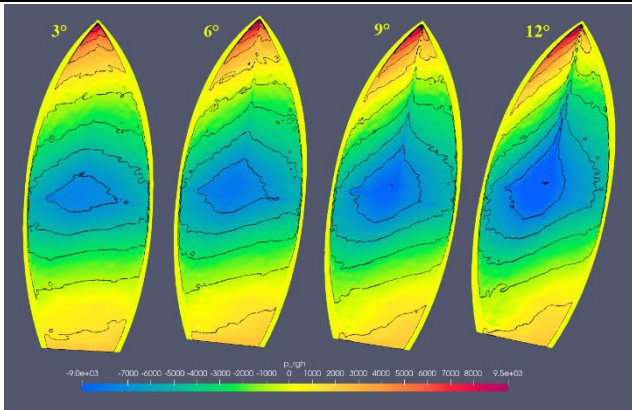


Fig.16 Pressure field on hull bottom wetted surface at drifts with $U=4\text{m/s}$

Applying vectors on free surface show velocity of the free surface interface, figure 17.

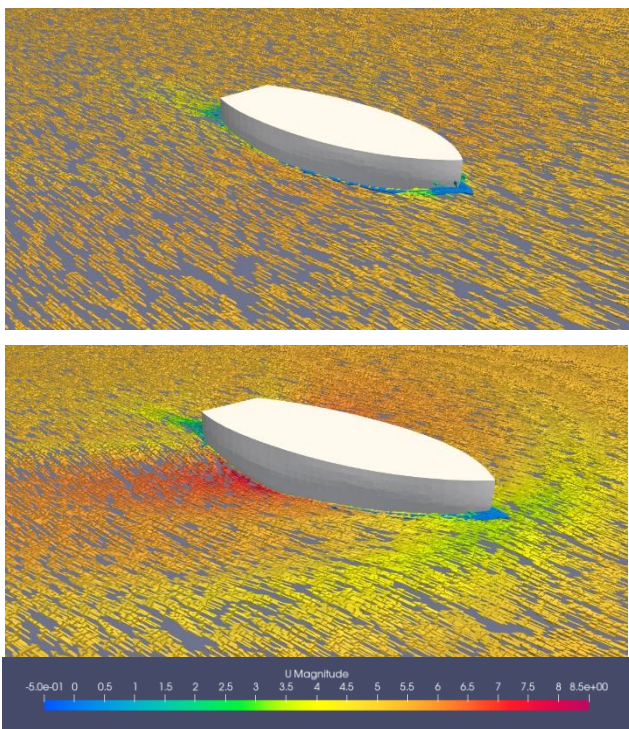


Fig.17 Comparing deep water and marginal shallow water depths at 0 deg drift. U vector at free surface. $U=5.2\text{m/s}$.

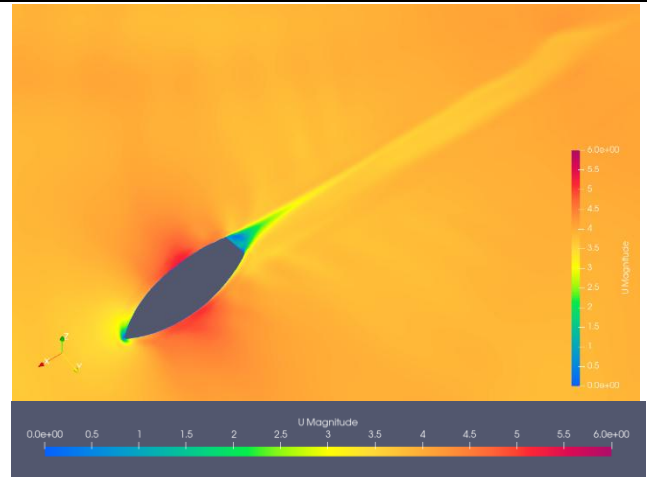
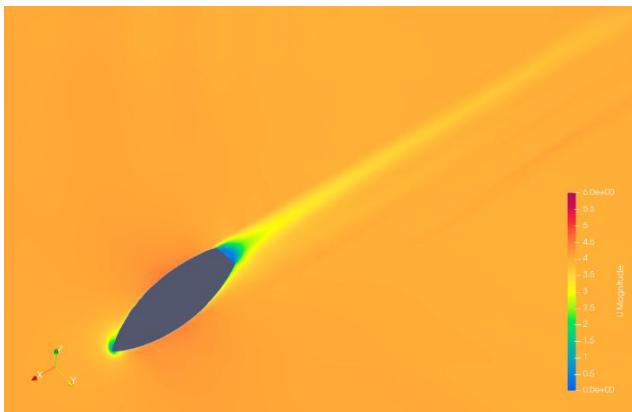


Fig.18 Drift angle of 12 deg at deep and marginal shallow water.

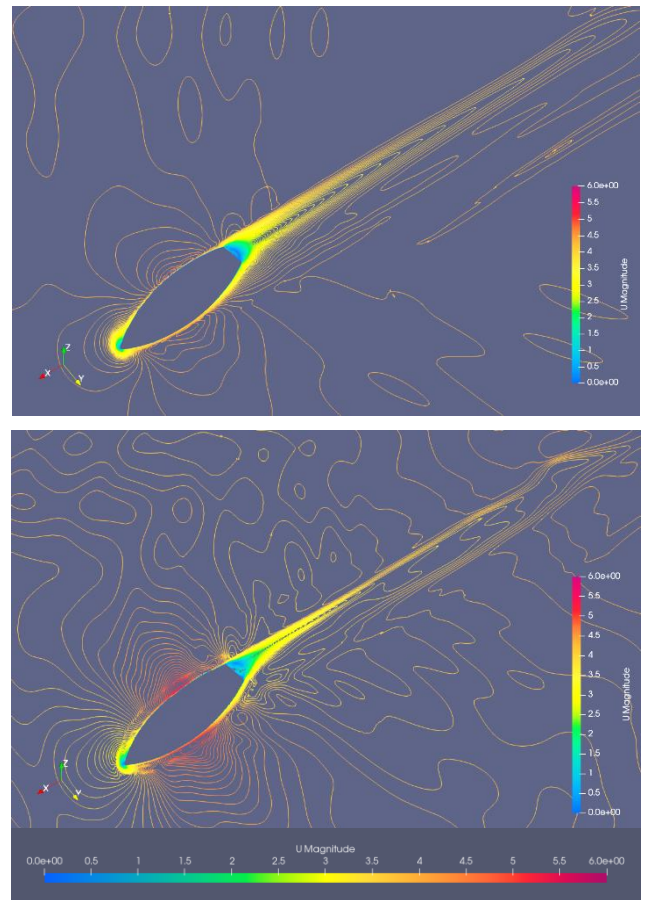


Fig.19 Drift angle 12[deg] wake 4d and 1.2d, ISO lines

Time for these quantitative results is around 90 days with a desktop computer: CPU Intel Core i7 6700 (Skylake), RAM DDR4 32 GB 2666 Mhz. For the same case and settings to have a medium mesh and higher accurate results, 64 GB RAM is necessary, which is confirmed with the last model set and performance for $h=1.2d$.

6. Conclusions

As a result of the simulations the following conclusions are made:

- can obtain free surface flow around body with good data for prediction of forces and moments acting upon hull.
- can generate quantitative results considerably fast, depending on computational resources. At least 64GB RAM is necessary for

more accurate values through medium or fine mesh compared to the coarse mesh used in this paper. However, despite this we can still get good enough results that can be of use.

- the CFD simulation with RANS enables accurate prediction flow details around hull in marginal shallow water problems and prediction of hydrodynamic capabilities for designed or an already constructed ships.

Diagrams and images from post-processing with ParaView show that the results from OpenFOAM are a reliable method for accurate prediction and analysis.

Recommendation for better understanding about ship-shape motion in shallow waters with CFD simulations is the use Multiple Reference Frame, MRF and Overset mesh techniques. MRF will recreate simulation for rotating arm test to obtain rotary derivatives, as for Overset to obtain trim and sinkage within 4DOF. It is important for harbor Pilots and ship Masters, who take sinking and trimming as a priority when navigating in channels and ports with limited depth, especially for large ships.

7. References

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Application of artificial neural networks for assessing the Psi-factor of thermal bridges under various geometries and materials

Stoyanka Ivanova^{1,*}

University of Architecture, Civil Engineering and Geodesy (UACEG) – Sofia, Bulgaria ¹

siva_fce@uacg.bg

Abstract: The publication examines the use of artificial neural networks to calculate the linear thermal conductivity (Psi-factor) of thermal bridges given various parameters, such as geometrical data and the thermal resistance R of the thermal bridge components. The neural network is trained on examples of IF, IW, and B thermal bridges, considering the straightforward task of determining Psi using given parameters. The neural network training results show high accuracy in calculations – RMSE is 1.132% on training data and 1.1423% on test data, and the correlation coefficient (R^2) is around 0.9997 for both data sets. The applicability of the approach to seismic conditions in the Balkans is assessed.

Keywords: ARTIFICIAL NEURAL NETWORKS, THERMAL BRIDGES, PSI-VALUE, ENERGY EFFICIENCY, MODELING AND OPTIMIZATION

1. Introduction

Thermal bridges are sections of the building envelope that transfer heat from the inside to the outside and vice versa more efficiently than other parts of the building envelope. A precise definition is given in [1, Art. 3.1.1], and according to it, a thermal bridge is a part of the building envelope where the heat transfer resistance changes significantly for one or more of the following possible reasons: full or partial penetration of materials with different thermal conductivity into the building envelope; change in the thickness of the main element; changing the configuration of the element (for external and internal corners, wall-roof connection, wall-floor connection, wall-internal wall connection, etc.).

Thermal bridges are diverse – they can be linear, point, geometric, constructive, mixed (geometric-constructive), convective, etc. Among them, the geometric-constructive ones are very significant, which in their composition include building elements with high density and thermal conductivity – for example slabs, beams and columns of reinforced concrete or metal, which are in close proximity to the external space.

Thermal bridges lead to greater heat loss as well as problems such as condensation and mold. Their reduction through proper insulation is of great importance to reduce the need for heating in winter, from cooling in summer and, in general, to lower carbon emissions.

According to conservative estimates for countries in seismic regions, the losses through thermal bridges are well over 20-25% of the total heat losses from heat transfer through the walls [2], although their area on the facades is much smaller. In order to improve energy efficiency, it is important to identify and minimize these losses through appropriate design and use of modern thermal bridge assessment and modeling methods.

The contribution of a thermal bridge to the losses through an external wall is estimated by determining the so-called coefficient of linear thermal conductivity ψ (Psi-factor) of the thermal bridge. This is known as a *forward problem* because the goal is to calculate ψ of a thermal bridge based on known input parameters such as geometry and thermal resistance of the components.

The value of the coefficient of linear thermal conductivity ψ is relatively difficult to determine – through specialized software that calculates the heat balance of the element, usually (but not only) by the finite element method (by dividing the cross-sectional area of the structure into a huge number of triangles). Examples of such software are BISCO by the Belgian company Physibel [3] for linear thermal bridges, which has been verified with the MKC EN ISO 10211 standard [1], as well as COMSOL (Comsol 2006) [4, 5], TRISCO (also by Physibel) [6], FLIXO [7] and etc. Mention should also be made of the Bulgarian temperature field program TEPOL, described in detail in [8], whose application is demonstrated in [9, 10]. These relatively universal and usually quite expensive software products are not suitable for the daily work of designers. Therefore, they are most often used to prepare catalogs of thermal bridges for use in design. Catalogs can be with simplified solutions, for example [11]. An example of a much more extensive and detailed

catalog is that of linear thermal bridges in buildings in seismic areas by Dr. Eng. Arch. Petar Nikolovski [12, 13]. In the catalog, the dimensions of the building elements are changed in a certain step (for structural elements – in 5 or 10 cm; for thermal insulation – in 2 cm) and typical values of the coefficient of thermal conductivity are used, for example $\lambda = 0.04$ W/(mK) for thermal insulation, $\lambda = 0.45$ W/(mK) for brick wall and $\lambda = 2.50$ W/(mK) for reinforced concrete elements – beams and slabs. Nikolovski's catalog includes over 350 linear thermal bridges typical of the construction practice of the Balkans, structured in groups and subgroups. It is also applicable in Bulgaria because it solves tasks in the specific conditions of seismic regions, such as our country. Although the catalog tries to include all significant variants, it is still possible in practice to determine the coefficient ψ of a thermal bridge whose dimensions do not exactly match the dimensions given in the catalog. It is possible that the desired intermediate values of U and ψ can be obtained by interpolation, but this requires additional effort and time and increases the element of uncertainty due to the possibility of introducing human error.

The need for new approaches arises due to the need for greater efficiency and accuracy in the estimation of the Psi-factor. One such alternative is described in an earlier development by the author [14, 15], based on the use of artificial neural networks (ANN) in one type of thermal bridges (the so-called IF – Interior Floor).

The concept of artificial neural networks [16] realizes in itself a computer analog of specifically connected neurons in a system. They are divided into layers with different purposes – input, hidden(s), and output. Each neuron is connected to all neurons of the previous and next layer by a connection that is numerically tunable. Each neuron processes in a special way (through an activation function) the influence of all neurons from the previous layer and sends the result of this processing to all neurons from the next layer.

The set of neurons in the form of an organized network uses input data and generates a final output and is capable of learning to perform this task better.

The expanding application of ANNs in design is based on their ability to learn from existing (measured or calculated in more laborious ways) data and predict outcomes for new situations. In the case of thermal bridges, trained neural networks can be used to calculate the Psi-factor without requiring detailed modeling and simulations. This can help to optimize the architectural parameters of the building envelope and structure, taking into account different material options, geometries, and climatic conditions.

Artificial neural networks (ANNs) have advantages that make them a useful choice for application in various tasks in building design:

- Ability to model complex interrelationships: Neural networks are capable of modeling complex dependencies between thermal bridge parameters, achieving higher accuracy than traditional analytical methods. Their training can be performed on the basis of measurements taken, and this significantly increases their accuracy and reliability.

- **Calculation speed:** Once a neural network is trained, depending on its structure, it can very quickly calculate the *Psi*-factor for new unknown data, which is much faster than the detailed modeling typical of the finite element method.
- **Adaptability:** Neural networks can be easily developed for different types of thermal bridges, materials and geometries. This makes them very flexible when design requirements change.
- **Process automation and simplification:** With the use of ANNs, the process of calculating the *Psi*-factor can be greatly automated, reducing the need for manual calculations or complex simulations. This simplifies the work of engineers and reduces the possibility of human error.
- **Applicability in different settings:** Networks can be trained on different types of structures, making them suitable for wide application, including in regions with high seismic activity, such as the Balkans.

These benefits do the artificial neural networks a powerful tool for solving tasks related to improving the energy efficiency of buildings by providing fast, accurate and flexible solutions for the assessment of thermal bridges.

2. Methodology

2.1. Types of thermal bridges considered.

In the present development, three different types of thermal bridges are considered – IF, IW, and B (Fig. 1) according to EN ISO 14683 [17].

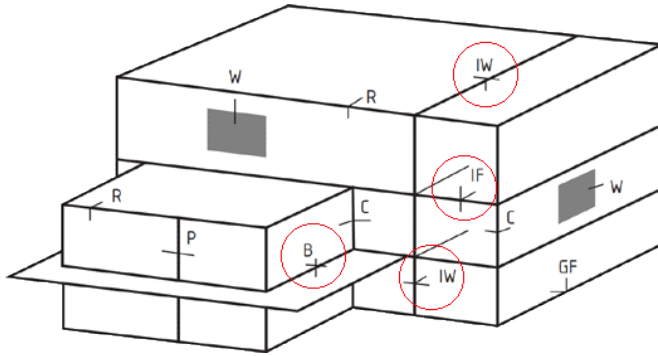


Fig. 1 Types of thermal bridges, according to EN ISO 14683 [17].

IF (Interior Floor) – Internal floor:

This is a thermal bridge that occurs when an interior floor or slab connects to an exterior wall (Fig. 2). This type of thermal bridge can appear in places where interfloor slabs break the enclosing wall and reach the outer space. Usually this is accompanied by an outer beam.

IW (Interior Wall) – Internal wall:

IW refers to a thermal bridge that occurs at the points where an interior wall abuts an exterior wall or slab of a building (Fig. 3).

B (Balcony) – Balcony:

This is a thermal bridge connected to the construction of the balconies (Fig. 4). They are directly exposed to external conditions and are structurally filled with materials with high thermal conductivity.

The three types of thermal bridges have some common parameters, as well as different but amenable to a common parameterization (see Table 1).

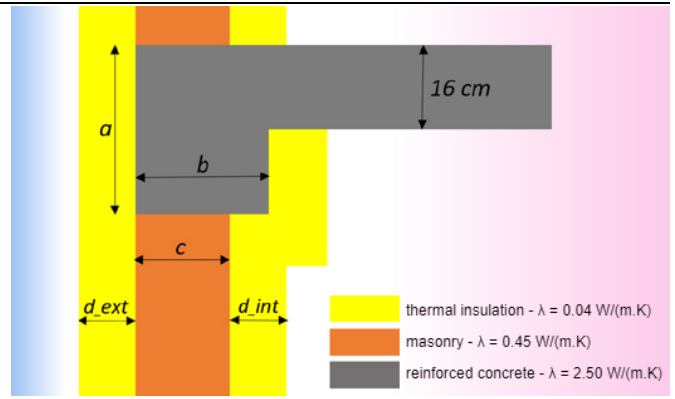


Fig. 2 Thermal Bridge Data – Type IF, with sample lambda values for the materials.

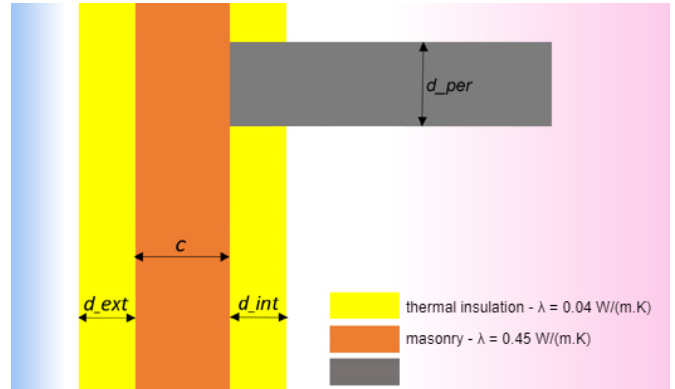


Fig. 3 Thermal Bridge Data – Type IW, with sample lambda values for the materials.

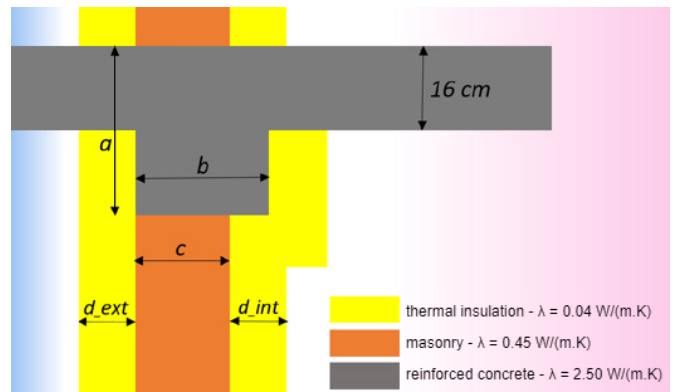


Fig. 4 Thermal Bridge Data – Type B, with sample lambda values for the materials.

Table 1: Parameters needed to train ANNs on thermal bridge types.

Parameter	type IF	type IW	type B
<i>a</i>	+	–	+
<i>R_b</i>	+	–	+
<i>R_c</i>	+	+	+
<i>R_{ext}</i>	+	+	+
<i>R_{int}</i>	+	+	+
<i>R_{per}</i>	+	+	+
<i>balcony</i>	–	–	+

The meaning of these parameters is as follows:

- *a* – height of the beam (in the range from 0 to 60 cm).
- *R_b* – horizontal thermal resistance of the beam (in the range of 0 to 0.2).
- *R_c* – thermal resistance of the outer wall (in the range of 0 to 3).

- R_{ext} – thermal resistance of the external thermal insulation (in the range from 0 to 5).
- R_{int} – thermal resistance of the internal thermal insulation (in the range from 0 to 5).
- R_{per} – thermal resistance of a perpendicular plate or wall (in the range of 0 to 3).
- $balcony$ – there is or no balcony (values 1 or 0).

The match in a large number of parameters is a prerequisite for all three types of thermal bridges to be modeled with one common neural network instead of three separate ones.

2.2. Description of inputs and outputs

From Table 1, it follows that seven input parameters are used in the developed neural network, which describes the different characteristics of thermal bridges. Among them, there is one geometric parameter (vertical size of the beam a in cm), the other parameters represent thermal resistance, and the last parameter plays the role of *True / False* for the presence of a balcony. The neural network has only one output – the value of the linear thermal conductivity Ψ , which ranges from -0.1 to 2.

To calculate the values of thermal resistance (R) of a material we use the formula $R = d / \lambda$, where d is the thickness of the material (in meters) and λ is the coefficient of thermal conductivity of the material (in W/m·K). For walls that have several components, a generalized thermal resistance is calculated.

2.3. Neural network training

The following steps should be considered when training an ANN:

Data partitioning: The database containing 422 rows (the input-output matching sample) was split into a training and a test set, with 80% of the data (323 rows) used for training and the remaining 20% (99 rows) – for testing.

Data normalization: This is bringing the values of the parameters and the target scores in the range of 0 to 1 and is done to improve the training efficiency.

Data shuffling: This is the process of randomly rearranging the rows in the dataset before training an ANN to prevent the model from learning any unintended patterns or sequences present in the data.

Training algorithm: The network was trained with a back-propagation algorithm at a variable learning rate according to the calculated error.

Number of epochs: Training lasted 370,000 epochs, which helped to reach quite low RMSE values and a very high correlation coefficient between target and modeled results. The RMSE errors of the training and test data are almost the same, indicating no overfitting.

Denormalization of the result: The ANN produces a normalized result that must be scaled back to its usual range to obtain its real value.

2.4. Data used and evaluation criteria

Data from the Catalog of Linear Thermal Bridges in Seismic Regions by P. Nikolovski [12], developed for North Macedonia, were used to compile the training database. They were calculated using BISCO [3] – software of the Belgian company Physibel for linear thermal bridges, which works by the finite element method.

In the present work, the following criteria are used to evaluate the learning outcomes:

- **Root Mean Square Error (RMSE):** This is a key metric for evaluating the quality of network performance. It has different values depending on whether it is calculated on normalized or denormalized scores.
- **Correlation coefficient (R^2):** it is used to measure the degree of correspondence between the target and the modeled values. Its value does not depend on whether the results are normalized or not.

2.5. Description of different neural network architectures (number of hidden layers)

Network with one hidden layer: The one used A neural network has one hidden layer that contains 10 neurons. This is a simple but effective architecture for regression tasks such as the present one.

Experiments with different numbers of hidden layers: Experiments were also conducted with networks with more than one hidden layer (e.g., 2 and 3 hidden layers) to see if increasing the complexity of the model would significantly improve the prediction accuracy. The results showed that increasing the number of hidden layers leads to a slight improvement in accuracy, but it does not significantly compensate for the complexity of the model.

3. Results

ANN training results after 370,000 epochs show very high model performance accuracy, both on the training and test data sets. The root mean square error (RMSE) was 1.132% on the training data (Fig. 5) and 1.1423% on the test data (Fig. 6). This shows that the model succeeds in predicting the Ψ -factor values with high precision, which is also confirmed by the correlation coefficient (R^2) of 0.999718 on the training set and 0.999607 on the test data.

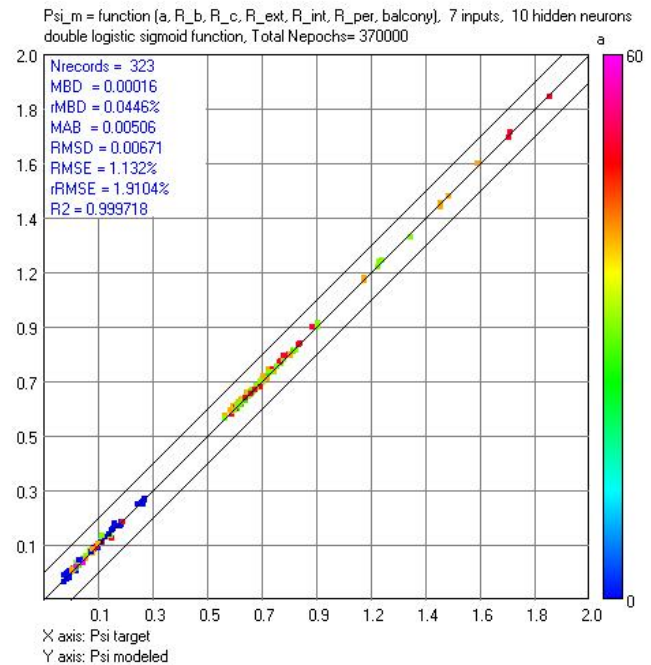


Fig. 5 Comparison of ψ coefficient values used for training (in the horizontal direction) with the ANN modeled ones (in the vertical direction) for the training data.

The applicability of the model was evaluated for the seismic conditions of the Balkans, where structural requirements lead to a higher percentage of reinforcement in slabs, beams, and columns, increasing the importance of thermal bridges and ways to neutralize them. The neural network used to estimate the Ψ -factor showed that it can be effectively used to predict heat losses, even in complex conditions such as those associated with higher seismic hazards. This shows the potential of the model to be used as a tool for the optimization of building solutions aimed at energy efficiency in these specific conditions.

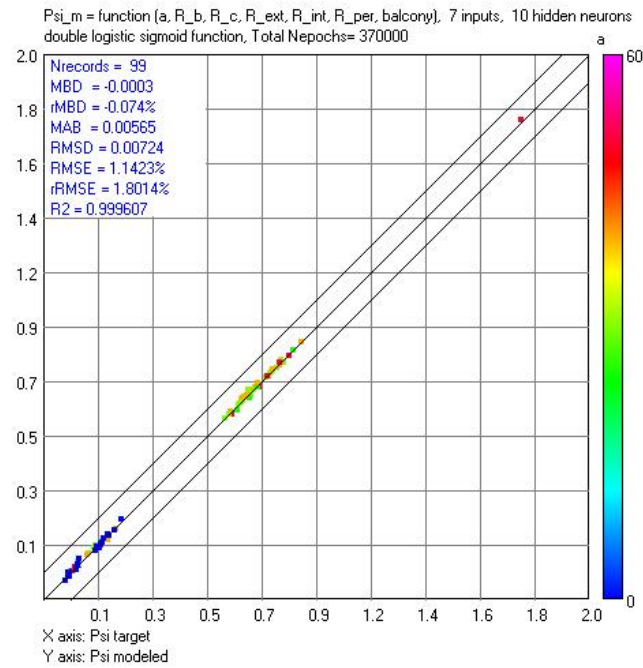


Fig. 6 Comparison of ψ coefficient values used for training (in the horizontal direction) with the ANN modeled ones (in the vertical direction) for the test data.

The trained neural network is integrated into an HTML page (Fig. 7) [18] using JavaScript code, which allows its interactive use. The user can select the type of thermal bridge (IF, IW, or B), and depending on the choice made, a different dialog is launched to enter the necessary information for the selected type of thermal bridge (for example, geometric dimensions of the beam, walls, presence of a balcony). From this data, thermal resistances are calculated, which are then normalized and fed into the JavaScript environment as input to the trained neural network.

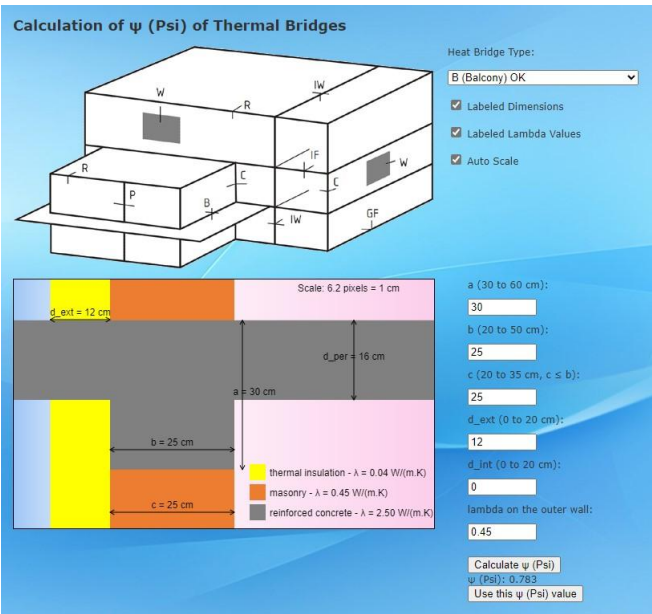


Fig. 7 HTML page for calculating ψ of linear thermal bridges of type IF, IW, and B [18].

After processing by ANN, the obtained result (*Psi-factor*) is denormalized and presented to the user. This value can be further used for calculations of losses through the thermal bridge, which provides a quick and convenient assessment of the energy efficiency of a given structure and building envelope [19].

4. Conclusions

The considered three types of thermal bridges cover a significant part of the losses through the thermal bridges of buildings. For this reason, a neural network that calculates their *Psi*-factor would be very useful in a series of heat gain and loss estimation software. The research results show that the trained ANN successfully predicts the linear thermal conductivity at different geometries and thermal resistances, achieving a low root mean square error (RMSE) and a very high correlation coefficient (R^2) between target and modeled results. This confirms the potential of neural networks to solve complex tasks related to improving the energy efficiency of buildings.

The neural network used with one hidden layer with 10 neurons and back-propagation algorithm demonstrates excellent generalization and generalization ability in this task. This makes it much easier to solve the task of determining the coefficient of linear thermal conductivity *Psi* in the specific conditions of seismic areas, compared to traditional methods that require more resources and time for modeling.

It is of interest in the future to combine these results with other modern technologies, such as 6D BIM, which would allow a more efficient calculation of heat losses and heat transfer gains directly in the modeling and design process. This will provide a better understanding of the opportunities to improve the building envelope already at the design stage, allowing optimization of materials and structures with a view to minimizing thermal bridging and improving sustainability. Another interesting direction is the use of more complex neural network architectures, exploring their ability to discover new dependencies between materials and structural parameters.

The development shows that neural networks can be used to solve complex tasks related to the assessment of thermal bridges in complicated climatic and seismic conditions. Such applications can support the design of sustainable buildings by taking into account specific environmental and climatic factors, making them extremely useful in complex and dynamic environments.

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Thermal bridging Inverse problem: Using neural networks to determine thermal bridge parameters at known Psi-factor

Stoyanka Ivanova^{1,*}

University of Architecture, Civil Engineering and Geodesy (UACEG) – Sofia, Bulgaria¹

siva_fce@uacg.bg

Abstract: This paper investigates the inverse problem for thermal bridges – determining design parameters (such as material, geometry, thermal resistance R of the components) of the bridge at a known Ψ -factor. By using artificial neural networks, a thermal bridge type IF (wall-floor connection) has been considered to evaluate the effectiveness of the methodology. The results show that the approach provides a fast and accurate way to predict the optimal parameters that meet specific energy efficiency requirements. In the future, this approach could help to determine the parameters of thermal bridges using thermographic images non-invasively.

Keywords: INVERSE PROBLEM, ARTIFICIAL NEURAL NETWORKS, HEAT BRIDGES, Ψ -FACTOR, ENERGY EFFICIENCY

1. Introduction

Thermal bridges are sections of the building envelope that transfer heat from the inside to the outside and vice versa more efficiently than other parts of the building envelope. In them, the heat transfer resistance changes significantly for one or several of the following possible reasons: full or partial penetration of materials with greater thermal conductivity into the building envelope; change in the thickness of the main element; changing the configuration of the element (for external and internal corners, wall-roof connection, wall-floor connection, wall-internal wall connection, etc.) [1].

Conducting heat through thermal bridges is a significant factor; in Bulgaria, it is over 20-25% of unwanted heat losses in winter and heat gains in summer. Unprotected thermal bridges are also a prerequisite for condensation and mold, which worsens the internal conditions in the building. The influence of thermal bridges can be limited with the help of thermal insulation layers in front of them so that the path of heat out or in is blocked to a significant extent.

Usually, when designing a part of energy efficiency and calculating heat losses/gains, the values of the linear coefficient of thermal conductivity (Ψ -factor) are needed for each thermal bridge in the building envelope. Its determination is known as a “**forward problem**”, solved with known design parameters – geometry, material characteristics and thermal resistance R of the components. An example of a solution to this task using neural networks can be found in [2, 3].

The “**Inverse**” problem involves solving it in the opposite direction: with a known Ψ -factor, the goal is to determine some of the design parameters of the thermal bridge, such as material, geometry, and thermal resistance of the components. This task is more complex because it requires finding the combination of parameters that results in the specified value of the Ψ -factor. The solution of the inverse problem is useful both for designing the building envelope and for determining parameters of already built structures, for example, using thermographic photographs.

Due to its complexity, solving the inverse problem is often avoided. However, there are some traditional methods for its solution – trial and error, catalog search, software modeling. This necessitates the search for new, more efficient ways of solving the inverse problem.

Artificial Neural Networks (ANN) enable modeling more complex relationships between related values. They are usually used to numerically determine the relationship between a series of input parameters and some result, for example, between the geometrical and thermotechnical parameters of a thermal bridge and the value of the Ψ -factor, i.e. forward problem.

In the inverse problem, when training the neural network, some parameters and the Ψ -value are given as input data, and other parameters are searched for. For this purpose, the function used to solve the linear problem must be monotonic (increasing or decreasing) concerning the sought parameter. In the absence of an analytical solution (as is the case), numerical methods, optimization algorithms, or neural networks can be used. The latter can learn the complex interrelationship and provide a solution to the inverse problem.

The present study aims to develop a methodology for determining the parameters of thermal bridges using ANN at a known Ψ -factor.

2. Methodology

2.1. Considered type of thermal bridge.

In the present work, one of the significant types of thermal bridges is considered: IF (Interior Floor, wall-floor connection) (Fig. 1) according to EN ISO 14683 [4].

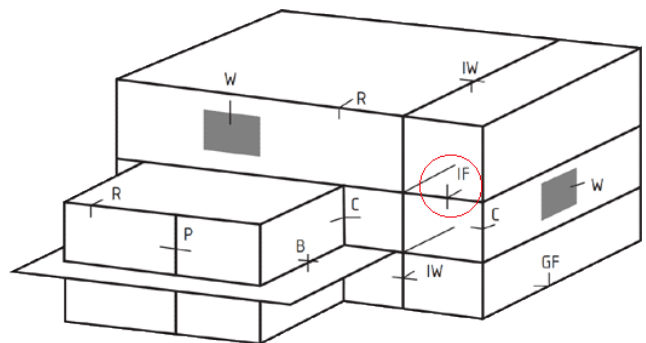


Fig. 1 Types of thermal bridges, according to EN ISO 14683 [4].

This thermal bridge occurs when an interior floor or slab connects to an exterior wall. It can appear in places where inter-floor slabs break the enclosing wall and reach outer space. Usually, this is accompanied by an external beam (Fig. 2).

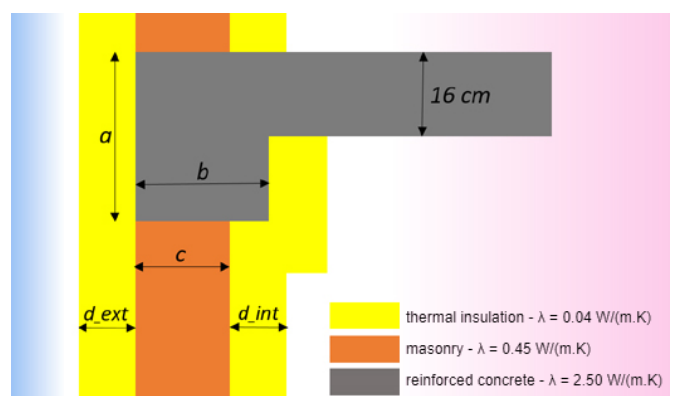


Fig. 2 Thermal Bridge Data – Type IF, with sample λ values for the materials.

IF type thermal bridge can be modeled with the following parameters:

- a – beam height (from 0 to 60 cm).
- R_b – horizontal thermal beam resistance (from 0 to 0.2).
- R_c – thermal resistance of the outer wall (from 0 to 3).
- R_{ext} – thermal resistance of the external thermal insulation (from 0 to 5).
- R_{int} – thermal resistance of the internal thermal insulation (from 0 to 5).

- Ψ – linear thermal conductivity (from -0.1 to 2).

To calculate a material's thermal resistance R , we use the formula $R = d / \lambda$, where d is the material's thickness (in meters) and λ is its coefficient of thermal conductivity (in W/m·K). A generalized (reduced) thermal resistance is calculated for walls with several components.

In the forward problem, Ψ is determined based on the first 5 parameters, and in the inverse problem, based on the first 3 parameters and the last (Ψ), the fourth and fifth, which are indicative of the thickness of the thermal insulation, must be determined.

2.2. Description of inputs and outputs

Data from the Catalog of Linear Thermal Bridges in Seismic Regions by P. Nikolovski [5], developed for North Macedonia, were used to compile the training database. They were calculated using BISCO [6] – software of the Belgian company Physibel for linear thermal bridges, which works by the finite element method. The geometry is modeled “manually” by Nikolovski in a graphic editor, which leads to minor deviations (for the building design).

The relationships between the parameters and Ψ for the IF type thermal bridge are described in a total of 135 lines (entries). The four graphs in Fig. 3 are based on these data.

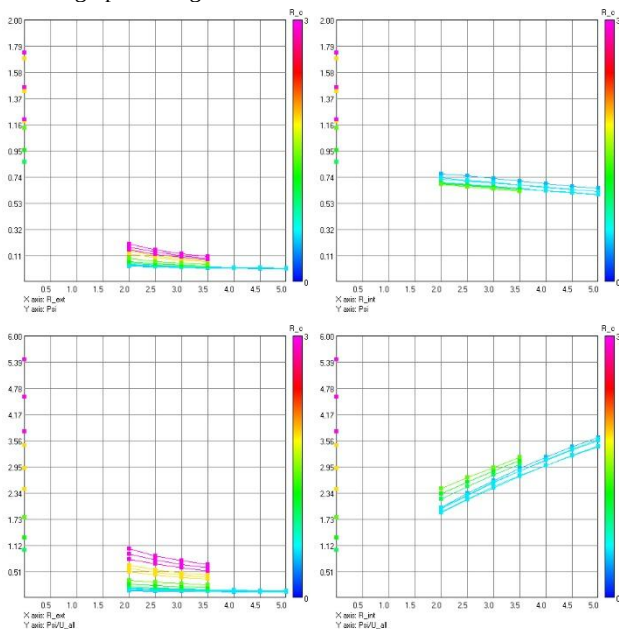


Fig. 3 Dependence between the thermal resistance of the external and internal thermal insulation R_{ext} and R_{int} on the one hand and Ψ (top) or Ψ/U_{all} (below) on an IF thermal bridge on the other. The color of the curves is a function of R_c .

The graphs of the top row of Fig. 3 show the dependence between the thermal resistance of the external and internal thermal insulation R_{ext} and R_{int} on the one hand and Ψ on the other. In the bottom row of the figure, the graphs show the dependence between the thermal resistance of the external and internal thermal insulation R_{ext} and R_{int} on the one hand and the ratio Ψ/U_{all} on the other, where U_{all} is the heat transfer coefficient of the outer wall with all its layers. All four graphs show a monotonically varying function within the investigated parameter values. However, the ratio Ψ/U_{all} (instead of Ψ) performs better because the steeper slope of the bottom row of graphs will give a higher accuracy of the result for R_{ext} and R_{int} .

The two graphs of the bottom row of Fig. 3 suggest that R_{int} will be more easily determined than R_{ext} because the slope of the curves is greater. Problems also arise from the “manual” modeling with slight deviations, as well as the low accuracy when recording Ψ in the catalog (up to 3 digits after the decimal point), which does not allow to distinguish well between relatively close and very low Ψ values for external thermal insulation.

2.3. Description of inputs and outputs

Above, in the description of the forward problem, the input parameters for the developed neural network were listed, five in number, which describe the different characteristics of the thermal bridges. Among them there is one geometric parameter (vertical size of the beam a in cm) and the other parameters represent thermal resistance. The neural network has only one output - the value of the linear thermal conductivity Ψ .

The newly developed neural network for the inverse problem has 4 inputs: a , R_b , R_c and Ψ (or Ψ/U_{all}), and output R_{ext} or R_{int} , which represent the thermal resistance of the external and internal thermal insulation. Based on a known value of λ – coefficient of the thermal conductivity of the thermal insulation (usually about 0.04 W/m·K), it is possible to calculate how much its thickness should be.

Thus, the two new neural networks for the inverse problem have the following input parameters:

- a – beam height (from 0 to 60 cm).
- R_b – horizontal thermal beam resistance (from 0 to 0.2).
- R_c – thermal resistance of the outer wall (from 0 to 3).
- Ψ/U_{all} – the ratio between linear thermal conductivity and the heat transfer coefficient of the wall with thermal insulation (from -0.1 to 6).

and one of the following results:

- R_{ext} – thermal resistance of the external thermal insulation (from 0 to 5).
- R_{int} – thermal resistance of the internal thermal insulation (from 0 to 5).

Based on each of the obtained results, the trained neural networks should enable non-destructive (non-invasive) determination of the internal and external thermal insulation thicknesses at a known λ -value.

2.4. Neural network training

The following steps should be considered when training an ANN:

Data partitioning: The database containing 135 rows (the input-output matching sample) was split into a training and a test set, with 80% of the data (111 rows) used for training and the remaining 20% (24 rows) – for testing.

Data Normalization: This is bringing the values of the parameters and the target scores in the range of 0 to 1 and is done to improve the training efficiency.

Learning algorithm: The networks are also trained with a back-propagation algorithm at an adaptive learning rate (Learning Rate), which decreases as training progresses and approaches the minimum error.

Number of Epochs: Training continues until a more significant local minimum of the RMSE error is reached for the training and test data.

Denormalization of the result: The ANN produces normalized results that must be returned to their normal range to obtain their true values.

Architecture of neural networks used: Two neural networks are trained with the same input of 4 parameters, 1 hidden layer and 1 output. One ANN gives the final result R_{ext} , and the other – R_{int} . The other option is to train a single network with two outputs, but training is usually more difficult in this case and slower and ends at a higher RMSE error. Sigmoid activation functions were used.

2.5. Evaluation criteria

In the present work, the following criteria are used to evaluate the learning outcomes:

Root Mean Square Error (RMSE): This is a key metric for evaluating network performance quality. Its value varies depending on whether it is calculated using normalized or denormalized scores.

Correlation coefficient (R^2): it is used to measure the degree of correspondence between the target and the modeled values. Its value does not depend on whether the results are normalized or not.

2.6. Description of the different neural network architectures tested (number of hidden layers)

Network with one hidden layer: For both results, the used ANN has one hidden layer that contains 20 neurons. This is a simple but effective architecture for regression tasks like the present one.

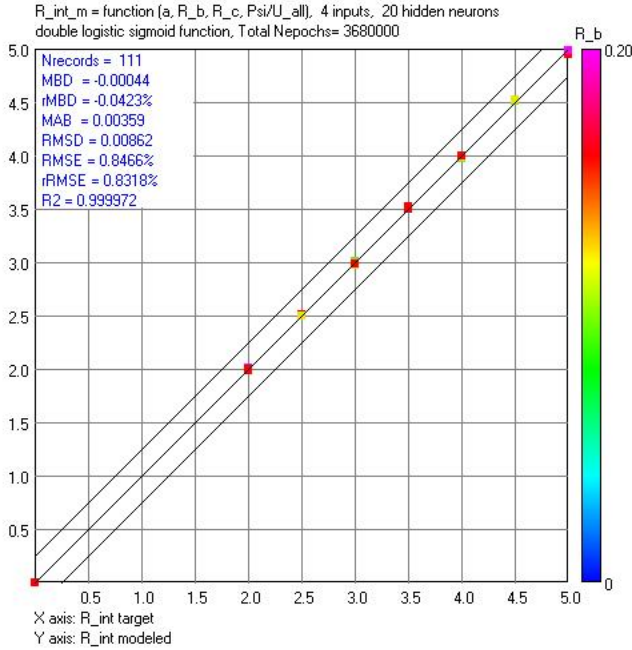


Fig. 5 Comparison of the thermal resistance values R_{int} of the target data (in the horizontal direction) with the ANN modeled (in the vertical direction) for the training data.

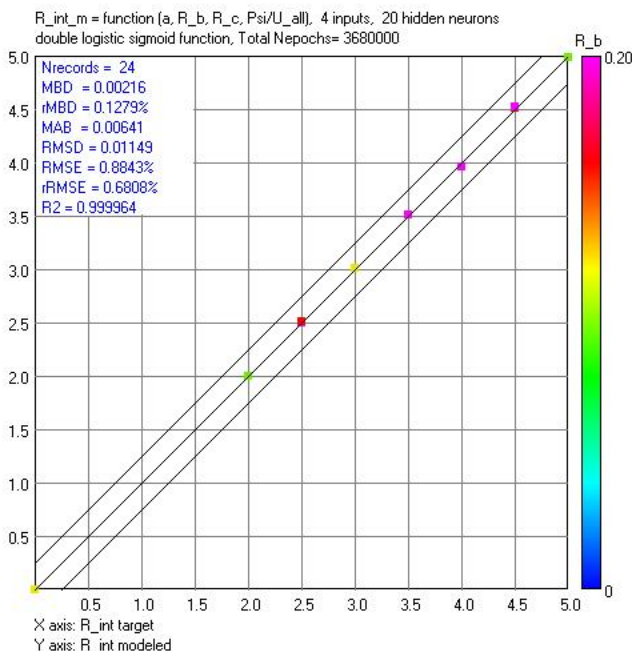


Fig. 6 Comparison of the thermal resistance R_{int} values of the target data (in the horizontal direction) with the ANN modeled (in the vertical direction) for the test data.

Experiments with different numbers of hidden layers: Experiments were also conducted with networks with two outputs and/or more than one hidden layer (e.g. 2 and 3 hidden layers) to see if increasing the complexity of the model would significantly improve the accuracy of forecasts. The results showed that

increasing the number of hidden layers leads to a slight improvement in accuracy, but it does not significantly compensate for the complexity of the model.

3. Results

Due to the different complexity of the two tasks, each of the two ANNs was trained with a different number of epochs.

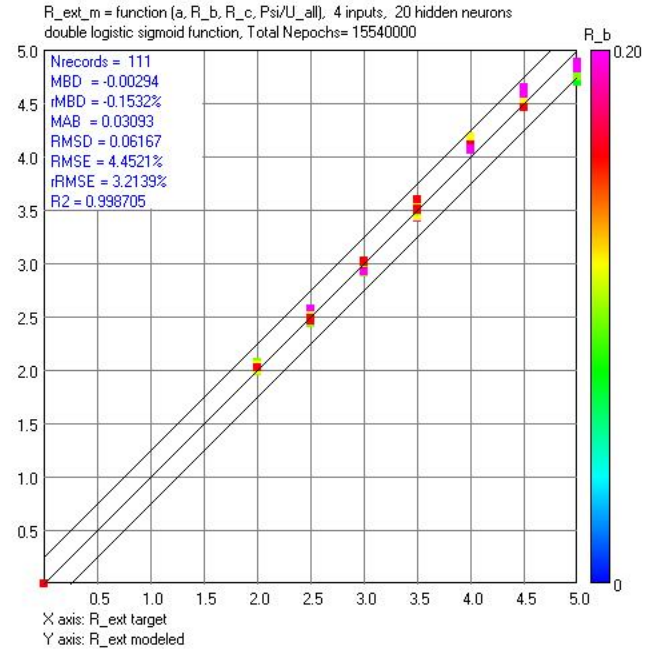


Fig. 7 Comparison of the thermal resistance values R_{ext} of the target data (in the horizontal direction) with the ANN modeled (in the vertical direction) for the training data.

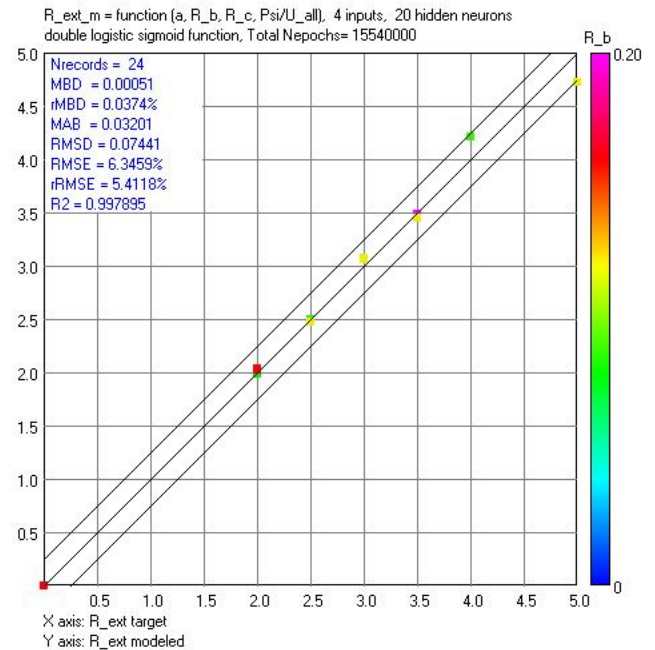


Fig. 8 Comparison of the thermal resistance R_{ext} values of the target data (in the horizontal direction) with the ANN modeled (in the vertical direction) for the test data.

The neural network for determining the thermal resistance of the internal thermal insulation was trained relatively more easily, with 3,680,000 epochs, reaching the lowest root mean square error (RMSE) of 0.008466 on the training data (Fig. 5) and 0.008843 on the test data (Fig. 6). The correlation coefficient (R^2) is 0.999972 for the training set and 0.999964 for the test data, which is an extremely high value and indicates very good training.

The neural network for determining the thermal resistance of the external thermal insulation was trained much harder, with 15,540,000 epochs, reaching a root mean square error (RMSE) of 0.044521 on the training data (Fig. 7) and 0.063459 on the test data (Fig. 8). The correlation coefficient (R^2) is 0.998705 for the training set and 0.997895 for the test data.

4. Discussion

To solve this task, two software products developed by the author were used with the same neural network architecture (one hidden layer with 20 neurons):

- 1) Program **PowerSolver** is written in the PowerBasic programming language. It is characterized by great speed (PowerBasic is comparable in speed to C++) but does not use optimization techniques during training.
- 2) Program **TensorSolver** in the Python programming language uses the TensorFlow standard library for working with neural networks [7] and, more specifically, Adam-optimizer for neural networks [8].

For several reasons, the second program is significantly slower to produce comparable learning outcomes. The Python language is used through interpretation, which itself is a slower process, and the TensorFlow library is written in the fast language C++ and compiled. Communication between the two languages, Python and C++, requires additional time for preparatory operations preceding learning. Training graph compilation and optimization in TensorFlow also add time to training implementation. Automatic optimizations for different hardware platforms make TensorFlow flexible and capable of different solutions but lead to performance delays.

Another problem is that the Adam optimizer aims to find a local minimum of the RMSE error, which rarely coincides with the global minimum. Combined with a low initial learning rate (e.g., $LR = 0.01$), this results in (relatively) faster learning (like for Python), but the RMSE error of the solution remains high. After the solution hits the local minimum of the error, the neural network cannot search for another minimum, and the training is terminated. Slightly better results are obtained with a higher starting value of $LR (0.2)$, balanced with a lower LR reduction factor (0.99) and lower patience = 5. This increases the time to search for the error minimum and also the chance of finding a lower local minimum. However, with this software, we were able to achieve a correlation coefficient of around 0.997 (at 0.999972 with PowerSolver) for internal thermal insulation and around 0.992 (at 0.9987 with PowerSolver) for external thermal insulation.

Experiments have shown that the PowerSolver software, which runs without the Adam-optimizer and starts with a higher initial learning rate (e.g., $LR = 0.5$ or even 0.8), precisely thanks to the larger steps at the higher learning rate “steers” the solution to areas with a more significant potential to contain a global minimum of the error.

Ultimately, although with more training epochs, PowerSolver achieved extremely low RMSE values and very high model correlation coefficients. Investing more computational time in training is justified because it is done once, and then its results are used many times (potentially thousands to millions of times).

Table 1: Evaluation of training with TensorSolver and PowerSolver by RMSE and correlation coefficients between target and model results.

	TensorSolver	PowerSolver
Training data	RMSE_ext: 0.14858 R^2_{ext} : 0.99247	RMSE_ext: 0.044 R^2_{ext} : 0.9987
	RMSE_int: 0.04228 R^2_{int} : 0.99942	RMSE_int: 0.008 R^2_{int} : 0.999972
Test data	RMSE_ext: 0.20586 R^2_{ext} : 0.98346	RMSE_ext: 0.063 R^2_{ext} : 0.9979
	RMSE_int: 0.08599 R^2_{int} : 0.99548	RMSE_int: 0.009 R^2_{int} : 0.999964

Table 1 shows the RMSE and correlation coefficients between the target and model results for the best models with the two software – TensorSolver and PowerSolver for external (denoted _ext) and internal (denoted _int) thermal insulation.

5. Conclusions

This development focuses on the inverse problem in thermal bridges and the use of artificial neural networks (ANN) to determine the design parameters of a thermal bridge at a known Ψ -factor. The method is innovative and can be used both in the design stage to determine the required thickness of thermal insulation and in non-invasive verification of this parameter in existing and renovated buildings. The development provides an opportunity for non-destructive measurements, which is a key point in modern construction and energy efficiency.

The solution has two separate ANNs with one hidden layer and one output each. Low RMSE values were achieved (especially for R_{int} for internal thermal insulation), indicating that the model could adapt to the input data. The high correlation coefficient (R^2) value also suggests an excellent agreement between the target and modeled values.

In future work, similar ANNs for the inverse problem in other types of thermal bridges are envisaged, and if a viable approach is identified, the solutions may be combined into a common ANN.

The significance of this development for the Balkan Peninsula and other regions with increased seismic activity, such as Southern Europe, Turkey, and others, where the need for seismically resistant structures often leads to more significant thermal bridges, should be emphasized. Artificial neural networks offer an effective approach to determining the thickness and placement of thermal insulation in such cases, especially in designing and evaluating building envelopes where thermal bridging has a significant effect. For regions with lower seismic hazards and buildings with lower Ψ values, the approach may be more difficult to implement, as the lack of significant thermal bridges makes the non-destructive measurement vaguer and less accurate.

In terms of building types, the method is particularly suitable for structures using internal insulation – a common practice in historic buildings or those with facade restrictions where external insulation placement is impossible. The internal insulation that often accompanies structures in seismically active regions increases the importance of precisely determining the parameters of thermal bridges, especially in the areas of contact between internal and external structural elements.

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Evolution of predictive analysis using GPT openai models

Mihail Mateev

Department of Computer-Aided Engineering – UACEG – Sofia, Bulgaria ¹
mikeamm_fce@uacg.bg

Abstract: Data analysis, particularly predictive analysis, has seen significant development with the emergence of modern LLMs, especially the latest GPT models. Nowadays, Generative AI is a turning point in modern industry. Many new LLMs have been available during the last several years, but an essential case is how these models are changing: what is the direction of evolution, and what can we expect from Gen AI shortly?

This study analyses different aspects of the evolution of predictive analysis systems using different LLMs: GPT 3.5 turbo, GPT-4, GPT-4o, GPT-4o1 OpenAI GPT o1.

This report includes comparative studies of predictive analysis for construction structures conducted using a comparative reference framework with different GPT models, reaching GPT-4o and GPT o1. The accuracy of the analysis on identical cases is compared. The study also compares the cost and performance of the different models. Current research will be useful for scientists, researchers, industry engineers, and businesses to estimate the cost and effectiveness of the GenAI solutions that they are going to implement and choose the right LLM for their cases and

Keywords: OPENAI, CHATGPT, GENERATIVE AI, CPT-4, GPT-4o, GPT-o1, PREDICTIVE ANALYSIS

1. Introduction

One of the main points in the new era of Generative AI, LLMs, and AI as a service, in general, is how models are changing and what the main trends in the evolution of large language models are. This paper is focused preliminary on the OpenAI GPT models, but the trend is similar for many other LLMs. The research covers the accuracy of the models and the learning curve during the adoption of GenAI technologies. The last point has to do with how easily users learn how to interact with AI.

The first OpenAI LLM generations up to GPT-3.5 focus on routine tasks. The accuracy is not very good, but these models are good for essential customer integration.

GPT-4.0 models provide options for perfect refining AI-powered customer interactions. These models are very accurate and have good interaction capabilities.

GPT-4o models bring more advanced language processing and adaptive learning. These models have no better accuracy than GPT-4.0 in a specific completion request, but they have superior capabilities to support complex business operations [2]

The current statistics on the preciseness of the OpenAI GPT models are relevant for specific cases analyzed for specific cases like problem-solving at the International Mathematical Olympiad (IMO)

Fig. 1 and Table 1 compare different GPT models (GPT-3.5 and the later models). Results demonstrated from GPT-4 models are the most accurate (in the case of mathematical tasks) compared to the other Open AI models (including also the latest one).

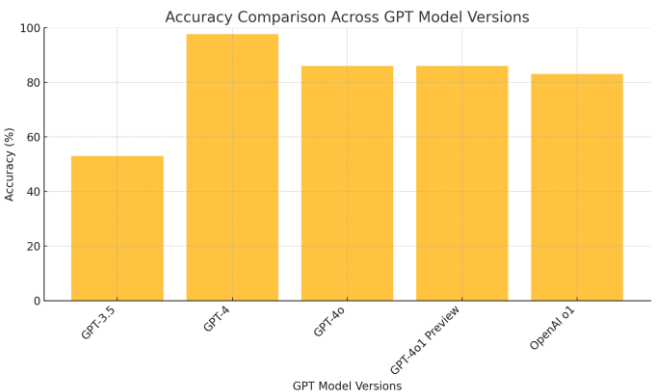


Fig.1. Accuracy Comparison Across GPT Model Versions [3]

Table 1. OpenAI Foundation GPT models The evolution of accuracy for OpenAI's language models

Model Version	Release Date	Accuracy in Specific Tasks	Notable Observations
GPT-1	June 2018	Not specified	Introduced the generative pre-training approach, setting the foundation for subsequent models.
GPT-2	February 2019	Not specified	Demonstrated significant improvements in text generation but raised concerns about potential misuse due to its ability to generate coherent and contextually relevant text.
GPT-3	June 2020	Not specified	Showed substantial advancements in natural language understanding and generation, capable of performing a wide range of tasks without task-specific training.
GPT-3.5	2022	~53%	Achieved approximately 53% accuracy in specific tasks, such as physiology and pharmacology assessments.
GPT-4	March 2023	97.6% (initially) 95.2% (updated)	Initially achieved 97.6% accuracy in identifying prime numbers. However, by June 2023, this accuracy declined to 2.4% for the same task, indicating variability in performance over time.
GPT-4o	May 2024	86%	Achieved 86% accuracy in physiology and pharmacology assessments, marking a notable improvement from earlier versions.
GPT-4o1 Preview	October 2024	86%	Maintained the improvements seen in GPT-4o, with 86% accuracy in specific assessments.
OpenAI o1	September 2024	83% (IMO qualifier)	In a qualifying exam for the International Mathematical Olympiad (IMO), o1 correctly solved 83% of problems, significantly outperforming GPT-4o's 13% accuracy on the same task.

Results from the general comparison are related to a benchmark framework used for the evaluation of LLMs. This framework includes:

- Quantitative Evaluation
- Human evaluation
- Computational Resource Analysis

- Robustness Testing (test on generalization)
- Longitudinal analysis (performance over time and model drift)

Details on the methods to evaluate and compare LLMs will be explained later in this paper.

It is important to get insights about the targets for each of the GPT models to understand why the accuracy has changed and is not only in one direction. Some of the newer GPT models are observed to have lower accuracy compared to some older ones. The directions of development for different GPT LLMs are described in Figure 2.

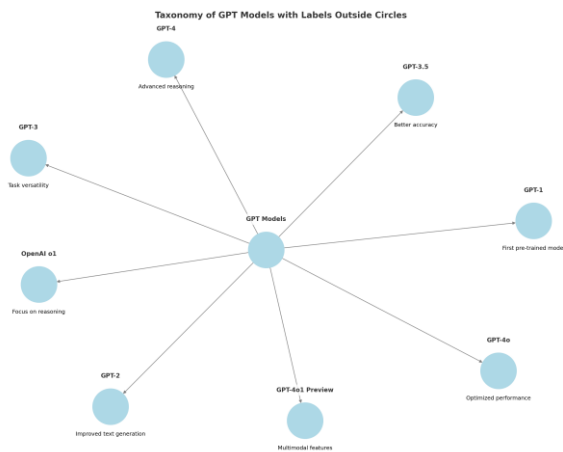


Fig.2. GPT models, including their main specifics [4]

Another important metric for LLMs is related to ease of prompting. The adoption of AI, and especially AI as a service, depends on how easily organizations can use these technologies.

Table 2. Metrics of Comparison. Ease of Prompting for Different GPT models.[5]

Metric	GPT-3	GPT-3.5	GPT-4	GPT-4o	GPT-4o1	OpenAI o1
Instruction Following	70%	85%	95%	88%	90%	92%
Few-shot Learning Ability	Medium	High	Very High	High	Very High	Very High
Tolerance to Ambiguity	Low	Medium	High	Medium	High	Medium
Response Coherence	Medium	High	Very High	High	Very High	Very High
Prompt Robustness	Medium	High	Very High	Medium	High	High
Overall Ease of Prompting	65%	80%	90%	85%	88%	86%

The main KPIs include:

- Instructions Following: measures the ability of the models to interpret detailed or ambiguous instructions
- Few-shot Learning Ability: shows how well the model adapts to examples provided in the prompt.
- Tolerance to Ambiguity: this metric demonstrates how well the model handles unclear and imprecise prompts.
- Response Coherence: considers how logically consistent and fluent the output is relative to the prompt

- Prompt Robustness: shows how well the model deals with noisy or suboptimal prompts.
- Overall Ease of Prompting: A combined score reflecting all the above factors

The last essential group of metrics that is needed to compare OpenAI LLMs is related to the pricing. Table 3 demonstrates the current pricing (December 2024) for different OpenAI GPT models

Table 3. OpenAI Foundation GPT models pricing

Model	Context Window (tokens)	Pricing
GPT-3	4K	\$0.02 per 1K tokens
GPT-3.5	16K	\$0.015 per 1K tokens
GPT-4	8K	\$0.03 per 1K tokens
GPT-4o	128K	\$0.005 per 1K input tokens; \$0.015 per 1K output tokens
GPT-4o mini	128K	\$0.00015 per 1K input tokens; \$0.0006 per 1K output tokens
OpenAI o1	128K	\$0.015 per 1K input tokens; \$0.06 per 1K output tokens
OpenAI o1-min	128K	80% cheaper than OpenAI o1

The main KPIs are described below:

- Context Window: this parameter is related to the maximum number of tokens used for the model in a single interaction.
- Pricing: Reflects the cost per 1,000 tokens processed, with distinctions between input and output tokens for certain models.

LLMs, and especially OpenAI GPT models, can be applied to various kinds of analysis.

- Descriptive analysis
- Diagnostic analysis
- Predictive analysis
- Prescriptive analysis

Descriptive analysis focuses on examining and summarizing data to provide insights into the current state of a specific situation. This type of analysis helps to interpret, visualize, and summarize data, often serving as a foundation for other analytical approaches. It is particularly well-suited for Computer Vision, as it can interpret and convey the meaning of images or videos. While it can leverage various technologies, using AI-powered solutions makes extracting metadata from diverse types of digital content significantly more efficient and manageable.

Diagnostic analysis is analyzing the root causes of something that happens (for example, construction failure). Descriptive metadata from images and videos can be critical in explaining why something (events, behaviors, outcomes) happened. It works together with descriptive analysis to get information describing the case and find the main reason for having a specific situation.

Predictive analysis focuses on forecasting future events or outcomes by leveraging various data inputs. This type of analysis can be enhanced with AI, either as a standalone analytical solution or through a hybrid approach integrating AI elements. Predictive analysis can be implemented using various Large Language Models (LLMs) such as GPT, DALL-E, DAVINCI, and WHISPER. One major scenario is related to the analysis of images and video content, where other AI technologies like Computer Vision often

play a critical role in extracting the necessary information to serve as input for predictive analysis. The predictions are then generated using suitable LLMs that analyze the metadata derived from Computer Vision processes. This scenario will be discussed later in chapter 3 of the paper.

Prescriptive analysis provides actionable recommendations for future decisions based on the outcomes of predictive analysis. It leverages statistical algorithms, machine learning techniques, and other AI-driven solutions to determine the optimal next steps in a given situation.

This research is focused on how different GPT models perform in scenarios related to predictive analysis. The comparison covers some of the latest GPT models, included in real-life scenarios for structure maintenance and prediction.

The next chapter explains the prerequisites to design and implement the PoC used for the experimental research.

2. Prerequisites and means for solving the problem

This paper covers the following areas:

- Design and implementation of Predictive Analysis based on Computer Vision using OpenAI
- Democratization of the implementation of flows, providing Predictive Analysis with OpenAI and Power Automate (Low Code/No Code)
- Analyze the results (preciseness and correctness, ease of prompting, and price) based on sample data (photos of structures and construction schema).
- Options to optimize the cost and performance
- A reference comparison between general performance, ease of use, and pricing metrics and the specific one for scenarios with predictive analysis is needed to analyze if general trends are valid for prediction use cases.

The current research uses a reference framework to implement solutions with a short time to market, analyze cases from images and video, and provide predictive analysis to implement predictive maintenance and decrease the overall maintenance cost for different structures in the construction industry.

The overall schema explaining different types of analysis and related AI technologies, Computer Vision, and Open AI is demonstrated in Fig.3

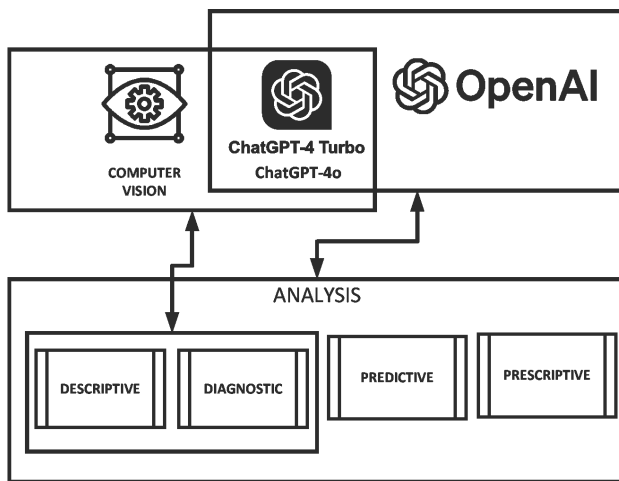


Fig. 3. Implementation of different types of analysis using Computer Vision, Open AI – general dependencies

2.1 Areas of Optimization for Solutions Using AI as a Service

Modern solutions stay more integrated with AI services that are used as a service. This approach makes the performance and cost optimization more complex and challenging. It is not enough to know the best-performing services in a sandbox environment.

Optimization of analysis is considered in three primary directions:

- 1) Improving the preciseness
- 2) Performance optimization
- 3) Cost optimization

The first is mainly related to solution design, decomposition, and a combination of analysis based on different AI-related technologies. The general performance uses, in addition to architectural patterns and a mixture of AI and Analytics technologies, to provide faster and cheaper solutions on a scale. In this aspect, the best-performing standalone AI services are not always components of the best-performing solution, solving specific problems. LLM Optimization directions are shown in Fig. 4.

This article's primary focus is on performance metrics related to image analysis for Predictive Analysis for Construction using OpenAI with Computer Vision, described in [7]. The concept is also applicable to a variety of different cases from different domains.

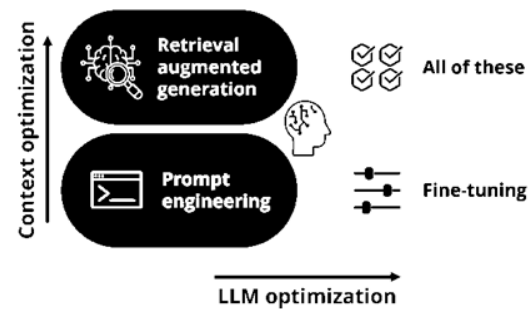


Fig. 4.. LLM Optimization stages [8]

The research covered a comparison between different OpenAI GPT models, working in a solution for predictive analytics based on OpenAI and Computer Vision, including RAG and fine-tuning. Details on the experimental setup are explained in the next chapter of this paper.

3. Solution of the examined problem

The main focus is on solving similar cases for Predictive Analysis for Construction using OpenAI with Computer Vision. Generative AI needs a very well-described case to generate a valuable answer. In the experimental solutions,

The subject of the research is to analyze the effect of using different concepts for improvement of performance and cost efficiency for image analysis, based on Open AI multi-modal LLMs (GPT-4, GPT-4o, GPT-4o1). GPT-3.5 is not applicable because it doesn't support image analysis.

The experimental environment uses configuration with GPT, Computer Vision, and Promptly.ai [9], RAG, and fine-tuning.

3.1 Implementation of Analysis based on Computer Vision and OpenAI/ChatGPT

The experimental setup includes a module for case decompositions based on Digital Twins (DT) on Azure (Azure Digital Twins / ADT). ADT is used to manage the overall context from the observed solution, decompose the case, and unify the analysis case, converting it from domain-specific to domain-agnostic subcases suitable for LLM analysis.

One high-level schema of the solution is presented in Fig. 5

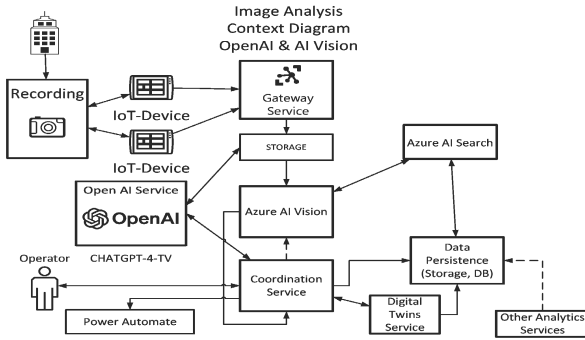


Fig.5. Experimental Setup: Predictive analysis using Image Analysis with Computer Vision Open AI LLM

The coordination service helps create and ask questions that clarify the search and allow the OpenAI service to provide the right solution. Digital Twins (DT) is a part of the solution that can be skipped if there is no decomposition of complex tasks. The coordination service is based on Low-code/No-code: Power Platform (Power Automate) for PoC. For analysis, sample data of rusty construction components from the USA, like the one in Fig. 6 :



Fig.6. Sample image of steel construction with corrosion

4. Results and discussion

In this paper, metrics related to the experimental project PoC are added and realized using Microsoft Azure, OpenAI, ten videos, and 2000 experimental images.

Test experiments are provided by deploying the test environment and LLM models in the Central Sweden Azure Region. The existence of all components in the same cloud region minimizes the variations in the latency based on the connectivity between different solution components (except Power Automate). Detailed results are shown in Table 4.

Table 4. OpenAI Foundation GPT models pricing

LLM	AI Vision	images	videos	success rate	time image[s]	time video[s]	RAG
GPT-4	no	2000	10	98.1%	540	790	no
GPT-4	no	2000	10	98.1%	298	710	yes
GPT-4	yes	2000	10	99.2%	540	780	no
GPT-4	yes	2000	10	99.2%	298	661	yes
GPT-4o	no	2000	10	98.2	278	410	no
GPT-4o	no	2000	10	98.2	188	340	yes
GPT-4o	yes	2000	10	99.4	278	399	no
GPT-4o	yes	2000	10	99.4	188	320	yes
GPT-4o1	no	2000	10	99.2	274	408	no
GPT-4o1	no	2000	10	99.5	187	338	yes
GPT-4o1	yes	2000	10	99.6	274	396	no
GPT-4o1	yes	2000	10	99.6	187	317	yes

5. Conclusions

The provided experiments demonstrate a list of dependencies and trends, explained below:

Predictive analysis can effectively use Open AI and AI-based image analysis to solve cases related to construction predictive maintenance.

Azure AI Vision for object detection provides relatively small additional precision, increasing the correctness of the description by up to 2-3%, but it has a higher impact on overall performance and cost reduction related to image analysis with LLM.

The overall analysis offered by automation solutions can effectively solve complex cases even on the PoC level using both custom and Low-Code/No-Code solutions. The approach is domain-agnostic and can be used in different business domains.

Cost and performance optimization rely on many factors. It depends on the specific LLM, but on a more significant level, and it can be improved up to several times using prompt optimization, Retrieval Augmented Generation (RAG), and fine tuning, especially for the analysis of complex images and videos.

The cheapest implementation is based on GPT-4o, but the best-performing solution is based on GPT-4o1, despite the fact that the in-sandbox GPT-4 performs better than other GPT models.

6. Future work:

Research will be extended based on more complex cases and improved MML models. The major focus will be to propose the best framework, such as LLM models and solution design, for real-life prediction and maintenance cases related to manufacturing systems.

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Класификация на безпилотни летателни средства

Магдалена Гарванова, Иван Гарванов

Университет по библиотекознание и информационни технологии, София, България

m.garvanova@unibit.bg, i.garvanov@unibit.bg

Резюме: През последните години безпилотните летателни апарати (БЛА), известни още като дронове, придобиха значителна популярност. Тяхното разнообразие по отношение на техническите характеристики оказва влияние върху приложението им в практиката. Те се използват както за военни, така и за граждански цели. В статията се прави анализ и класификация на дроновете по техните характеристики, физически параметри и приложение. Специално внимание е отделено на гражданските дронове, а тези с военна употреба са разглеждани в по-общ аспект.

Ключови думи: БЛА, видове дронове, приложение на дроновете в практиката

1. Въведение

Безпилотните летателни апарати (БЛА), известни още като дронове, са управляеми летателни апарати без пилот [1]. Те може да се управляват дистанционно или притежават системи за автономно управление. Съществуват най-различни видове безпилотни летателни апарати, имащи две основни разделения в зависимост от тяхното крило: дронове с неподвижно крило и с ротационни (въртящи се) крила. Има и дронове, движещи се по земната повърхност и такива, които плават по или под вода. Тези дронове се наричат и *роботи*. Идеята за създаването на радиоуправляеми устройства възниква още през 1898 г. от световноизвестния учен Никола Тесла, който за първи път използва радиосигнал за управление на лодки [2]. В настоящата статия се разглеждат само въздушните безпилотни летателни апарати, които намират широко приложение за откриване и проследяване на обекти, обществена сигурност, видеонаблюдение на пътен трафик, военни операции, проучване на скрити или опасни зони, навигация на открито и закрито, атмосферни наблюдения, операции след бедствия, здравеопазване, споделяне на данни, управление на инфраструктурата, справяне с извънредни ситуации и кризи, товарен транспорт, мониторинг на стихийни пожари и логистика [3].

Работоспособността и приложимостта на БЛА зависят от ограничената издръжливост на батерията, ограничената подвижност, ограничената автономия и ограничената продължителност на полета. Времетраеността на полета се дължи на различни фактори, включително тежки атмосферни условия, размер на фиксираното крило и издръжливост на батерията. Безпилотните летателни апарати притежават и слабости, които ограничават тяхното използване в практиката. Съществуват проучвания, посветени на оценката на уязвимостите, атаките и заплахите на БЛА, като се предлагат решения за преодоляване на тези трудности, като например използване на висококачествени устройства за комуникация, качествени батерии, аеродинамична геометрия, високотехнологични материали, надеждни двигатели и др. [4, 5, 6].

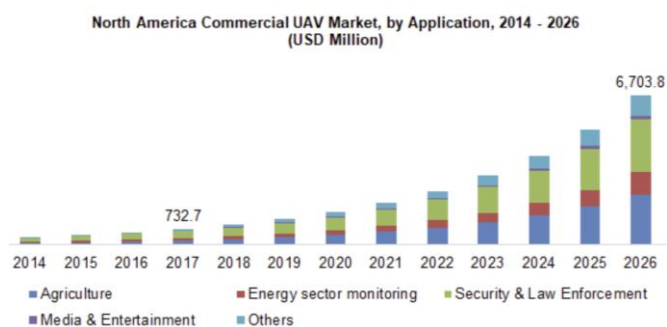
БЛА се управляват лесно и притежават висока маневреност. Те се различават по конфигурация, размер, обхват на полета, тегло, тип двигател и експлоатационни характеристики. В литературата се срещат различни класификации на безпилотните летателни апарати според различни параметри като конфигурация, тип, тегло, обхват и размер на двигателя [7, 8].

В настоящата статия се предлага класификация на въздушните безпилотни летателни апарати според техните технически характеристики и тяхното приложение в практиката.

2. Развитие на пазара на БЛА

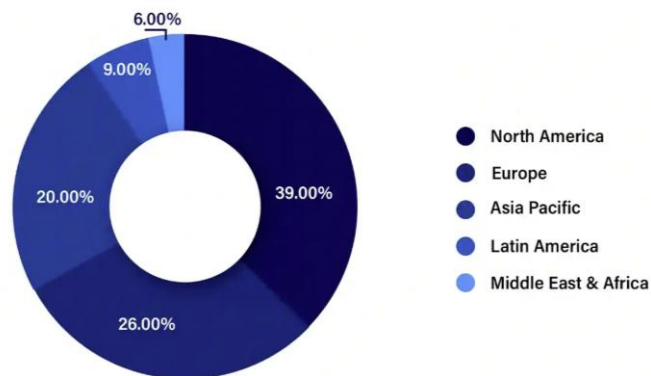
През последните години се забелязва увеличаване на приложението на БЛА както за военни, така и за граждански цели. На фигура 1 е показана динамиката на пазара на комерсиални

БЛА в САЩ по сектори на приложение, като се очаква тяхното потребление да се увеличава в бъдеще.



Фиг. 1. Търговски пазар в млн. долари на безпилотни летателни апарати в Северна Америка (2014-2026) [9]

В края на 2023 г. Северна Америка притежава най-големия пазарен дял в световен мащаб, както е показано на фигура 2, но в следващото десетилетие се очаква азиатско-тихоокеанският регион да изпревари Северна Америка.



Фиг. 2. Пазарен дял на комерсиални дронове в световен мащаб към края на 2023 г. [10]

Динамичното развитие на БЛА изисква бързо да се създадат правила, разпоредби и насоки от авиационната администрация за тяхното законно и безопасно използване от бизнеса.

3. Класификация на БЛА

Безпилотните летателни апарати се предлагат с различни технически параметри, оборудват се с разнообразни сензори и апарати и намират широко приложение в заобикалящия ни свят.

Според вида на управление БЛА биват с ръчно-дистанционно управление или автоматично управление чрез сензори, микропроцесори и други електронни приспособления

[11]. Дроновете комуникират на къси и дълги разстояния посредством безжични технологии.

В зависимост от начина на летене дроновете се класифицират като роторни, с фиксирано крило и хибридни. Дроновете, които се задвижват с двигатели (ротори) и нямат фиксирани крила, се наричат *роторни дронове*. Тези дронове са най-разпространената категория дронове. Предимството на тези дронове е, че могат да излитат и кацат вертикално. Също така те могат да останат във въздуха сравнително неподвижни (зависват) за дълъг период от време. Като недостатък на тези дронове е ограничената продължителност на полета, която зависи от издръжливостта на тяхната батерия. Също така те имат сериозно ограничение в скоростта на движение. В зависимост от броя на роторите тези дронове притежават специфични характеристики, от които зависи и тяхното приложение в практиката. На пазара БЛА присъстват с различен брой ротори или витла, както е показано в таблица 1 [12].

Таблица 1. Категории безпилотни летателни апарати въз основа на броя на роторите

Брой ротори	Видове БЛА	Характеристики
1	Монокоптер	Големи витла, много ефективни, висока товароподемност, но са скъпи и нестабилни (силни вибрации)
2	Бикоптер	Нестабилни, малка подъемна сила
3	Трикоптер	Нестабилни, маневрени
4	Квадрокоптер	Стабилен полет, лесно управление, продължителен полет
6	Хексакоптер	Стабилен полет, лесно управление, летят и при отказ на двигател, скъпи, голяма товароподемност
8	Октокоптер	
m	Мултироторни	

Дроновете с фиксирано крило са подобни на самолетите. Те се движат само напред, използват подъемната сила на крилата си, могат да развиват по-високи скорости и изминават по-далечни разстояния. Излитането им изисква специална установка, а за кацането е необходима писта. Основният им недостатък е в това, че не могат да излитат и кацат вертикално, както и да се задържат на едно място във въздуха. Задвижването им се осъществява от двигател, който в повечето пъти е ротор, но може да се използват и газови двигатели.

Хибридните дронове се срещат по-рядко в практиката, но те обединяват горните технологии, като използват предимствата на крилото и многото ротори. Те съчетават предимствата и на двата вида дронове. Хибридни са и дроновете с алтернативни източници на хранване като бензиново-електрически и др. За момента обаче са по-скъпи и са по-трудни за управление.

4. Характеристики на БЛА

4.1. Скорост и продължителност на полет

По-малките безпилотни летателни апарати могат да летят със скорост по-малка от 15 м/сек, докато големите могат да летят със скорост до 100 м/сек. Продължителността на полета на дрона зависи от количеството енергия в батерията, както и от размера, теглото и метеорологичните условия. Големите БЛА могат да летят с часове, докато по-малките летят за ограничено време от 20-30 минути.

4.2. Полезен товар

Полезният товар, който може да бъде повдигнат и носен от БЛА, варира от няколко грама до стотици килограма. По-голямата товароподемност се постига за сметка на по-краткото полетно време, високата консумация на батерията и по-голям размер на дрона. В повечето случаи полезният товар представлява сензори, видеокамери и др.

4.3. Обхват и надморска височина на полета

Обхватът на полета на БЛА зависи от разстоянието, до което може дистанционно да се управлява дронът. Той варира от няколко метра за малките дронове до стотици километри за по-големи дронове. От друга страна, надморската височина на полета се отнася до височината, на която БЛА може да лети. Таблица 2 представя категоризация на безпилотните летателни апарати въз основа на височината на полет.

Таблица 2. Категоризация на БЛА по височина на полета [4]

Категория	Макс. прод. на полета (ч)	Надморска височина на полета (м)	Обхват (км)	Маса (кг)
Ниска надморска височина, малка времетрайност на полета	0.5–1	50–900	>250	250–2500
Ниска надморска височина, голяма времетрайност на полета	>24	<3000	>500	15–25
Средна надморска височина, голяма времетрайност на полета	24–48	>3000	>500	1000–1500
Висока надморска височина, голяма времетрайност на полета	24–48	20,000	>2000	2500–5000

Дроновете могат да се оборудват с различна помощна апаратура като: навигационна система за определяне на местоположението (GPS), сензори, стабилизатори, камери и др.

4.4. Области на приложение в зависимост от оборудването

Областите на приложение на дроновете зависят както от техническите им параметри, така и от апаратурата, с която са оборудвани. Развитието и усъвършенстването на сензорите води до непрекъснатото предлагане на нови видове услуги и появата на различни приложения за безпилотни операции.

4.4.1. Военно предназначение

Безпилотните летателни апарати играят съществена роля във военните мисии за наблюдение. Няколко държави са добавили безпилотни летателни апарати в своите отбранителни стратегически планове. Държавите използват тези летящи роботизирани машини за откриване на врага, борба с браконьерството, граничен контрол и морско наблюдение на важни морски пътища. Евтините, надеждни и гъвкави (приспособими спрямо условията и ситуацията) безпилотни летателни апарати понастоящем имат значителен принос във въздушното разузнаване, наблюдението и проучването на всяка територия, за да се предотврати каквато и да е незаконна дейност [13]. Например, наблюдението с дронове може да открие всяко движение и заплаха в зони с ограничен достъп. БЛА може да предостави тези услуги, като регистрира автоматично предупреждение с минимална човешка намеса.

Военните дронове се категоризират въз основа на тяхното тегло, обхват на полета, скорост, както и специфичните им възможности. НАТО използва класификация според Министерството на отбраната на САЩ и разделя дроновете в три класа, както е показано в таблица 3 [7].

БЛА от клас I, тъй като са по-малки по размер, обикновено са преносими, пускат се ръчно и се управляват от отделен

контролер. Обикновено имат обхват по-малък от 20 мили и издръжливост до два часа. Те са подкатегоризирани като микро, мини и малки.

БЛА от клас II са средно големи тактически системи, които могат да летят до 10 000 фута над нивото на земята (AGL) с радиус на мисията от 200 километра (линия на видимост).

Таблица 3. Класификация на НАТО на БЛА [7]

Клас	Категория	Максимален обхват на летене	Максимална височина на полета
I. < 150 кг	Микро	До 5 км	До 200 м
	Мини	До 5 км	До 3000 м
	Малки	До 50 км	До 5000 м
II. от 150 кг до 600 кг	Тактически	До 200 км	До 10 км
III. > 600 кг	Дълга издръжливост на средна височина	Неограничен	До 45 км
	Дълга издръжливост на голяма височина	Неограничен	До 65 км
	Боев	Неограничен	До 65 км

От друга страна, клас III БЛА с фиксирани крила, за разлика от клас I, изисква писти за излитане и възстановяване и допълнителна логистична поддръжка и инфраструктура. Те също така имат повече съображения за управление на въздушното пространство, сравними с пилотираните самолети. БЛА от клас III включват самолети за дълга издръжливост на средна височина и самолети за дълга издръжливост на голяма височина.

4.4.2. Цивилно предназначение

БЛА се използват за получаване на изображения с висока разделителна способност на отдалечени райони, острови, планински върхове и брегови линии и др. [14]. Благодарение на БЛА се подобряват значително данните от дистанционно наблюдение за сравнение с космическите и наземните данни, получени от сателити. Ниските разходи и подходящи характеристики на безпилотните летателни апарати предлагат качествено наблюдение с висока времева и пространствена разделителна способност. Възможностите за дистанционни изследвания от безпилотни летателни апарати подпомагат мониторинга на качеството на водата, мониторинга на сушата, нефта и газа, оценки за добива, хидроложкото моделиране, опазването на биологичното разнообразие, геоложките проучвания, бедствия, наблюдението на терени, картографирането на горите и мониторинга на културите. Тази технология се използва и за картографиране и създаване на 3D карти, както и картографиране на археологически обекти. Използването на БЛА в дистанционните изследвания с различно приложение е показано на фигура 3.

Търсене и спасяване

Безпилотните летателни апарати са от основно значение в критични сценарии като справяне с бедствия и спасителни операции. Те могат да ускорят операциите по търсене и спасяване в критични ситуации като откриване на загубени хора, лица, пострадали от лавини, пожари, земетресения и др. БЛА могат да доставят медицински продукти, хранителни стоки, дрехи, вода и всякакви необходими продукти на бедстващи хора в недостъпни райони преди пристигането на спасителните екипи.

Прецизно земеделие

БЛА, оборудвани с подходящи сензори и камери, могат да наблюдават здравето на културите по отношение на растителното покритие, нивото на хлорофила и температурата

[15]. Безпилотните летателни апарати се използват в прецизното земеделие за събиране на данни от наземни прибори и устройства относно качество на водата, свойства на почвата, влага и др., пръскане с пестициди, откриване на болести и вредители, планиране на напояването, оценка на заплевеността и наблюдение на хода на развитие на културите.

Дистанционните изследвания от безпилотни летателни апарати играят ключова роля в прецизното земеделие, осигурявайки данни относно състоянието, развитието и нуждите на културите въз основа на данни и изображения с висока времева, пространствена и спектрална разделителна способност. Безпилотните летателни апарати могат да окажат значително въздействие върху селскостопанското производство чрез извършване на интелигентно въздушно картографиране. Получените от БЛА изображения могат да се използват за изследване на болести по растенията и оценка на растителния стрес.



Фиг. 3. Приложение на БЛА за дистанционни изследвания

Мониторинг на движението по пътищата в реално време

БЛА е нов обещаващ инструмент за събиране на данни за пътната обстановка по магистралите. За разлика от конвенционалните устройства за наблюдение като микровълново оборудване, камери за видеонаблюдение и детектори за контури, дроновете могат да наблюдават огромни пътни участъци [16]. Те могат да бъдат управлявани от местната полиция, за да получават ясна представа относно пътнотранспортните произшествия или за бързото откриване на издирвани превозни средства. Дронът може да се използва и за определяне на скоростта на дадено превозно средство. Безпилотните летателни апарати могат да се използват за наблюдение както на пътните условия, така и за мониторинг на пътната настилка с цел навременно откриване на пукнатини и дупки по нея.

Архитектура, геодезия и строителство

Картографирането, както и наблюдение на археологически или строителни обекти е възможно с помощта на безпилотни летателни апарати. Мониторингът на археологически или строителни обекти от началото до края гарантира качествен напредък на работата. Това може да включва доклади, съдържащи изображения, видеозаписи и 3D картографиране за евентуалните заинтересовани страни. Използваните в БЛА технологии могат значително да подпомогнат инспекцията на инфраструктурата при строителството. Дроновете предлагат голяма помощ при геодезични заснемания, предоставят богата визуална информация за създаване на цифрови карти и 3D модели на повърхността, както и на различни обекти и сгради.

Фото- и видеозаснемане

Дроновете, включително любителските, масово се използват за фото- и видеозаснемане от „птичи поглед“ [17]. Благодарение на тази фотография се получава нова гледна точка за заобикалящата среда. Бързото развитие на съвременните фотоапарати и видеокамери, както и възможността за високоскоростен пренос на данни чрез безжична технология дава възможност в реално време да се добие представа за околния свят. Дроновете са удобни за заснемане на спортни дейности и състезания, като предоставят различна визуална перспектива. За високото качество на изображенията е необходимо дроновете да са снабдени с автопилоти и модули за позициониране и навигация. Много често тези дронове са оборудвани с технологията „Следвай ме“ и гарантират стабилизация на камерата при непрекъснато поддържане на фокуса върху действието.

Пренос на товари

В зависимост от техническите параметри на дроновете те притежават различни товароподемни възможности и могат да доставят товари на различни разстояния. Компании като Amazon, Google и други успешно използват дронове за пренос на пратки и доставки на стоки и услуги. В паралел с доставките на пощенски и търговски пратки се забелязва и приложението на дронове за пренос на незаконни стоки като наркотици, оръжие и др.

Мониторинг и инспекция на съоръжения и инфраструктура

Дроновете позволяват да се осъществява по-бърз и евтин мониторинг и инспекция на труднодостъпни съоръжения и инфраструктурни обекти като кули, комини, антени, електропроводи, ветрогенератори, фотоволтаични централи, мостове, пътна- и ЖП инфраструктура и др. Навременното откриването на неизправности и предотвратяването на аварии от критичната инфраструктура би спестило огромни средства, както и би предотвратило инциденти с фатален край.

Дронове за забавление

Немалка част от употребата на дронове се отнася до забавление. Тези дронове са евтини и лесни за употреба. Те са предимно малки, нано и мини дронове. Подходящи са за начинаещи поради ниската си цена и малки размери. В повечето случаи са снабдени с камери за видеозаснемане.

4. Заключение

От направения анализ и класификация на съществуващите дронове се вижда, че те навлизат масово в дейността и живота на хората, като предлагат неограничени възможности за приложение. Възможността им да летят както с висока скорост, така и да зависват във въздуха увеличава тяхното приложение в практиката. Те за незаменим помощник в критични ситуации и позволяват бърза реакция при кризи, като намират приложение както за военни, така и за граждански операции. Представеното изследване не претендира за изчерпателност, а е по-скоро опит за класификация на една бързо развиваща се индустрия с неограничени приложения.

Благодарности

Статията е реализирана по проект „Иновативни методи и алгоритми за откриване и разпознаване на подвижни обекти чрез интегриране на хетерогенни данни“, КП-06-Н 72/4/05.12.2023, финансиран от ФНИ-МОН.

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Откриване на подвижни обекти чрез космически радиосигнали

Иван Гарванов¹, Магдалена Гарванова¹, Никола Петров²

¹Университет по библиотекознание и информационни технологии, София, България

²Институт по астрономия с НАО, София, България

i.garvanov@unibit.bg, m.garvanova@unibit.bg, nick@astro.bas.bg

Резюме: В статията се изследват възможностите за откриване на летящи обекти с радарна система с пряко разсейване на сигнала, използваща космически радиосигнали, излъчени от космически тела като Слънце, пулсари и др. Тази възможност е оценена, като са определени стойностите на отношението сигнал към шум на входа на сигналния откривател, изчислени в зависимост от честотата на сигнала, размера на обекта и разстоянието от приемника до обекта в момента на пресичане на базовата линия на радара под приблизително прав ъгъл.

Ключови думи: откриване на подвижни обекти, обработка на сигнали, радар с пряко разсейване на сигнала

1. Въведение

Радарът с пряко разсейване (Forward Scatter Radar – FSR) е специфичен вид пасивен бистатичен радар, който притежава някои съществени предимства в сравнение с моностатичния радар. Работата на тези радари се основава на прилагането на ефекта на пряко разсейване (Forward Scatter – FS) [1]. Този ефект се появява, когато даден обект е облъчен от сигнал и линейните му размери са много по-големи от дължината на вълната на сигнала. В този случай енергията на сигнала се разсейва в резултат на дифракционния ефект на вълната. В близост до обекта се формира зона на радиосвянка, а в далечната зона от обекта се получава увеличаване на енергията, разсеяна по линията „предавател-приемник“. В резултат на този ефект се получава многократно увеличаване на ефективно отразяващата площ на обекта (Radar Cross Section – RCS) в сравнение с RCS на обекта в традиционния моностатичен радар [2, 3]. Една от характеристиките на системата FSR е наличието на силен директен сигнал от предавателя, който трябва да бъде потиснат преди откриването на обекта. Напоследък бистатичните FSR радари, използващи естествени или изкуствени източници на космически сигнали (сателити, пулсари и др.) предизвикват особен интерес [4, 5, 6].

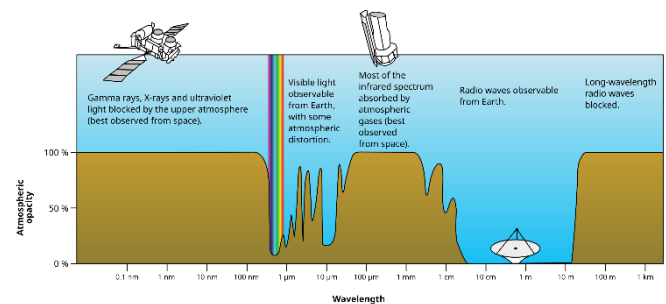
През последните години наблюдението на космоса и защитата на Земята от нежелани космически обекти се осъществява от почти всички технологично развити държави с помощта на телескопи и радиотелескопи. За съжаление превантивното откриване на големи и малки летящи космически обекти с наличните технически средства като радари, телескопи и радиотелескопи не е достатъчно ефективно, тъй като се откриват около 30% от прелитащите обекти [7, 8]. Като цяло се забелязва тенденция на по-честото използване на FSR системи за откриване на подвижни обекти, включително и за космически обекти. С цел да се увеличи процентът на откриване на различни космически обекти, ние предлагаме да се прилагат принципите на FSR система, използваща естествени космически сигнали като Слънце, пулсари и др. В [9] се предлага използването на FSR система за защита на Земята от нежелани космически обекти, където източник на сигнали са радиопулсарите и/или изкуствените сателити.

Идеята на тази статия е теоретично да се изследва възможността за откриване на летящи обекти от FSR система, която използва космическо радиолъчение. В такава FSR система източник на радиоизлъчване може да бъде Слънцето, пулсар или друг източник на космическо радиоизлъчване, а за наземен приемник да се използва радиотелескоп. Изборът на Слънцето за източник на радиоизлъчване има много предимства. Сигналите от него са много мощни, излъчването е в широк честотен диапазон, както и възможността да се работи през деня, когато телескопите са неизползваеми.

2. Космически радиоemisии

В космоса има тела, които излъчват сигнали в широк честотен диапазон. Такива излъчвания са Слънцето, пулсарите

и много други космически тела. Излъчените сигнали се характеризират с висока мощност и могат да преминат разстояния от порядъка на десетки слънчеви години. Част от тези сигнали достигат и до Земята, като земната атмосфера отразява, абсорбира или разсейва повечето електромагнитни лъчения. Въпреки това има прозорци в честотния диапазон, през които преминават космически сигнали и достигат повърхността на Земята. Тези прозорци са във видимия диапазон в части от инфрачервената зона, както и в радиочестотната област (включително някои честоти, класифицирани като микровълнови). Тези прозорци са показани на фиг. 1. Благодарение на тях учените наблюдават космоса от Земята и изследват сигналите, идващи от дълбокия космос.

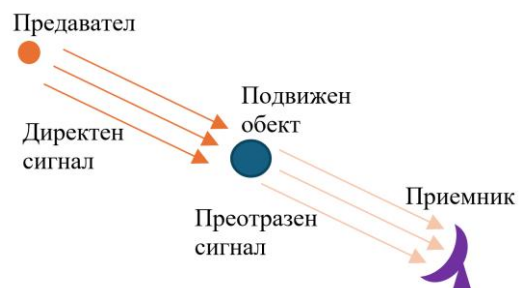


Фиг. 1. Непрозрачност на земната атмосфера, взета от НАСА

От фигура 1 се вижда, че слънчевите и пулсарните излъчвания могат да се използват за откриване на подвижни обекти в радиосистеми, прилагащи принципа на пряко разсейване на сигнала.

3. Радар с пряко разсейване

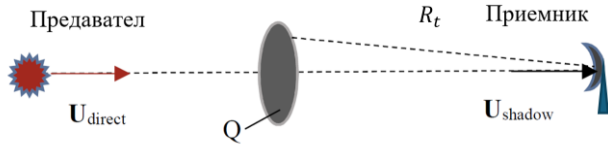
Радарът с пряко разсейване е специфичен вид бистатичен радар, при който предавателят и приемникът са разнесени в пространството, но ефектът на пряко разсейване се появява, когато бистатичният ъгъл между предавателя, обекта и приемника клони към 180 градуса. Този ефект се получава, когато обект пресича базовата линия между предавателя и приемника. Конфигурацията на този вид радар е показана на фигура 2, където източникът на сигнал ще бъде Слънцето или неутронна звезда (пулсар).



Фиг. 2. Конфигурация на радар с пряко разсейване

4. Теоретичен разчет на характеристиките на радар с пряко разсейване

Радарните системи, използващи космически сигнали, генерирани от Слънцето, пулсари или други източници на радиосигнали използват като приемник радиотелескопи. При липса на обект на базовата линия „предавател-приемник“ в приемника се получава директен сигнал от космоса U_{direct} . Ако някакъв обект пресече базовата линия „предавател-приемник“, то директният сигнал U_{direct} ще е изцяло или частично блокиран от обекта (фиг. 3).



Фиг. 3. Топология на експеримента

В този случай блокираният сигнал на входа на приемника U_{Rx} може да бъде представен като сума от директен безпрепятствен сигнал U_{direct} и блокиран (сенчест) сигнал U_{shadow} [7]:

$$U_{Rx} = U_{direct} + U_{shadow} \quad (1)$$

Съгласно принципа на Babinet, директното лъчение U_{direct} и блокираният сигнал U_{shadow} , създадени от непрозрачен обект, имат противоположни фази. Според теорията на физическата оптика, математическо описание на полето на сенките, което се създава от обекта, се основава на дифракцията на Кирхоф-Френел [10]:

$$U_{shadow} = j/\lambda \iint_Q U_{direct} \frac{\exp(-jkR_t)}{R_t} dq \quad (2)$$

В (2) Q е площта на силуета на обекта, dq е малка част от площта на силуета на обекта, R_t е разстоянието от обекта до приемника. Според [1] полето на сянката не зависи от формата или материала на засенчващия обект, а се определя изцяло от размера и геометрията на силуета на обекта. Когато обектът е достатъчно далеч от предавателя и приемника (далечна дифракционна зона), може да се приеме, че: (i) – директното поле U_{direct} от предавателя е разпределено равномерно върху площта на силуета на обекта; (ii) – стойността на разстоянието R_t почти не се променя при промяна на позицията на dq върху площта на силуета на обекта. В далечната зона на дифракция интегралът (2) приема формата:

$$U_{shadow} = \frac{j \exp(-jkR_t)}{\lambda R_t} U_{direct} \iint_Q dq \quad (3)$$

След интегрирането уравнението (3) приема формата:

$$U_{shadow} = \frac{j \exp(-jkR_t)}{\lambda R_t} U_{direct} Q \quad (4)$$

От (4) следва, че обвиващата на сенчестия сигнал е:

$$|U_{shadow}| = E_{shadow} = \frac{E_{direct} Q}{\lambda R_t} \quad (5)$$

Радарът с пряко разсейване използва сигнала зад обекта (сянката) за откриване на обекта. Мощността на директния сигнал обаче е много по-силна от сигнала в сянката. Следователно, когато се обработва входният сигнал е необходимо да се премахне (компенсира) директният сигнал от входния сигнал или да се разделят директните и сенчестите сигнали по честота и след това да се използва амплитудата (мощността) на сенчестия сигнал за откриване на обекта. Общата блокова схема на предлаганата в статията обработка на сигнала в FSR система е показана на фиг. 4. Използването на ефекта на пряко разсейване на сигнала предполага местоположението на приемника (радиотелескопа) да се намира от другата страна на обекта спрямо предавателя (космическото тяло). Радарите с пряко разсейване имат малка зона на наблюдение, която е в близост до базовата линия между предавателя и приемника. От друга страна те не притежават разделителна способност по разстояние, но както

всяка радарна кохерентна система притежават Доплерова разделителна способност и могат да откриват и разделят целите по скорост.



Фиг. 4. Блокова схема на алгоритъма за обработка

В статията се разглежда случаят, когато бистатичният ъгъл е около 180 градуса, което е най-благоприятният случай и ефективно отразяващата повърхност е максимална. За извличане на полезния за нас сигнал, създаден след контакта му с обекта (сенчест сигнал), могат да се използват методите за моделиране и компенсация на сигнала, както и времева и/или честотна селекция на сигнала.

Един от най-важните параметри, който характеризира всеки естествен източник на радиосигнал, е спектралната плътност на потока, измерваща се в Янски. Мощността на един Janski (Jy) е еквивалентна на 10^{-26} вата на квадратен метър на херц. Съгласно (5), пиковата спектрална плътност на потока, получена от обект с площ на силуета Q от антената на радиотелескопа с ефективна площ A_{eff} , е:

$$S_{antenna} = S A_{eff} \frac{Q^2}{(\lambda^2 R_t^2)} \quad (6)$$

Където S е пиковата плътност на потока, предавана от космическия източник на радиация преди да бъде разпръсната от обекта към радиотелескопа, R_t е разстоянието от обекта до радиотелескопа и λ е дължината на вълната на сигнала. Уравнението (6) може да бъде пренаписано като:

$$S_{antenna} = S A_{eff} \frac{\sigma}{(4\pi R_t^2)} \quad (7)$$

Където σ е ефективно отразяващата повърхност (RCS) на обекта. В радиоастрономията ефективната площ на антената на радиотелескопа се изчислява като [2]:

$$A_{eff} = 2k_B G \quad (8)$$

Където G е усилването на антената на радиотелескопа (в K/Jy), а k_B е константата на Болцман ($1,38 \cdot 10^{-23}$ W/Hz/K). Според [1] ефектът на пряко разсейване възниква, когато обектът е разположен на или много близо до базовата линия между радиотелескопа и космическия източник на радиация (Слънце или пулсар), както е показано на фиг. 3. В този случай RCS на обекта може да се изрази като:

$$\sigma = \frac{4\pi Q^2}{\lambda^2} \quad (9)$$

Където Q е площта на силуета на обекта.

В статията се анализира случаят, когато обектът (астероид) пресича базовата линия „предавател-приемник“ под приблизително прав ъгъл.

Предположението е, че силуетът на обекта е приблизително диск с диаметър h . В този случай уравнението (9) приема формата:

$$\sigma = \frac{\pi^3 h^4}{4\lambda^2} \quad (10)$$

След полагане на σ в (6) за пиковата спектрална плътност на потока се получава:

$$S_{antenna} = \frac{\pi^2 S G k_B h^4}{8 R_t^2 \lambda^2} \quad (11)$$

Спектралната плътност на шума на приемника може да бъде приблизително оценена с помощта на температурата на приемната система като:

$$N_0 = k_B T_{sys} \quad (12)$$

Като се вземат предвид (11) и (12), съотношението сигнал/шум (SNR) на изхода на антената може да се изрази като:

$$SNR_{antenna} = \frac{S_{antenna}}{N_0} = \frac{\pi^2 S G h^4}{8 T_{sys} R_t^2 \lambda^2} \quad (13)$$

За откриване на обекта е необходимо да намерим максималното разстояние до обекта, което съответства на минималното SNR, необходимо за откриване на обекта с предварително определената вероятност за откриване [11, 12]. За тази цел стойностите на SNR се изчисляват като функция на разстоянието между радиотелескопа и обекта:

$$SNR_{direct} = \frac{C}{R_t^2} \quad (14)$$

Където C е константа равна на:

$$C = \frac{\pi^2 S G h^4}{8 T_{sys} \lambda^2} \quad (15)$$

5. Резултати

Според принципа на Бабинет директното лъчение и сенчестото лъчение, създадено от непрозрачен обект, имат противоположни фази [13, 14]. Следователно, обвивката на сумарния сигнал на входа на приемника се определя като:

$$E_{Rx} = E_{direct} + E_{shadow} \quad (16)$$

От (16) следва, че сенчестият сигнал E_{shadow} може да се разглежда като намаляване на директния сигнал E_{direct} , получен в радара с пряко разсейване. Така е в сила следното неравенство:

$$E_{direct} \geq E_{shadow} \quad (17)$$

Като се вземат предвид (5) и (17), можем да заключим, че изчисляването на SNR на входа на откривателя с помощта на (13) може да се извърши само за разстояния (R_t), които удовлетворяват следното неравенство:

$$R_t \geq \frac{Q}{\lambda} \quad (18)$$

Където площта на силуета на астероида се изчислява като:

$$Q = \frac{\pi h^2}{4} \quad (19)$$

При изчисляването на SNR приемаме, че FSR системата има антена с диаметър $d = 25$ m и системната температура на приемника в радиообсерваторията е 150 K.

Ако се използва слънчевата радиация като източник на сигнал, спектралната честотна плътност (поток) на слънчевото радиолъчение зависи от честотата, на която се приема слънчевото лъчение. Стойностите на слънчевия поток за различни честоти са дадени в таблица 1, където 1 SUF е еквивалентен на 10^{-22} вата на квадратен метър на херц.

Таблица 1. Спектрална честотна плътност на слънчево радиолъчение

f [MHz]	410	1415	15400
Flux [SUF]	26	45	530

За настоящото изследване са избрани три обекта с диаметри $h_1 = 2$ m, $h_2 = 4$ m и $h_3 = 6$ m.

Най-важните параметри на обектите, които влияят на стойностите на SNR, са тяхната ефективно отразяваща повърхност (σ) и ъгълът на повторно излъчване (θ^0).

В таблица 2 са показани стойностите на FS RCS на трите обекта в зависимост от техните размери (h) и честотата на слънчевото радиоизлъчване (f). Изчисляването на ефективно отразяваща повърхност (σ) се извършва с помощта на уравнение (10).

Таблица 2. Ефективно отразяваща повърхност на три обекта

f [MHz]	RCS (σ) [dB]		
	$h_1 = 2$ m	$h_2 = 4$ m	$h_3 = 6$ m
410	38.2	57.9	66.0
1415	49.0	68.6	76.4
15400	69.7	89.4	97.5

Според теорията на дифракцията ъгълът на повторно излъчване (θ^0) се изчислява в зависимост от траекторията на движение на целта и честотата на излъчваните емисии:

$$\theta^0 = 180/\pi \frac{\lambda}{h} \quad (20)$$

Таблица 3 показва стойностите на ъгъла на повторно излъчване на всяка цел в зависимост от най-големия размер на силуета на целта. Този ъгъл на практика показва ширината на лъча на целта в посока към пасивния приемник, в нашия случай, радиотелескопа.

Таблица 3. Ъгъл на повторно излъчване

f [MHz]	θ^0		
	$h_1 = 2$ m	$h_2 = 4$ m	$h_3 = 6$ m
410	20.96	10.48	6.98
1415	6.07	3.03	2.02
15400	0.56	0.28	0.19

Времето на престой на обект в зоната на пряко разсейване се определя не само от ъгловата ширина на диаграмата на излъчване на обекта (θ^0), но също и от ъгловата ширина на диаграмата на насоченост на приемната антена (θ_{ant}), която зависи от диаметъра на антената (d) (таблица 4):

$$\theta_{ant} = 180\lambda/(\pi d) \quad (21)$$

Когато обектът пресече базовата линия „предавател-приемник“, времето на престой на обект в зоната на разсейване се определя като:

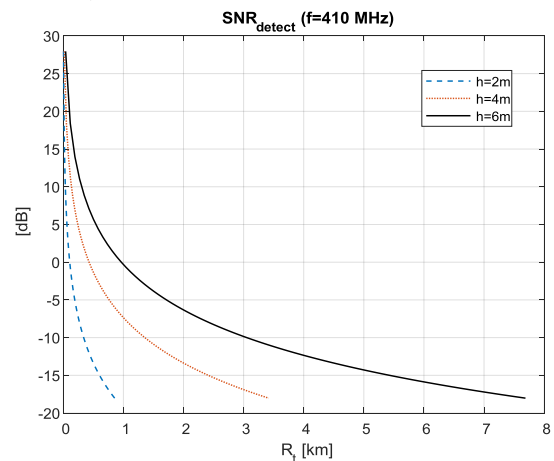
$$t_{cont} = R_t/V \min(2\theta, \theta_{ant}) \quad (22)$$

Където R_t и V са разстоянието до обекта и неговата скорост.

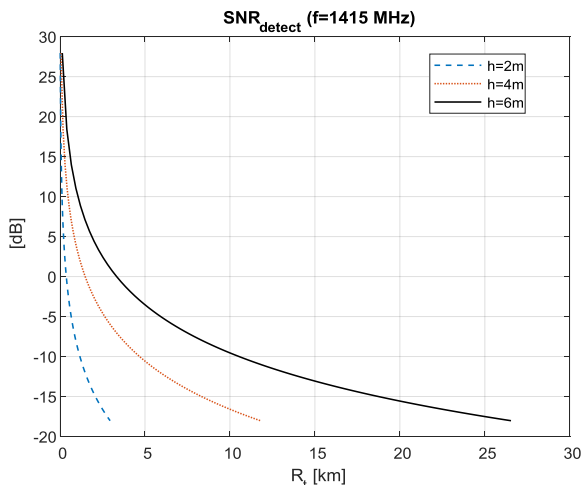
Таблица 4. Ъглова ширина на диаграмата на излъчване на приемната антена

f [MHz]	θ_{ant}		
	$d = 5$ m	$d = 25$ m	$d = 300$ m
410	8.38	2.79	0.14
1415	2.42	0.81	0.04
15400	0.22	0.07	0.004

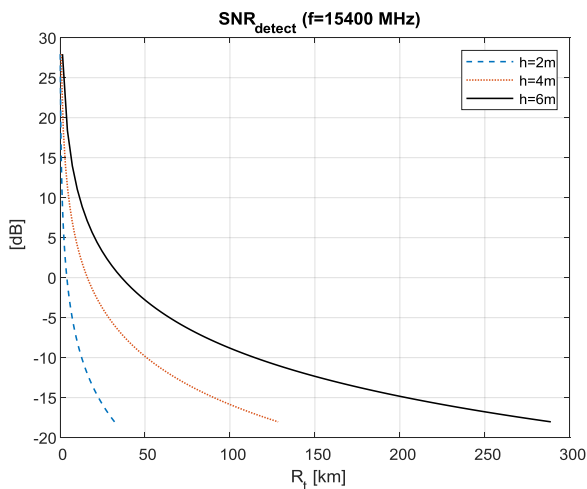
Стойностите на отношението сигнал към шум SNR, изчислени за три стойности на честотата на радиоизлъчване в зависимост от разстоянията до обекта, са представени на фиг. 5-7. Видът на получените резултати може да се обясни, като се отчете и вариацията на стойностите на ефективно отразяваща повърхност (σ) от честотата на слънчевото радиоизлъчване (таблица 2).



Фиг. 5. Отношение сигнал към шум при $f = 410$ MHz



Фиг. 6. Отношение сигнал към шум при $f = 1415$ MHz



Фиг. 7. Отношение сигнал към шум при $f = 15400$ MHz

Получените резултати са функция на разстоянието и са изчислени за соларна FSR система, като диапазонът на изследване е в интервала от $R_{t_min} = Q/\lambda$ до $R_{t_max} = 200R_{t_min}$.

От фигурите се вижда, че колкото е по-висока честотата на сигнала, толкова подвижният обект ще бъде открит на по-голямо разстояние. В същото време, колкото е по-голям размерът на обекта, толкова той е откриваем на по-голямо разстояние от приемника. Отношението сигнал към шум е максимално при минимално разстояние между предавателя и обекта, а е минимално при максимално отдалечени приемник и обект. Колкото е по-мощен сигналът от космоса, толкова е по-голямо отношението сигнал към шум на входа на приемника и обектът би бил открит с по-голяма вероятност.

6. Заключение

Получените резултати се отнасят за случая, когато Слънцето се използва като източник на сигнал.

В разглеждания случай обектът пресича базовата линия перпендикулярно, когато времето за контакт на обекта с приемната антена е минимално и целта бързо излиза извън диаграмата на насоченост на радиотелескопа и продължителността на сигнала, получен от обекта, е малък. При тази конфигурация на изследването се получава максимална ефективно отразяваща повърхност и съответно максимално отношение на сигнала към шума.

Получените резултати показват, че предлаганата радарна система за откриване на подвижни обекти при използване на сигнали от космоса може да бъде интегрирана в съвременните системи за наблюдение и управление на въздушното движение.

Благодарности

Статията е реализирана по проект „Иновативни методи и алгоритми за откриване и разпознаване на подвижни обекти чрез интегриране на хетерогенни данни“, КПИ-06-Н 72/4/05.12.2023, финансиран от ФНИ-МОН.

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Statistical processing of set up error occurred during turning in self-centering three-jaw chuck and between centers on CNC machines

Chukalov, Konstantin¹, Sabev, Sabi²
 Technical University Sofia, Bulgaria, branch Plovdiv
 chukalov@tu-plovdiv.bg ; sabi_sabev@tu-plovdiv.bg

Abstract: In this article, the objects of research are 40 pieces sleeves made from aluminum alloy 6080 and results were obtained from the measurement of the observed sign of inner cylindrical surface runout relative to the external one. The graphical visualizations of the analyzed data were made. A comparison is made between the amount of error obtained by two setting methods on a CNC lathe - in a universal self-centering chuck and between centers.

Keywords: ALIGNMENT, MACHINING ERRORS, CNC MACHINES, PRECISION, STATISTICAL PROCESSES, SELF-CENTERING CHUCK

1. Introduction

The accuracy of CNC machines is determined by various factors, including machine class, type and work condition of used tools, type of material being processed and selected machining technology [1]. The requirements for CNC machined parts are becoming higher and higher, and at the same time complexity of details is increasing [2]. This necessitates a more detailed analysis of CNC errors such as geometric errors of tools, errors due to deformation processes, set up errors etc [3]. Setting error during machining cylindrical parts in self-centering chuck depends on:

- Degree of precision of the chuck
- Hesitation of the clamping
- Deviations from the correct position of the part set up bases relative to base surfaces of chuck

When the setup base is fine, influence of the form accuracy on setup error is insignificant compared to of other factors.

Sleeves are details that have more than one internal or external surface and meet the condition $1 < L/D < 3$. Their functional purposes in machines and mechanisms are very diverse. They often determine relative position of single parts in assembly, joining parts of different sizes, for leading tools and mechanisms. Depending on accuracy of the central hole, the sleeves are particularly accurate - 7 degree of precision, accurate - 8-9 degree of precision and reduced accuracy - 10-11 degree of precision. In addition to the mentioned requirements for the accuracy of the central hole, there is a requirement for forms deviation in relation to internal and external surfaces, accuracy to the longitudinal functional dimensions and low roughness of the processed surfaces to increase durability of components [4]. Alignment of rotationally symmetrical parts is performed on external, internal and frontal surfaces, depending on type of workpiece. The purpose of the first operation is to process an internal or external surface and the adjacent face. The alignment error is a sum of two errors - of set up and clamping.

2. Materials and methods

The objects of the research is a series of 40 pieces sleeves from material-AL 6082. fig 1[5]. The research was carried out on a CNC lathe equipped with an 8 inch chuck with quenched jaws [6]. The runout of the self-centering chuck was pre-measured to be 0.03mm [7]. The drawing is presented in fig.2.



Fig 1. A series of 40 pieces sleeves

The measurement was made with dial gauges with an accuracy of 0.001 mm and 0.002 mm. The blanks have a fine external base $\phi 33$ and a pre-prepared length - 180mm.

Examination of the machining error in a three-jaw chuck follows the following methodology: the workpiece is set up in the chuck, then the bearing seats and a 30° chamfer are turned. After relocation, the other bearing seat is processed - the short one and a 30° chamfer. After processing the two seats, the control checking using dial gauges is performed fig.3. The examination of the runout error when turning between centers follows the following methodology: the workpiece is set up and the external cylindrical surface is turned to dimension $\phi 32$, fig 3.

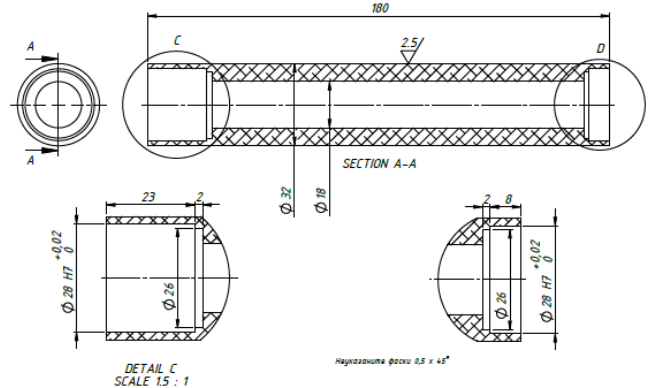


Fig.2 The drawing of the sleeves



Fig 3 Processing between centers

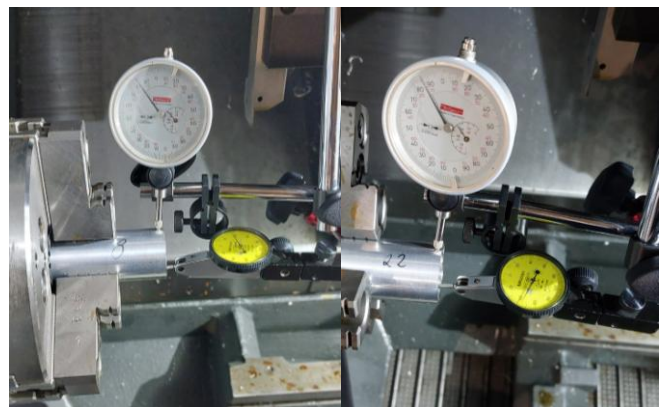


Fig.4 Experimental set up

When measuring the runout, the samples are set up at random angle in the chuck. In this position, which the workpiece has occupied in the radial direction, the error is obtained as a difference between the external and internal runout. The absolute value of the deviation is measured using dial gauges-fig 4.

3. Results and discussion

The one-time sampling method was used. For its application, a population was considered, processed under nominally unchanged conditions [8]. The condition that the measuring device has a scale division value of 1/6-1/10 of the tolerance of measured size is fulfilled for correct results. The measurements of runout of the short and long bearing seats are presented in tab 1.

Table 1: Measurements of runouts of the short and long bearing seats, processed in the chuck

No:	Short beating seats			Long bearing seats		
	External surface [μm]	Internal surface [μm]	Error absolute value [μm]	External surface [μm]	Internal surface [μm]	Error absolute value [μm]
1	25	10	15	27	22	5
2	22	20	2	28	102	74
3	35	52	17	24	14	10
4	24	54	30	26	34	8
5	30	34	4	42	80	38
6	35	6	29	26	18	8
7	32	72	40	30	28	2
8	30	70	40	24	62	38
9	28	8	20	25	36	11
10	30	34	4	32	50	18
11	25	70	45	27	24	3
12	33	8	25	29	22	7
13	25	68	43	32	70	38
14	32	42	10	26	2	24
15	26	6	20	25	38	13
16	37	88	51	38	24	14
17	25	14	11	27	66	39
18	30	38	8	29	2	27
19	27	92	65	30	42	12
20	35	68	33	34	38	4
21	30	18	12	32	56	24
22	30	48	18	26	46	20
23	32	76	44	30	18	12
24	38	68	30	31	88	57
25	29	48	19	30	56	26
26	25	10	15	36	60	24
27	35	36	1	31	38	7
28	25	84	59	29	14	15
29	25	64	39	30	10	20
30	27	50	23	30	74	44
31	30	58	28	30	26	4
32	34	54	20	31	44	13
33	26	28	2	32	52	20
34	22	56	34	26	74	48
35	32	46	14	30	40	10
36	18	70	52	30	72	42
37	26	10	16	25	74	49
38	34	62	28	30	18	12
39	30	82	52	23	76	53
40	32	58	26	29	64	35

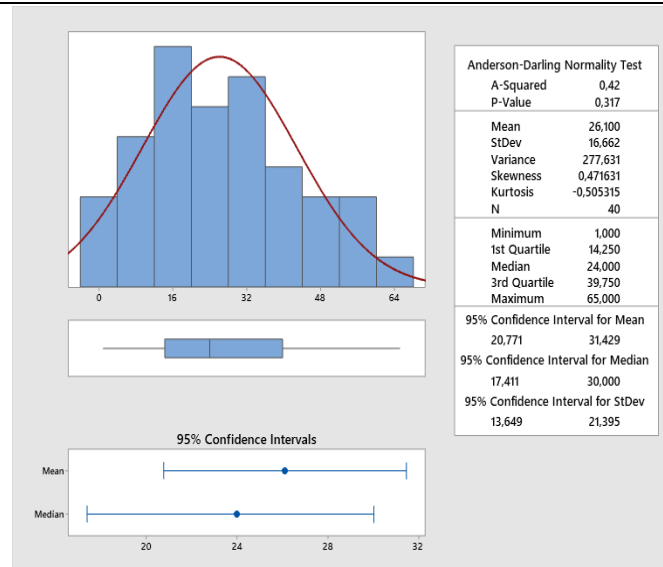


Fig.5 Summary report-runout short beating seats

The summary report samples fig. 5 and fig. 6 for the short and long seats gives an idea of the symmetry of the distribution.

An Anderson-Darling statistical test was used, which measures how the data follow a chosen distribution[9]. For a given data set and distribution, as much as the distribution fits the data, smaller is the value. In this article, all data are sampled with a normal distribution.

For the short seat, fig3 the sample volume N=40, the mean is 26.1, the sample standard deviation (Std. Deviation) is 16.662, the sample dispersion (Variance) is 277.631, the sample coefficient of asymmetry (Skewness) is 0.472, so the distribution is right asymmetric, the sample coefficient of kurtosis is -0.501. Similarly for the long seat, fig4 the sample volume N=40, the mean is 23.2, the sample standard deviation. (StDev) is 17.506, the sample dispersion (Variance) is 306.472, the sample coefficient of asymmetry (Skewness) is 0.965, so. the distribution is right asymmetric, the sample coefficient of kurtosis is 0.344.

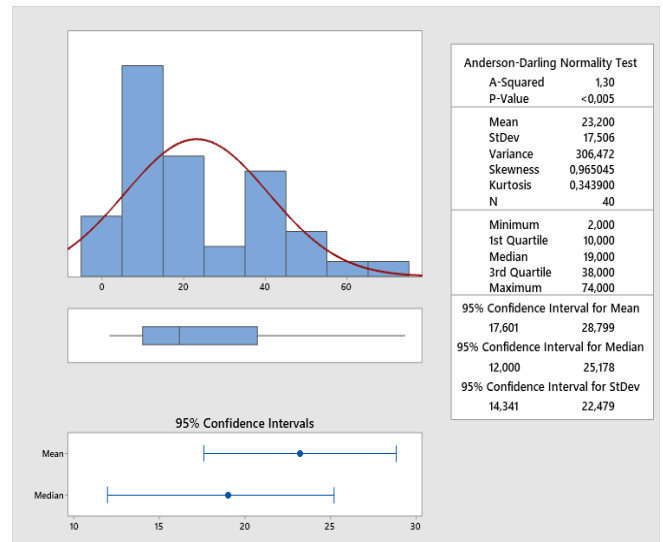


Fig.6 Summary report-runout long bearing seats

Figures 7 and 8 show normal distributions of the measured deviations of the external and internal cylindrical surface of the seats during processing in the three-jaw self-centering chuck.

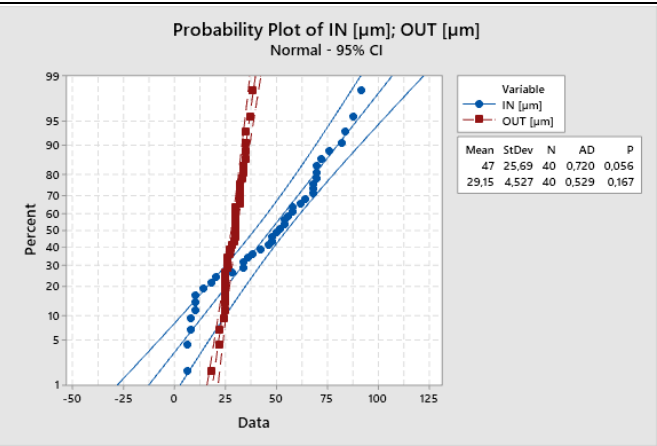


Fig.7 Probability Plot short seat

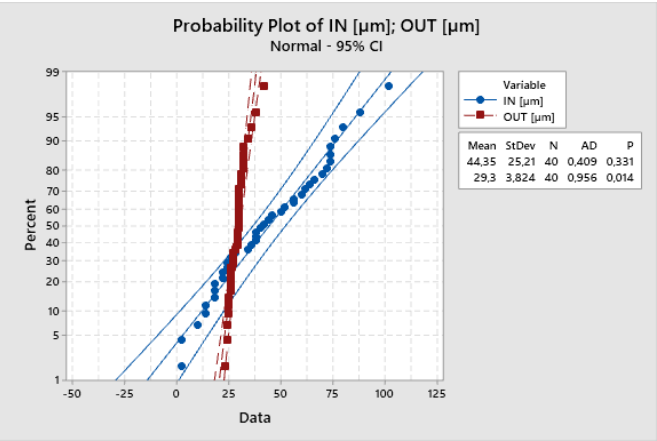


Fig.8 Probability Plot for long seat

Table 2: Measurements runout-long and short seats, processed between centers

No:	Short bearing seats			Long bearing seats		
	External surface [μm]	Internal surface [μm]	Error absolute value [μm]	External surface [μm]	Internal surface [μm]	Error absolute value [μm]
1	35	32	3	28	22	6
2	37	43	6	37	22	15
3	30	40	10	35	30	5
4	35	30	5	43	42	1
5	42	30	12	37	43	6
6	32	18	14	30	40	10
7	40	28	12	30	32	2
8	35	38	3	27	39	12
9	38	46	8	30	18	12
10	30	28	2	35	30	5
11	25	22	3	37	22	15
12	32	18	14	35	30	5
13	40	44	4	30	32	2
14	30	40	10	40	28	12
15	23	24	1	26	16	10
16	30	28	2	45	22	23
17	45	22	23	35	30	5
18	40	44	4	40	30	10
19	35	38	3	40	30	10
20	45	22	23	32	18	14
21	25	22	3	40	28	12

22	45	22	23	35	30	5
23	35	38	3	37	22	15
24	37	43	6	35	30	5
25	30	40	10	43	42	1
26	35	30	5	37	43	6
27	42	30	12	30	40	10
28	32	18	14	35	30	5
29	40	28	12	42	30	12
30	35	38	3	40	28	12
31	38	46	8	30	28	2
32	30	28	2	35	30	5
33	25	22	3	40	30	10
34	45	22	23	40	30	10
35	35	38	3	32	18	14
36	38	46	8	40	28	12
37	30	40	10	35	30	5
38	35	30	5	37	22	15
39	30	28	2	35	30	5
40	35	30	5	35	26	9

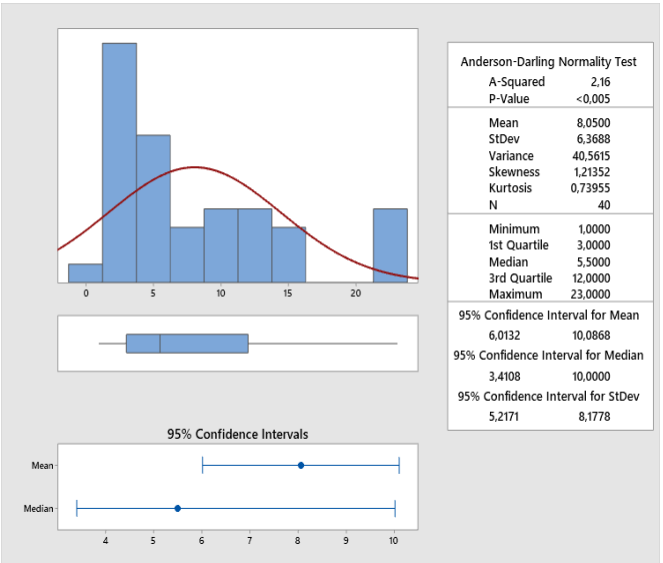


Fig.9 Short bearing seats

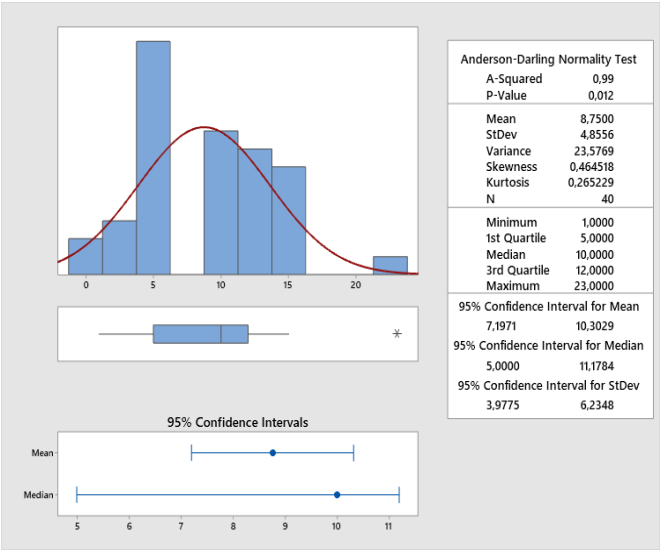


Fig.10 Long bearing seats

The summary report sample tab.2 fig.9 and fig.10, for the short and long necks in the second processing based between centers gives an idea of the symmetry of the distribution, which in this case is right asymmetric.

It should be noted that in technological research the main goal is to obtain the probable scattering field indicator of the studied phenomenon. In this case, what has been stated about the determination of practical scattering limits is sufficient.

Figures 11, 12, 13 show the graphs for the normal distribution of the measured values of the external and internal cylindrical surfaces of the seats when processing between centers.

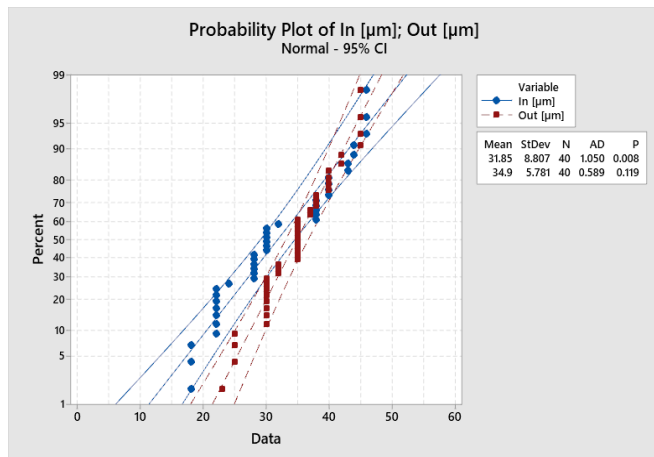


Fig.11 Probability plot-external and internal cylindrical surface-short seats

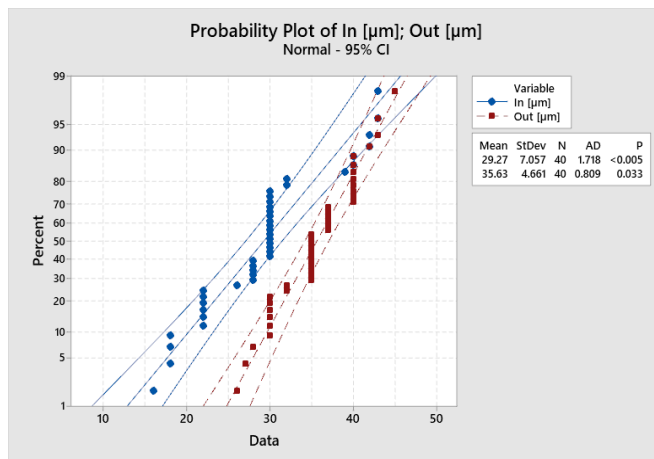


Fig.12 Probability plot-external and internal cylindrical surface-long seats

The test rejects the hypothesis of normality when the p-value is less than or equal to 0.003. A failed normality test allows us to state with 95% confidence that the data does not follow a normal distribution.

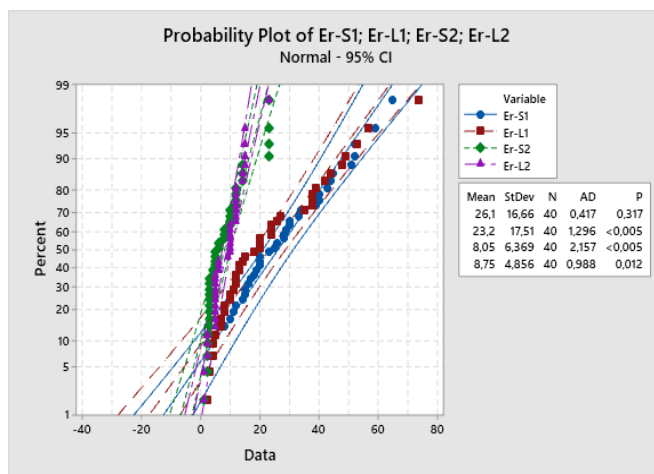


Fig.13 Probability plot summary of set up errors-in the chuck and between centers (Er-S1-error short seat processed in the chuck, Er-L1,error long seat processed in the chuck, Er-S2-error short seat processed between centers, Er-L2-error long seat processed between centers.)

Anderson-Darling statistic may be used to compare the fit of several distributions to determine which is better. However, to conclude that a distribution is the best, its Anderson-Darling statistic should be significantly lower than the others[10]. When statistics are close together, you should use additional criteria, such as probability plots.

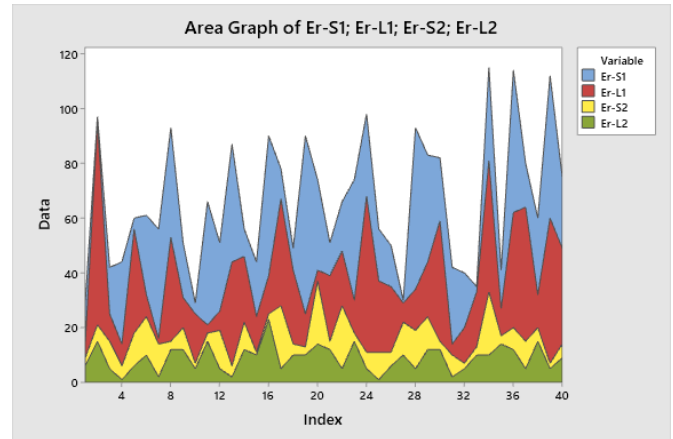


Fig.14 Area graph of Er-S1;Er-L1,Er-S2,Er-L2

From fig. 14, it may be seen visually that the error from runout of the bearing seats has decreased by more than 3 times. Research on beating in CPU continues to be extremely current[11]

4. Conclusions

The experimental data set is subjected to statistical processing in order to analyze the dimensional space and extract the most valuable information contained in the experimental data set.

Passing the normality test only allows us to state that no significant departure from normality was detected.

The obtained high percentage of accuracy confirms the successful implementation of the set task. The proposed methodology may be applied to different details.

Grouping of the results is observed, which is most likely due to a measurement error due to the small values of the dispersion of the runout processed between centers (Er-S1, Er-L2)..

The error from runouts of the bearing seats has decreased by more than 3 times.

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Structural and technological aspects of the production of ceramic beehives

Lyuben Lakov, Bojidar Jivov, Todorka Lepkova*, Krasimira Toncheva, Dimo Mihaylov

Bulgarian Academy of Sciences, Institute of Metal Science, Equipment and Technologies with Hydro- and Aerodynamics Centre
"Acad. A. Bolevski", 67 "Shipchenski prohod" Blvd., 1574 Sofia, Bulgaria, e-mail: lepkovatodorka@ims.bas.bg

Abstract: Applied research work carried out for the development and manufacture of an innovative movable frame ceramic hive with increased operational stability and efficiency is presented. A brief justification of the design solutions used and the choice of the applied technological approach is made. The main stages of the developed technological regime for the preparation of structural ceramic elements and various modifications of experimental prototypes are discussed in a summarized form. The existing possibilities for the production of new modifications of ceramic beehives with improved performance characteristics by applying different technological approaches are analyzed. The technological regime for the preparation of structural details is fully compatible with the production methods typical for the ceramic industry and provides the opportunity for further implementation.

Keywords: INNOVATIVE CERAMIC BEEHIVE, EXPERIMENTAL MODEL, TECHNOLOGICAL MODE

1. Introduction

Different beehive systems have been developed with a variety of design features [1]: Dadant-Blatt, Langstroth-Ruth, Roger-Delon Alpine hive, Farrar, Lezhak, Hybrid model and a number of others. There are single-hull, double-hull and multi-hull hives with different volumes of the working space and the possibility of installing additional hulls in some of the systems.

The predominant construction types in the modern production of standard movable frame beehives use different materials [1]: solid wood, particle board, plastics, polystyrene, polyurethane and others. The movable frame structure of modern standard frame hives ensures good exploitation functionality and high efficiency in the production of bee products by applying highly productive methods.

The existing standard hives made of different materials are characterized by a relatively limited operating period, unreliability in case of fires and more intensive depreciation accompanied by aging of the material [2, 3]. Daily and seasonal climatic cycles in temperature, the amount and intensity of rainfall, the formation and duration of snow cover and a number of other factors further accelerate the depreciation of hives [4]. Different types of standard beehives are at (some) risk of the emergence and spread of fungal cultures and microbiological agents with toxic effects [5, 6]. At the same time, the use of traditional primitive reed non-movable frame hives continues at some beekeeping farms.

An appropriate approach to effectively improve the state of the beekeeping industry and its adaptation to global climate change and intensive industrial and noise pollution of the environment involves increasing the functional characteristics and core capabilities of the material base of modern bee farms [7, 8]. In this respect, the development of innovative beehives based on materials with proven durability and increased resilience under critical environmental conditions is of immediate interest. Existing opportunities in various technological directions have been analyzed [9-30].

Following a technical study, an original conceptual model of an innovative movable frame hive made of ceramic structural parts containing chambers with air cavities was developed.

The development is based on the hypothesis that the ceramic materials and the designed chamber structural elements allow the construction of a beehive which provides a suitable microclimate and adequate protection of the bee colonies from the dynamic change of the external environment and the negative impact of various natural and anthropogenic factors.

The use of classical ceramic technological methods allows the production of durable, waterproof, fire-resistant, environmentally friendly construction details, superior in performance to the materials commonly applied in the production of various standard beehive systems. At the same time, the use of ceramic materials for the manufacture of beehives has a beneficial environmental effect as it reduces wood consumption.

The use of ceramic parts with chambered air cavities ensures good thermal and acoustic insulation properties of the main structural elements of the hive.

A complete design documentation has been prepared and a suitable technological model has been developed for the production of a complete range of ceramic construction parts. Experimental prototypes of an innovative ceramic beehive with high operational stability and increased productivity were prepared. The first expert analysis of the idea provides the basis for the development of a utility model. The presumed main advantages of the ceramic hive have been confirmed by the experts.

The analysis of the experimental data obtained from comparative studies involving ceramic prototypes and standard beehives confirms the formulated working hypothesis and proves the constructive practicability of the developed conceptual model.

The aim of this publication is to present in a summarized form the technological approach applied in the preparation of ceramic structural parts for different modifications of innovative beehives. Much of the specific technological data is presented in a series of separate publications [31-39] and does not constitute the subject of this work. Existing technological possibilities and trends for further development of the product with a view to realizing new modifications with increased exploitation characteristics are discussed.

2. Experimental model

An experimental model of a Dadant Blatt-system beehive (10 frames for stationary farm) was designed. The Dadant Blatt type was chosen since it is the most widely used one in the country. The construction of the beehive consists of ceramic plates (forming the brood box), a supporting metal structure and a standard lid (commercially available). The developed brood chamber is made of single-chamber ceramic plates (with a cavity of more than 66%). The ceramic plates (in the shape of a parallelepiped) are mounted on the supporting structure, forming the inner volume of the brood box. The main support structure performs a load-bearing and supporting function (through mounted corner profiles) and can be made of different materials - wood, metal or ceramic. To the base of the frame are mounted (by welding) auxiliary elements - handles and support of the movable bottom drawer located in the base (of an open type with a net or fully closed). The drawer is a sliding one, providing the possibility to adjust the temperature and air circulation (according to the season and the outside temperatures), and it can be pulled out for cleaning or other operational needs during the maintenance of the hive and colony. The dimensions of the prototype design are in accordance with existing standards for Dudden-Blatt hives.

3. General technological regime

For the preparation of the designed hollow chamber ceramic parts, the slip casting method was selected as the most appropriate and efficient technological approach for moulding. It is a classical moulding method used in the ceramic industry and allows the preparation of a variety of complex products.

After conducting a series of preliminary laboratory experiments using standard casting slurry masses, it was found that from a

technological perspective, they are not suitable enough for the full realization of the main objectives of the development.

Further indicative laboratory studies were carried out to specify the most appropriate raw materials potentially applicable for the development of formulations suitable for the preparation of slurries for the moulding of hive structural parts.

Necessary quantities of raw materials were obtained from accessible local deposits in the country. The chemical and phase composition, as well as the technological, mechanical and physico-chemical characteristics of the raw materials samples were studied.

After the analysis of the experimental results of those studies, it was found that the marl raw materials originating from deposits near the town of Debeleets (Veliko Tarnovo region) and the village of Lovets (Targovishte region) meet to the greatest extent the envisaged technological requirements.

Thermal treatment of a marl raw material originating from a deposit near the village of Lovets yielded polyphase samples in which the presence of anorthite (dominant phase), diopside, leucite, wollastonite, and quartz was recorded (using X-ray fluorescence analysis).

At the same time, for the purpose of the prototype development kaolin raw material (deposit "Saragyl", located near the village of Doirantsi, Shumen region) was selected. The use of washed kaolin is suitable due to its characteristic natural whiteness, fire resistance and stability under high temperatures.

On the basis of the studied raw materials, formulations were developed for the preparation of slurry masses with appropriate consistency and complying with the defined technological norms.

After a primary processing of the raw materials with a collergang (mix miller), the resulting product was subjected to sieving using a set of standard sieves.

The preparation of the slip mass is carried out by mixing and intensively stirring the required quantities of raw material and water. The resulting homogenized mass is subjected to straining and technological residence (minimum 48 h or more).

Under laboratory conditions, the shrinkage coefficient of sample bodies prepared from the cast slurry masses was determined. For the purpose of the project, a complete set of original gypsum moulds was designed, in accordance with the technological characteristics of the moulding masses and the shrinkage processes during drying and high-temperature processing of the samples until they have reached the required dimensions as stipulated in the design documentation.

Moulds were developed for the front and side plates consisting of two elements (element 1 and element 2). Due to the large size of the hive's side and the possibility of combining the moulds to produce the side of the honey supers, it is envisaged that it is made of two elements, which are interconnected by means of a structural step. This allows the use of the same matrix to produce the brood box side and the ceramic honey super. The construction solution used ensures a more stable and robust construction of the brood box, guarantees easy and quality assembly and the possibility of stability when transporting the hive in an assembled state.

The designed gypsum moulds were prepared (fig. 1 and 2) and applied for the moulding of blanks (in the form of structural parts) from slurry masses.

After a series of laboratory experiments, the required technological residence time (from 10 to 40 minutes) of the slurry in the gypsum moulds for the preparation of hollow chamber specimens with the required wall thicknesses was specified. The duration of the technological process of molding was determined taking into account the temperature of the working room, the temperature of the slurry, the wall thickness of the gypsum molds, the time for the deposition of the material on the walls of the molds, all of which affect the speed of formation of the wall thickness of the samples.

For the moulding of the designed structural elements, a portion of the prepared casting slurry was introduced into the pre-assembled gypsum moulds. After forming the required wall thickness of the structural elements, the residual liquid phase of the slurry was removed by draining. After the completion of the envisaged process

time (4 to 6 hours), the resulting specimens were freed from the plaster molds by disassembling them (fig 3 and 4).



Fig 1. Part of a plaster mold.



Fig 2. Parts of a plaster mold.



Fig 3. Molded structural element.



Fig 4. Molded structural elements.

Moulded blanks are hollow three-layer structural parts consisting of solid walls and an intermediate air chamber.

The resulting blanks were subjected to drying (to a residual moisture content of about 6-8%), by free drying for about 5 days or by forced drying at 100°C for 24 h in a drying unit.

To reduce the risk of manufacturing defects, it is advisable to position them vertically when carrying out the temperature treatment (drying and firing).

After the drying process was complete, the resulting specimens were subjected to high temperature processing. According to the specifics of the compositions used and the envisaged performance characteristics of the products, specialized heat treatment modes (in air environment) were developed. The regime of high-temperature treatment was established experimentally after analysis of the data obtained from the laboratory studies (differential thermal analysis, X-ray phase analysis and a number of others). The synthesis conditions, firing interval, risk of formation of deformation defects, phase composition, physico-chemical and mechanical characteristics of the experimental specimens were analyzed.

For the firing of the moulded structural parts with a composition based on marl raw material, a heat treatment regime was developed consisting of the following stages: heating rate of 3°C/minute to 150°C, isothermal hold of 30 minutes at 150°C, temperature rise at 2°C/minute to 605°C, isothermal hold of 30 minutes at 605°C, temperature rise at 2°C/minute to 850°C, isothermal hold of 30 minutes at 850°C, temperature rise at a rate of 1°C/minute to 1115°C, isothermal hold of 3 hours to 1115°C, temperature reduction at a cooling rate of 1°C/minute, opening of the oven when 70°C is reached, process hold to a temperature of 40°C, removal of the ready products.

For the firing of the moulded structural parts with a composition based on marl raw material and washed kaolin, a heat treatment regime was developed with the following stages: heating rate of 3°C/minute to 150°C, isothermal hold of 30 minutes at 150°C, temperature rise at 2°C/minute to 605°C, isothermal hold of 30 minutes at 605°C, temperature rise at 2°C/minute to 850°C, isothermal hold of 30 minutes at 850°C, temperature rise at a rate of 1°C/minute to 1180°C, isothermal hold of 3 hours at 1180°C, temperature reduction at a cooling rate of 1°C/minute, opening of the oven when 70°C is reached, process hold to a temperature of 40°C, removal of the ready products.

Various technological factors play a significant role in the formation of the structural and performance characteristics of the ceramic samples: fractional, chemical and phase composition of the raw materials, grinding mode, developed recipe compositions, technological parameters of the prepared casting slurry mass, methodology of moulding the blanks, conditions of the drying process, specifics of the high-temperature processing mode, etc.

On the basis of the developed formulations and experimentally determined optimum parameters of the technological process, a complete technological cycle was carried out for the preparation of a set of construction details up to the assembly of experimental prototypes.

The method used for the preparation of structural elements for ceramic beehives meets the conditions typical for the silicate industry and is applicable for carrying out profitable production activities in existing factories based on available standard equipment. The development of the entire technological cycle (from the quarry to the final product) allows for the preparation of detailed technological regulations and the planning and organisation of the production process.

As an original alternative option, a technological regime for the preparation of structural parts (for beehives) from quartz ceramics has been developed. A process flow diagram of a workshop for the production of beehives from quartz ceramics has been prepared.

To further improve the conditions of an adequate hygienic living environment for the bee colonies, the application of polycomponent silicate glaze coatings (of different types - transparent, colourless, coloured, coating, matt, shiny, etc.) on the internal surfaces of the ceramic structural elements is applicable. At the same time, the presence of a glaze layer allows for more effective disinfection (if necessary). The glazing of the external surfaces of the products (or of the whole parts) provides protection against the effects of various environmental factors and improves the performance and aesthetic characteristics of the product. On the other hand, the introduction of glazing as a separate technological

stage complicates, prolongs and makes more expensive the production process.

To improve the decorative characteristics of beehives, it is possible to produce naturally coloured (ecological) ceramic construction parts based on natural raw materials (without introducing additional synthetic colouring agents). The main disadvantage of this type of product is the relatively limited colour palette. At the same time, the production of articles with a variety of colour characteristics from coloured moulding masses with introduced colouring agents broadens the basic product range.

An adequate technological direction for effective modification of the characteristics of ceramic parts is the modification of the developed formulations or modifying the technological regime. The introduction of additional components and modifiers allows for adjusting the technological parameters of the moulding masses, modifying the firing interval and improving the performance of the final products (e.g. refractoriness, mechanical resistance, thermal and acoustic insulation, etc.). In some cases, modifying the compositions necessitates a partial modification of the heat treatment regime and other technological conditions.

The main directions for creating new modifications of ceramic beehives with lower operating mass include the preparation of structural parts with higher hollowness and porosity or the introduction of additional components such as silicate lightweight additives, etc. into the moulding masses. At the same time, maximum lightweighting of the support structure allows for further reduction of the overall mass of the hive.

4. Conclusions

The development of innovative modifications of modern beehives with increased operational efficiency is an adequate approach for the long-term improvement of the state of the beekeeping sector as a whole in the face of climate change and intense industrial pollution.

Based on an original working hypothesis, a substantiated conceptual model of an innovative movable frame beehive consisting of long-lasting fire-resistant ceramic structural parts with chambered air cavities (with improved thermal and acoustic insulation characteristics) is developed.

The main arguments for the choice of the conventional ceramic technology as an appropriate manufacturing approach to the preparation of the designed structural elements for beehives are presented.

The technological method of slip casting which was used allows for the moulding of a variety of products with complex geometry and is optimal for the realization of the objectives of this project.

Based on the raw materials used, a series of formulations have been developed, applicable for the preparation of various slurry masses with the necessary technological parameters and suitable for moulding structural parts.

Original sets of gypsum moulds for the structural elements (for beehives) using the slip casting method were prepared. The moulds are tailored to the technological characteristics of the slurry-casting masses used and the volumetric changes of the specimens during drying, heating and high-temperature heat treatment.

An optimal technological regime for precision moulding (using the slip casting method) of a complete set of the designed hollow chamber structural elements was experimentally established.

Adequate temperature treatment modes (drying process and high-temperature treatment) have been developed, in accordance with the composition and specificity of the moulding masses used and the envisaged performance of the final products.

The role of the individual technological factors in the formation of the structural characteristics and the main performance parameters of the prepared chamber ceramic parts is analyzed.

Original experimental working prototypes of innovative movable frame beehives were built by assembling the prepared ceramic structural elements.

In summarized and chronological form, the entire technological cycle for the preparation of ceramic structural details and individual modifications of ceramic movable frame beehives is presented.

The technological regime developed for the preparation of ceramic beehives is consistent with the production conditions and basic machinery typical for the silicate industry, which allows for easy implementation of the development.

Some of the existing different technological possibilities for the development and preparation of new modifications of ceramic beehives with increased exploitation characteristics are discussed.

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Remote detection, recognition and tracking of objects in drones aircraft

Ivanova Eleonora, Stefanov Ivan

1Faculty of Computer Systems and Technologies, Technical University - Sofia, Blvd. Kliment Ohridski 8, 1000 Sofia, Bulgaria

E-mail: el_ivanova@tu-sofia.bg, ivan.ts.stefanov@tu-sofia.bg

Abstract: A review and analysis of methods for the detection and recognition of unmanned aerial vehicles (UAVs) has been carried out. UAV detection channels were considered - acoustic, optical, radar, infrared, radio reconnaissance channel. The advantages and disadvantages of the channels used are compared and evaluated. In the case of small UAVs, there are a number of significant difficulties and limitations. One of the directions in UAV detection is acoustic observations. The noise created by the UAV's power plant and propeller is an important unmasking feature. The creation and improvement of methods for the detection, direction-finding and recognition of small UAVs by receiving and processing their sound signals is an urgent task. In the implementation of this method of detection of UAVs are used frequency spectra, spectrograms, normalized autocorrelation functions and phase portraits of acoustic signals. Information features of the UAV sound image can be estimates of spectral coefficients determined from a discrete implementation containing a given number of samples, as well as parameters of autoregressive models.

KEYWORDS: MULTISENSOR SYSTEM, DETECTION AND CLASSIFICATION, UNMANNED AERIAL VEHICLES, ARTIFICIAL INTELLIGENCE, HUMAN FACTOR, COMMUNICATION AND INFORMATION SYSTEM, NETWORK-CENTRIC ENVIRONMENT

1. Introduction

One of the most important tasks in ensuring security against threats arising from the use of unmanned aerial vehicles (UAVs) is their detection and determination of their movement parameters.

The following requirements apply to UAV detection equipment:

- high target detection efficiency; ease of use; profitability (low cost); safety for people and wildlife; absence of obstacles in the operation of other technical systems.

2. Methods for detection and determination of UAV motion parameters

Currently, the most common methods for detecting and determining UAV movement parameters are:

- radio technical control (RTK); radar control; optical control; acoustic control.

In radiotechnical monitoring, two methods of obtaining information are used: search and observation. [1]

The search includes detection of radio signals from radio emission sources (ERS), their technical analysis, recognition of radio signals of ERs, recognition of ERs themselves and processing of spatial parameters of radio signals (bearing of ERs) to determine the coordinates of emitters.

The surveillance includes the implementation of radio interception operations of RES messages, tracking of the trajectory of RES, technical analysis of radio signals and recognition of RES signals.

The main tasks of radio technical control are:

- search and detection of UAV radio signals during panoramic viewing in the required frequency range or when tracking a fixed set of frequencies; determination of parameters and type of modulation of detected signals; demodulation of certain types of signals; determination of the type and structure of binary sequences (protocols), types of synchronization, primary and noise-resistant coding;

decoding and extracting messages; logging signals and messages, archiving data; direction finding of radioactive sources and determining their location during search; tracking the trajectory of the UAV during surveillance.

To solve these problems, it is necessary to use automated radio engineering control systems that provide:

- setting alerts; automatic scan (review) in a set range with display of scan results; determination in automatic mode and in dialogue mode with the operator of the modulation parameters of the analyzed signals; demodulation of certain classes of signals; Recording of signals on computer media; maintaining a database of processed signals; signal classification and exposure detection; direction finding and location determination of the UAV. [2]

Currently, unmanned aerial vehicles (UAVs) are widely used in various fields of human activity. For example, in agriculture, UAVs with GPS navigation are used to pollinate plants in fields. At the same time, significant savings in chemicals and more thorough crop treatment are achieved compared to manned aircraft. UAVs are used to deliver medicine and humanitarian aid to hard-to-reach areas and can be used to inspect power lines and pipelines. Drones,

another name for UAVs, can also be used by the state emergency service for surveillance and forecasting, as well as for the control of dangerous sites.

3. Main types of UAVs

Based on the variety of designs, there are four main types of UAVs. Fig. 1.

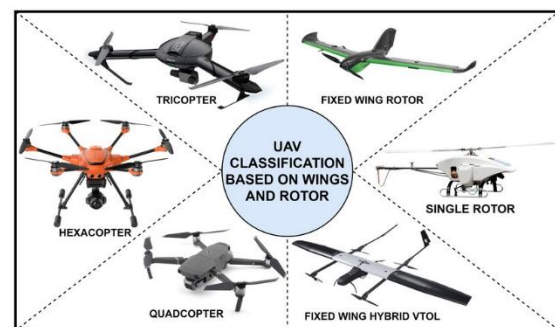


Fig. 1. Classification of UAV based on wings and rotors.

Multicopter drones are a flying platform with brushless motors and propellers. They have the ability to take off vertically or hover over an object and are the cheapest and most accessible version of UAVs. [3] Fixed-wing UAVs fulfill the structure of an aircraft and are ideal for long-range operations. Single-Rotor Drones – Unmanned helicopters are much more efficient than the multi-rotor versions. They have longer flight times and can even be powered by internal combustion engines. Hybrid drones are also known. As drones become more common, the issue of detecting UAVs in the air becomes more relevant. The following methods and means are used for this: radar, optical and acoustic. UAV optical detection is highly dependent on environmental factors. Increasing the detection range is achieved by narrowing the field of view, reducing the field of view and increasing the search time. Therefore, visual sensors are inefficient search devices. The use of acoustic channels for UAV detection is becoming more and more relevant. Acoustic sensors allow ground assets to search for and detect UAVs in passive mode, thereby reducing the likelihood of the enemy identifying their own positions. Therefore, modifying existing acoustic search systems or creating new systems can provide a reliable method of UAV detection. Drones can also be detected by receiving and analyzing radio signals: communication and control links, radar altimeters, active jammers and radar stations. However, this method can only determine the direction to the UAV, and the accuracy of the determination increases as the observation time increases. Some low-frequency communication links can be detected over considerable distances. Emissions from airborne radar stations (radar) and active jamming of UAVs can be detected at even greater distances. This method requires minimal equipment and allows you to quickly determine the direction of the target for further issuing target designations to optical or infrared surveillance equipment. [4, 5] Searching for UAVs using active radar stations is quite productive, since they have a relatively large

pulse search volume and a significant detection range. A significant drawback of the radar method is that most UAVs are made of composite materials that reflect electromagnetic waves rather poorly. Radio waves penetrate the surface of the device and are only partially reflected by it. Another problem is that due to the small size of UAVs, bandwidth limitations and, importantly, high cost, surveillance radars cannot be used often, especially when a network of radars needs to be deployed to ensure full coverage of the controlled area. Continuous wave (CW) and frequency modulated continuous wave (FMCW) radars currently represent the most attractive and cost-effective solution to this problem. An FMCW signal consists of a linearly modulated continuous wave transmitted in the desired direction. These types of signals differ from a CW signal where the operating frequency does not change during transmission. In most cases, target detection aims to detect the presence of objects that are not constant in the observed scenario, that is, objects that can dynamically appear or disappear. The moving target indicator is a mode of operation of the radar that allows the system to distinguish the target both among noise and among stationary objects in the observation area. This property is based on the Doppler effect, since stationary targets do not cause any Doppler frequency shift in the observed signals. Thus, the main method for detecting UAVs at significant distances is the radar method and the corresponding radars, characterized by a significant energy potential.

In world practice, there are two approaches to detecting objects using infrared (IR) images. The first approach is related to identifying an object by its own radiation using thermal imaging cameras. The spectrum of the object's own radiation is in the range of 7-14 microns. Modern thermal imaging cameras have a light temperature sensitivity of about 0.05 K. In the future, such systems should be equipped with a zoom lens up to 10-20 times. The second approach involves the use of active infrared laser illumination, for example, an infrared laser of 903 nm or 1560 nm for object detection and identification, topography of the area with subsequent identification of moving UAVs against the background of moving wildlife objects. In order to be able to detect UAVs at a distance of up to 2 km, the authors suggest using 1560 nm with a pulse duration of 1 ns, a repetition rate of 1 MHz and a pulse power of 700 kW. The divergence of the laser beam is of the order of 0.5 degrees. In this case, the system is equipped with a matrix photodetector (150 x 20 pixels) and an optical system so that the angular field of view of the matrix photodetector corresponds to the angular field of the laser beam. In other words, the system works by recording the reflected signal from the UAV in a given angular space from a matrix photodetector unit (PDU). The scanning system is equipped with a high-speed galvanometric mirror ($f = 1$ kHz) for sequential scanning of the laser illumination field. Such systems also perform the function of a laser range finder - LIDAR. [6, 7] Fig. 2.

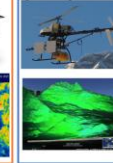
RGB-camera	Multi-spectral camera	IR-camera	SAR	LIDAR
Function: Captures visible light, providing high-resolution color imagery; Limitations: Limited to day light conditions	Function: Captures data across multiple spectral bands, aiding vegetation identification and classification; Limitations: Might limited spatial resolution	Function: Detects infrared radiation for identifying temperature; Limitations: Cannot detect geological feature directly; Might limited spatial resolution	Function: Penetrates through clouds and darkness, providing all weather and day/night monitoring; Limitations: Lower spatial resolution, complex data processing	Function: Measures distance using laserpulses creating 3D terrain model directly; Limitations: Can be affected by atmospheric conditions, cost
				

Fig. 2. Functions and limitations of on-board sensors.

4. Optical spectral methods

The ability to use optical spectral methods to solve problems with the detection and recognition of unmanned aerial vehicles against the background of wildlife objects largely depends on the power of the radiation sources, which decreases with increasing distance to the object and the sensitivity of the recording equipment . Estimating the potential maximum detection distances

of UAVs using optical methods requires further basic science research. The goal of such research should be to develop the scientific foundations for remote detection, identification, tracking and determination of UAV parameters and UAV membership in different groups using optical localization methods and optical spectroscopy, as well as automatic optical recognition in different environments of the background of moving live objects. Research should encompass existing and promising spectral optical methods aimed, among other things, at identifying new informative detection features. [8, 9] For their implementation, an experimental bench is created, which enables the implementation of the research objectives.

5. Conclusion

The analysis of the modern state of methods and technical means, optical location and optical spectroscopy showed the prospects for use in problems with the detection and identification of moving objects. At the same time, a complete effective system for spectral optical control of UAVs has not yet been created, as many unsolved problems, such as the speed of neural networks and the need for their constant training; physical limitations of the range of different types of optical methods; the complexity of the task of remote differentiation of objects of different nature. To solve them, it is necessary to combine methods of optical location and spectral analysis, methods of statistical theory, graphics, machine learning, neural networks and automatic control methods, which is an interdisciplinary fundamental scientific problem.

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Development of Custom GPT as a System for Communication and Promotion of Climate Analysis in a GIS Environment: Planning, Structure and Application in Projects

Stoyanka Ivanova^{1,*}, Tamara Ilieva¹

University of Architecture, Civil Engineering and Geodesy (UACEG) – Sofia, Bulgaria¹

siva_fce@uacg.bg

Abstract: This article presents the development process of Custom GPT based on GPT-4o for paid users and GPT-4 for non-paid users to promote and explain climate analysis and the use of GIS technologies in scientific projects. The bot's work will be as a communication system, offering detailed scientific explanations on the topic, navigation and pointing to additional resources such as web pages, reports and visualizations. The article examines the planning of the bot, the structure and volume of the submitted information, as well as the possibilities of expanding its functions in the future. Potential additional tasks that the bot could take on, such as automating processes and assisting with data work, are being explored. The conclusions highlight the benefits of using GPT for the promotion of scientific results and the possibilities for future development of its functionalities.

Keywords: CLIMATE ANALYSIS, GIS TECHNOLOGIES, ARTIFICIAL INTELLIGENCE, SCIENTIFIC COMMUNICATION, CONTEXT WINDOW

1. Introduction

A revolutionary new technology is beginning to change our world: Large Language Models (LLM). They are entering more and more fields and transforming more and more industries. They are based on deep learning, are trained on vast amounts of human knowledge, and are capable of generalization (extracting rules and principles from the data they are trained on) and generalization (applying the learned principles to completely new and unknown data). The latter makes them very useful for a wide variety of applications, including education, scientific research, and science popularization.

One of the directions for their use is as chatbots that communicate with people and answer questions. Development of these possibilities are the so-called **custom GPT** bots that are further trained for a specific user task. OpenAI offered this technology to its users in November 2023. [1] and since then tens of thousands of user bots have been developed with a variety of purposes and applications.

The task of the present development is to create a user chatbot based on the GPT-4 model [2] of OpenAI, which will serve as a system for communication and promotion of climate analyzes in the GIS environment. The main idea is to make it easier for the user to access scientific information, to be assisted in its analysis and to be directed to appropriate sources of additional information.

Users of such a GPT could be:

- Researchers: Through the created chatbot, they can get acquainted with information related to their interests, analyses and research in the field of climate and GIS within a targeted conversation.
- Students and teachers: For them, the chatbot can serve as a useful tool in the educational process, helping students understand complex scientific concepts and supporting teachers in their academic disciplines.
- Broad audience: Custom GPT can be used by people who do not have specialized knowledge but are interested in information about climate change and related GIS technologies. They can get easily understandable information from the bot.

A characteristic of such bots is that they are able to adapt to the level of users and present information in a way that is understandable to them - both for specialists and for the general audience.

Communicating climate and other scientific information through user GPT bots requires new ways of thinking, new understanding of scientific information, and new information structuring technologies. For more complex tasks and high goals, this requires knowledge of the way of work and technological features of user bots for different groups of users. Acting on intuition and without knowledge would not allow the creation of a user chatbot with more complex behaviors and capabilities.

This article presents the development process of a user bot named ClimaGeo GPT, based on the model GPT-4o for paid users

and GPT-4 for non-paid users. The main purpose of this bot is to promote and explain climate analysis and the use of GIS technologies in climate science projects.

2. Methodology

The methodology for developing a custom GPT bot includes several stages, tailored to the features of the currently available versions of GPT:

- Collection of complementary information to GPT 's knowledge of climate analysis and GIS;
- Shaping this information in a way that is consistent with the features of the bot;
- Setting up the bot with the collected information;
- Testing and Optimization.

2.1. Basic information of chatGPT-4.

The core learning process of any basic GPT model involves the provision of increasingly large and increasingly specialized volumes of information in a variety of scientific domains. As a result, the current versions chatGPT-4 [2] (for non-paid users) and chatGPT-4o [3] (for paid users) have a solid understanding of climate science [2] and geographic information systems (GIS), especially when it comes to fundamental concepts and principles. The development of chatGPT-4o is based on the same GPT-4 model, but implemented with a larger **context window** (i.e., it has more memory for a single chat session). Its basic knowledge [2] allow it to provide useful information about:

- Main climate models and scenarios;
- Processes and components of climate systems;
- GIS technologies – basic and intermediate levels of GIS functionality;
- Application of GIS for climate analysis and assessment of environmental impacts.

According to chatGPT-4o, his knowledge in this complex field is more basic and extensive, rather than narrowly specialized, unlike other fields such as programming and artificial intelligence, where he has a greater depth of knowledge. The latter helps him to be a valuable advisor and facilitator in the field of AI applications in climate analysis and GIS.

2.2. Additional information.

User GPT models include the usual base information of the GPT 4 model, but before each dialog session with a user is started, they also load additional information. It is structured in two main parts: **Instruction** and **Knowledge** and is accessed differently. The instructions [4] are plain text generated by the chatbot's creator or by a GPT-4 helper session. The size of this text can be at most 8192 tokens. Knowledge is stored in auxiliary files of various types:

- Text documents – files with extensions .TXT, .DOCX, .PDF, these can be articles, lectures, educational materials, documents with information and instructions;

- Spreadsheets – files with extensions .CSV, .XLS, .XLSX, they are useful for uploading tables of results, statistics, lists and graphs.
- Presentations – files with extensions .PPTX, they enable information to be extracted from the slides;
- JSON files – with extension .JSON, these are structured data and records from databases or configuration files; can also contain Python programming code for the user bot to execute.

The length of the knowledge files can be longer because GPT is not trained from them by sequential reading, but searches them for keywords and phrases and can perform selective citation. This allows efficient use of the files as external knowledge base without them being loaded into GPT memory within token limits.

When asked specific questions, the user GPT model prioritizes its local knowledge base over its base knowledge created during its basic training by OpenAI.

2.3. Tokens – meaning, limitations, features

The basic text unit of the GPT model is the “token”. It can be a word, part of a word, a space or a punctuation mark. The text of the prompts that the user enters is divided into tokens that the model processes. Its responses also consist of tokens.

In English, a simple word is usually a single token, but longer or more complex words can be divided into several tokens that contain a prefix, a root and an ending. In other languages with complex structures (for example, Bulgarian), longer words are divided into several tokens. Prefixes and suffixes are also often separate tokens. In program code, tokens include syntactic elements such as operators (+, =), keywords (if, for), variable identifiers, as well as individual characters or combinations.

The context window of the dialogue between the user and the GPT determines the volume of text in tokens that the model can work with at once, and thus indirectly affects the complexity of the task that the model can handle. For English, 8192 tokens are approximately 6150 words (about 22 standard pages), and in Bulgarian this is about 15-18 standard pages. When the context window fills up (in a longer conversation), the model starts to get rid of the older information in the conversation, i.e. to "forget" it.

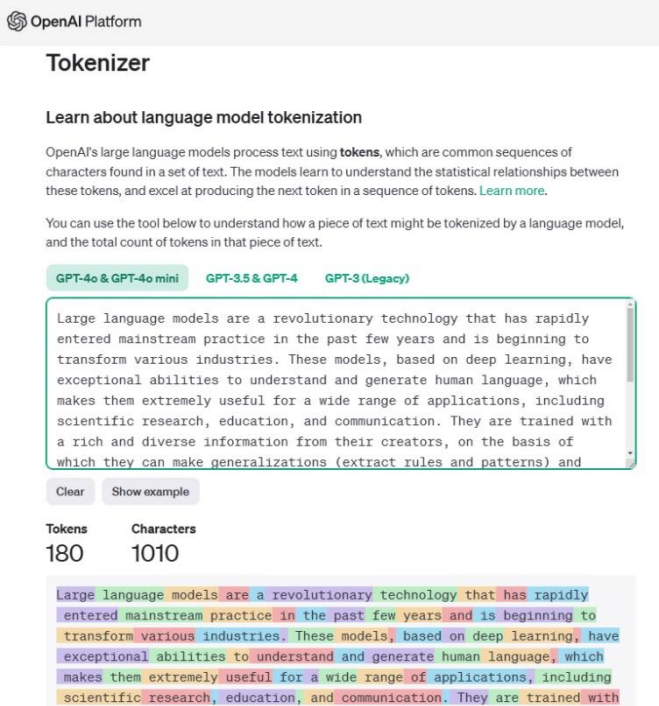


Fig. 1 Tokenization of the first paragraph of the post, in English is 180 tokens with model GPT-4o [5].

Open AI offers an online tool – OpenAI Tokenizer [5] for determining the number of tokens in a given text. This can also be

done by chatGPT-4 in a direct dialog (provided access is available to the ability to execute the necessary code). It should be noted that tokenization in GPT-4 models is different from that in GPT-4o and GPT-4o mini, with the latter giving a lower number of tokens. For example, the first paragraph of the present article in English with 1010 characters is 181 tokens according to the GPT-4 model and 180 according to GPT-4o (Fig. 1). The same text in Bulgarian is 1048 characters, with 489 tokens according to the GPT-4 model and 299 according to GPT-4o (Fig. 2).

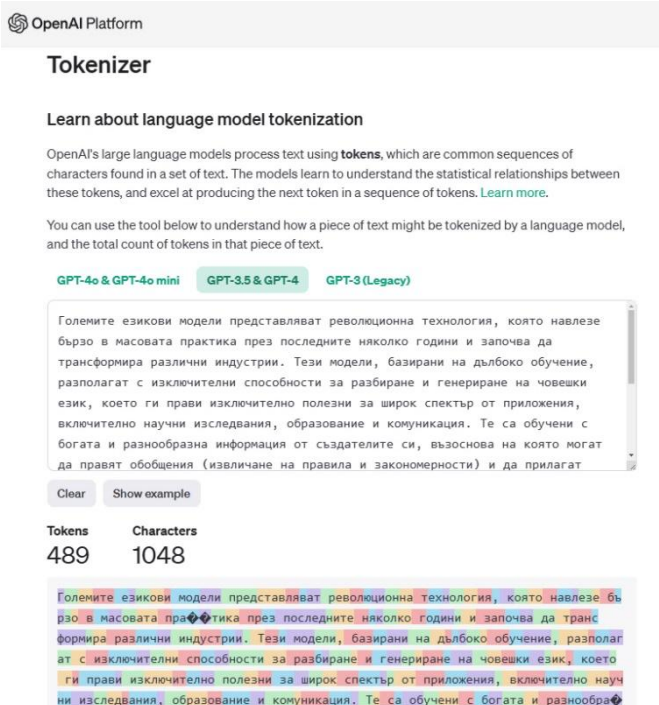


Fig. 2 Tokenization of the first paragraph of the publication, in Bulgarian, there are 489 tokens with the GPT-4 model [5].

2.4. Versions of the models for paid and non-paid users

Chatbot users are divided into two main groups: paid and unpaid, who have access to different models and functionalities of GPT. Paid users can use the GPT-4o model, which has more computing power, more customization options, and a context window of 32,000 tokens. Non-paid users use GPT-4, which provides a high level of functionality but with a smaller context window of 8192 tokens. This difference requires consideration of access to tasks of different complexity and a different communication strategy depending on the level of access to the system. Users with the Enterprise access level have access to a context window of 128,000 tokens. This allows them to have even longer conversations and solve more complex structural tasks.

3. Strategy for preparing and structuring the information in the additional knowledge base.

3.1. General principles

Some general principles can be formulated that the creators of the supplementary knowledge base for custom GPT models should follow:

- Clear content structure – divided into logical sections, categories and subcategories. This facilitates navigation and makes information more accessible to users;
- Clear and unambiguous presentation language – using understandable language, without redundant terminology when unnecessary. This helps a wide range of users to understand the content.
- GPT-specific directives should be at the beginning of the document - these directives direct the model to a specific goal or behavior that makes it more efficient in handling user queries.

- For structured data, it is best to use a tabular format – for example in XLS and CSV files. Tabular format is suitable for faster data search and retrieval, as well as for presenting large volumes of information in a clear manner.
- For unstructured data, it is best to use .TXT files, which are faster to process and do not require additional tokens to store structured information. Format as .txt is much more suitable for semantic search. Since the text is not separated with formatting tags, the model can perform better and more accurate searches for the required keywords and phrases.
- The glossary of specialized terms used in training the chatbot helps users quickly become familiar with specific terms and concepts.
- The sample question and answer file can serve as a “guide” for users on how to use the chatbot and what type of information they can expect.
- JSON files are suitable for describing complex data relationships. They allow for easy integration with the chatbot and searching for specific fields of information.
- JSON files with Python code are available for execution in the GPT-4o version (for paid users) and can be used for a number of tasks, such as running neural networks to generate forecast values of climate data, running various computational scenarios, or processing data in real time.
- Finally, the creators of the user bot need to run a test with sample questions. This provides a check of the functionality and quality of the answers. It is an important step to ensure that users will receive relevant and accurate answers.

With a complex and extensive structure of the additional knowledge base, optimization (reduction of the number of tokens) may be necessary. This requires that this knowledge base be created without unnecessary duplication of information, without unnecessary texts and using keywords. This is important in order to achieve more efficient use of the context window and to preserve the maximum amount of useful information within the token limit.

The current requirements for knowledge files are: up to 20 files [6] of up to 512 MB each, with a total of up to 2 million tokens [7]. In these files, the bot uses semantic search, which allows it to find relevant information based on the context and meaning of words, rather than just exact matches.

3.2. Guidelines for structuring a text file

The most economical way to provide unstructured text for additional knowledge bases is text files. When creating and formatting them, the following should be considered:

- Clear headings and subheadings – such a structure helps GPT quickly find the necessary information.
- A section with questions and answers (FAQs) about the main functions of the bot and its capabilities. This makes it easier for GPT to navigate in the expectations from it.
- Lists and bullet points for important information (key points or instructions) are easier to perceive, not only by humans, but also by chatbots.
- Tables for presenting quantitative data or comparisons.
- Short summaries at the end of each section help to emphasize the most important points.

It is important to remember that chatGPT can help structure the file by creating an example structure template, a question and answer section, a glossary of terms, as well as suggesting an appropriate organization of content to meet the specific needs of users. This not only saves time, but ensures that the document is well organized, consistent and easy to navigate. Structuring the content in this way ensures maximum efficiency and makes it easier for the GPT bot to search and use the information.

If it is necessary to reduce the volume of information, it should be remembered that for the same content, the Bulgarian language requires more tokens than the English language. If more unpaid users are expected, both their more limited context window and the efficiency with which the free GPT-4 model (in English or Bulgarian) tokenizes are relevant.

4. ClimaGeo additional knowledge base GPT

The discussed principles for structuring the additional knowledge base of the custom GPT were applied in the development of the ClimaGeo GPT, available on the OpenAI site at address [8]. Below follows the description of all the files that make up the functionality of the bot in the field of climate analysis for the territory of Bulgaria.

4.1. Information about the project (saved in a text file Project_information.txt)

This file contains a detailed description of the project “GIS-based analyzes of climate change impacts on road infrastructure to build adaptive capacity” project at the Research, Consultancy and Design Center of UACEG, emphasizing the main tasks that will be performed, and the scope of climate analyses. The objectives are presented in a clear and understandable manner. The file also includes information about the expected results, as well as what specific benefits the analyzes bring to different groups of users. Such information is particularly useful for demonstrating the added value of the project and how it can support informed decision-making related to climate change.

4.2. Glossary of terms and methods (saved in text file Glossary_of_terms.txt)

This file contains a brief explanation of the terms used in the project – both scientific and GIS terms. For example, “climate models”, “temperature anomaly”, “GIS layers” and many others.

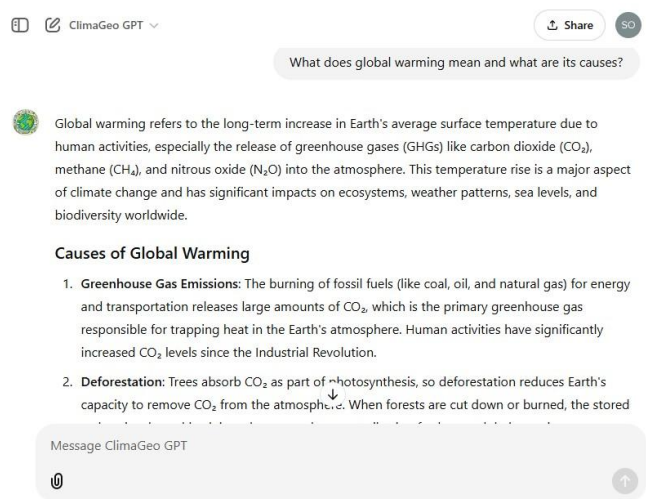


Fig. 3 ClimaGeo GPT dialog [8].

4.3. Description of climate models and scenarios (recorded in text file Climate_models_scenarios.txt)

This file contains a detailed description of the climate scenarios used, such as RCP 4.5, 6.5 and 8.5, and their key characteristics. The inclusion of information about each model and its purpose helps users understand the main differences and applications of the climate scenarios that are possible in the future. In addition, a comparison between the different climate scenarios is included in the analysis, which will be useful for analyzing the complications that arise from their implementation. This information is important to support informed decision-making when analyzing climate data and projections.

4.4. Climate analysis data by zones and periods (saved in a text file Climate_data_by_zones.csv)

This file contains tabular data with some climate indicators for different regions such as average temperatures (Fig. 4), precipitation and temperature anomaly forecasts. This information is useful for defining climate conditions that will affect the economy, agriculture, maintenance of settlements, etc.

4.5. Results of the specific climate analyzes (saved in file *Results_of_analyses.xlsx*)

This file contains the results of analyzes that include forecast data for regions of Bulgaria, as well as for the entire country. Forecast data includes information on changes in temperatures, precipitation and other indicators, divided by scenarios. The information is presented in tabular form to facilitate analysis and comparison of different scenarios and time periods.

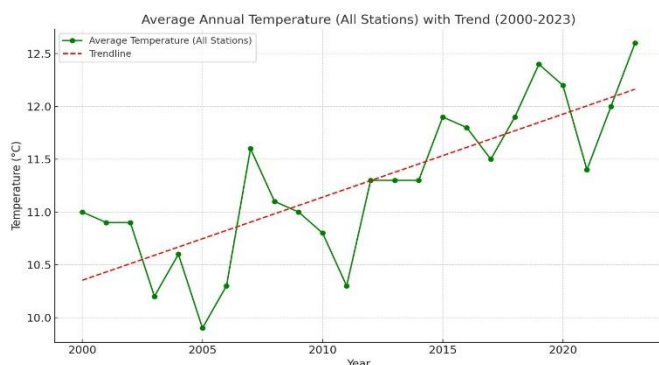


Fig. 4 Graph displaying the average annual temperature for all weather stations in Bulgaria from 2000 to 2023, created by ClimaGeo GPT [8].

4.6. Sample questions and answers (saved in a text file *FAQ_questions_and_answers.txt*)

This file contains a list of frequently asked questions and their answers that users may encounter. An example question could be: "What is the predicted temperature change in North-Eastern Bulgaria by 2050?". Such information helps users to quickly find answers to their questions and helps them to better orient themselves in the content of the project.

4.7. Summary results and conclusions (saved in a text file *Conclusions_from_the_project.txt*)

This file contains a summary of the most important findings of the analysis, presented in understandable and accessible language. The inclusion of key data and findings by region and scenario helps users quickly navigate key findings. Summary conclusions are especially useful for people who don't have time to delve into the technical details but want to get an overall picture of the project.

4.8. Instructions for using ClimaGeo GPT and the analyzes (saved in the text file *Instructions_for_use.txt*)

This file contains guidance for users on how to most effectively use ClimaGeo GPT, as well as advice on formulating questions related to climate analyses. These instructions are intended to facilitate users in using the tool to get the most out of its capabilities. The file also includes examples of questions and good practices.

4.9. Additional resources and links (saved in text file *Additional_resources.txt*)

This file contains links to important articles, research reports, external sources and official websites that provide additional information on the project topic. The selection of resources is made with a view to their reliability, so that users can deepen their knowledge and find additional materials that can be useful for their work.

It is important to note that according to OpenAI's custom GPT design [4], chatbot creators do not have access to the chats that other users are having with their GPT. OpenAI emphasizes that privacy and safety are fundamental to GPT. All interactions remain private and are not shared with model creators, and users retain full control over whether data is sent to third parties.

ClimaGeo GPT is about to be tested in the educational process at UACEG. In the future plans are both the addition of new capabilities implemented with Python code, and the connection of

the chatbot with external sites on the same topic to expand its functionalities.

5. Conclusions

The development of the ClimaGeo GPT bot for climate analysis and GIS shows the potential of artificial intelligence as a tool for the popularization of scientific information and scientific data. The created bot helps to facilitate access to complex scientific information and facilitate the understanding of complex climate processes for both scientific experts and the general audience. In order for GPT to become an effective assistant in the popularization of scientific research work and the educational process, careful development and installation of an additional specialized knowledge base is required, which contributes to the bot providing well-thought-out and focused answers.

The developed structure of the additional knowledge base for ClimaGeo GPT based on a strategy for creating such content demonstrates the importance of proper planning and clear structuring of information. As a result, ClimaGeo GPT can not only answer questions, but also act as an auxiliary tool for analysis, significantly increasing the productivity of its users.

The main advantages of the developed model include:

- Increasing the accessibility of complex information: Through the use of GPT technology, barriers to understanding complex scientific concepts and analyzes are overcome.
- Research and education support: Custom GPT supports researchers, educators, and students by providing them with easy access to data and analysis needed for their assignments and studies.
- Popularization of climate analyses: This is an important contribution to raising awareness of the mass audience about climate change and GIS technologies for assessing these changes.

Prospects for future development of this project include expanding the knowledge base with new data, Python programming code, and adding functionalities to automate some aspects of climate analyses. In addition, it is planned to connect the chatbot with external databases and visualization systems, which will improve the functionality of ClimaGeo GPT in practical scientific research and applied projects.

Acknowledgments

The development was financed under the "GIS-based analyses of climate change impacts on road infrastructure to build adaptive capacity" project at the UACEG Research, Consultancy, and Design Center.

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Пространствено моделиране на данни за оценка на климатичните промени в България: ГИС-базиран анализ и съпоставка на тенденциите с различните климатични сценарии

Тамара Илиева¹, Нина Николова², Стоянка Иванова¹
 Университет по архитектура, строителство и геодезия¹
 Софийски университет „Св. Климент Охридски“²
 ilieva_fgs@uacg.bg, nina@gea.uni-sofia.bg, siva_fce@uacg.bg

Резюме: Тази публикация представя пространствено моделиране и анализ на данни за климатичните промени в България, използвайки географски информационни системи (ГИС) и исторически данни от инструментални измервания в метеорологични станции. Целта на анализа на данните за минал период е да се идентифицират основните тенденции на температурните и валежните промени в различните региони на страната, като се отчита тяхното местоположение, надморската височина и принадлежността им към определена климатична зона. Чрез този диференциран подход се оценява как различните климатични условия в различни географски и височинни зони ще се изменят във времето. Изведена е и обобщена оценка на тенденциите за територията на цялата страна, която е съпоставена с различни прогнозни климатични модели, основаващи се на GIMP (Global Integrated Model Projections) проекциите на съответни RCP (Representative Concentration Pathways) и SSP (Shared Socioeconomic Pathways) сценарии. Заключениета подчертават значението на ГИС за оценка на климатичните тенденции, съответните рискове и разработването на стратегии за адаптация.

Ключови думи: ГИС, ПРОСТРАНСТВЕНО МОДЕЛИРАНЕ, ГИС-БАЗИРАН АНАЛИЗ, КЛИМАТИЧНИ ТЕНДЕНЦИИ, КЛИМАТИЧНИ СЦЕНАРИИ, БЪЛГАРИЯ

Spatial data modeling for assessment of the climate changes in Bulgaria: GIS-based analysis and comparison of the trends with different climate scenarios

Tamara Ilieva¹, Nina Nikolova², Stoyanka Ivanova¹
 University of Architecture, Civil Engineering and Geodesy¹
 Sofia University "St. Kliment Ohridski"²
 ilieva_fgs@uacg.bg, nina@gea.uni-sofia.bg, siva_fce@uacg.bg

Abstract: This publication presents spatial modeling and data analysis of climate changes in Bulgaria using Geographic Information Systems (GIS) and historical data from instrumental observation in weather stations. The purpose of the data analysis for the past period is to identify the main trends of temperature and precipitation changes in different regions of the country, taking into account their location, altitude and belonging to a certain climate zone. Through this differentiated approach, it is assessed how different climatic conditions in different geographical and altitudinal zones will change over time. A generalized assessment of the trends for the territory of the entire country was also derived, which was compared with various predictive climate models based on GIMP (Global Integrated Model Projections) of relevant RCP (Representative Concentration Pathways) and SSP (Shared Socioeconomic Pathways) scenarios. The conclusions highlight the importance of GIS for assessing climate trends, relevant risks and adaptation strategies development.

Keywords: GIS, SPATIAL MODELING, GIS-BASED ANALYSIS, CLIMATE TRENDS, CLIMATE SCENARIOS, BULGARIA

1. Увод

През последните десетилетия климатичните промени са факт, както в глобален, така и в регионален мащаб с дълбоки екологични, икономически и социални последици. Съществени изменения в температурата, количеството и режима на валежите и увеличаване на честотата на екстремни метеорологични явления се наблюдават и в България [1]. Въпреки малката площ, територията на страната се характеризира с разнообразни орографски и климатични условия, поради което проследяването на пространствено-хронологичните изменения на климата е предизвикателство. Поради това настоящото изследване има за цел да покаже приложението на географски информационни системи (ГИС) за климатични анализи. ГИС позволяват обработката на големи обеми от данни и разполагат с набор от мощни инструменти за изпълнението на пространствени анализи и визуализация на климатични тенденции.

2. Обща характеристика на територията на страната – климатична и географска

За целта на настоящото изследване са използвани данни от измерванията в метеорологични станции на територията на страната [2, 3] в периода 2000 до 2023 г. – за приземни температури, и в периода 2005 до 2023 г. – за валежи. Установените тенденции за температурата и валежите в страната са на повишаване при първите с 1,5°C (около 0,06°C

на годишна база) и намаляване при вторите с 80 mm (около 4 mm годишно) за изследваните периоди.

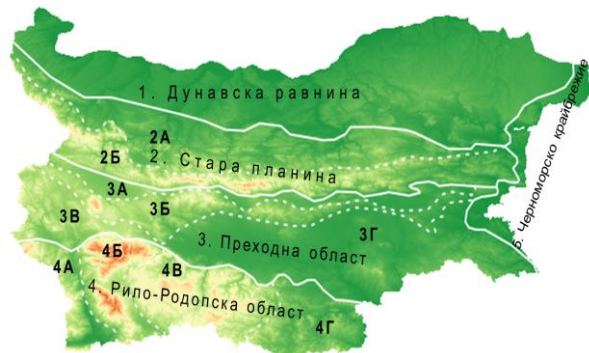
Релефът на България е разнообразен – предимно низинен и равнинно-хълмист – общо около 72% от територия на страната, предимно в северната и югоизточната част с надморска височина от 0 до 600 m [4, 5]. Останалата част е с планински релеф, това е около 28% от територията, разделена на нископланински, среднопланински и високопланински райони с надморска височина съответно от 600 до 1000 m, от 1000 до 1600 m и над 1600 m. Големите теренни форми са ориентирани запад-изток [4].

Основните природни области в България са показани на фиг. 1 [4]:

- 1) Дунавска равнина;
- 2) Стара планина;
- 3) Преходна област;
- 4) Рило-Родопска област;
- 5) Черноморско крайбрежие.

В зависимост от морфографските особености природните области се делят на подобласти (фиг.1).

В резултат на радиационни, циркуляционни и физикогеографски фактори на територията на България са формирани пет климатични зони [5, 6], илюстрирани във фиг. 2 и описани в таблица 1.

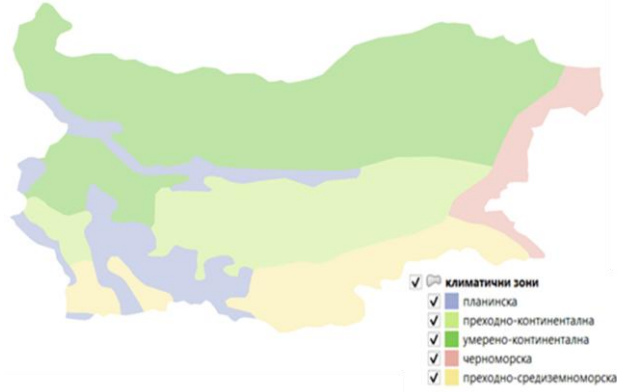


Фиг. 1 Природни области в България: 2А) Предбалкан; 2Б) Стара планина; 3А) Задбалканските полета, 3Б) Средна гора и Витоша, 3В) Краище и 3Г) Горнотракийска низина, Сакар и Странджа; 4А) планините Осогово и Беласица, 4Б) Рила и Пирин, 4В) Западни Родопи и 4Г) Източни Родопи

Таблица 1: Общо описание и характеристики на климатичните зони в България

Зона, обхват	Ср. темп. зима [°C]	Ср. темп. лято [°C]	Валежи [mm/год.]	Сн. покр. (месец)	пос. вятър
Умерено-континентална зона: Обхваща части от Дунавската равнина, Предбалкана, ниските части на Източна Стара Планина и Софийската котловина.	-1 до 2	20-23	500-800 Максим. май-юни, Мин. февруари	В равн. дек.-март В план. от ср. на ноемв. до ср. на апр.	З, СЗ, СИ, И
Преходно-континентална зона: Горнотракийската низина, източната половина на Задбалканските котловини и Благоевградската котловина.	0 до 3	22-24	550-750 Максим. 1) май-юни, 2) ноемв. Минимум 1) август, 2) февр.	Краткотрайна	З, СЗ, И, СИ
Преходно-средиземноморска зона: Обхваща долините на реките Струма, Места и Арда, районите около Странджа. и Сакар.	1 до 4	23-25	500-600, за южните планински и части 700-1000 Максим. ноемв.-дек. Мин.-лято	Краткотрайна-макс. за 1-2 дни	С, СИ, И, З
Планинска зона: нископланинска (до 1000 m); ср. планинска (до 1600 m) високопланинска (над 1600 m)	-2 до -3 -3,5 до -4,5 -6 до -10	15-18 10-13 6-9	800-1000 Максим. зима (юг) и пролет (север)	1-2 месеца през зимата около 3-4 месеца до 7 месеца	З, СЗ, ЮЗ *
Черноморска зона: Обхваща крайбрежната зона с ширина до 40 km	1 сев. до 3,5 юг	22-23	450 сев. до 750 на юг	в сев. част се задържа 2-4 седмици, а в южната 4-5 дни	С, СИ, И

* Зависи от сезона, формата и ориентацията на релефните форми.



Фиг. 2 Климатични зони в България

3. Определяне на тенденции в климатичните промени – резултати и дискусия

Климатичните промени в България се проявяват чрез промени в средните и екстремни температури, разпределението на валежите и увеличаване на честотата на екстремни явления като суши и наводнения. Предвид това, че климатичните зони са с различни характеристики, то и промените в тях са анализирани поотделно и са установени различни тенденции (таблица 2). Данните за температурите и валежите от климатичните станции по месеци и години [2, 3] са осреднени и са изведени уравнения на регресия за оценка на промените.

Таблица 2: Оценка на тенденциите на изменение по климатични зони

Зона, обхват	Измен. ср. год. темп. [°C]	Изм. Кол. валежи [mm/год.]
Умерено-континентална зона Оценка от станции: Видин, Ловеч, Разград и София	+0,063	-5,2
Преходно-континентална зона: Сливен и Пазарджик	+0,060	-7,9
Преходно-средиземноморска зона Оценка от станции: Кърджали и Сандански	+0,046	+2,2
Планинска зона Оценка от станции: вр. Мусала и вр. Мургаш	+0,049	-1,7
Черноморска зона Оценка от станции: Варна и Бургас	+0,061	-4

Установените промени според климатичните зони са следните:

- **Умерено-континентална зона:** Наблюдава се най-висок темп на затопляне и повишен риск от засушаване и намаляване на водните ресурси.
- **Преходно-континентална зона:** Има висок темп на повишаване на температурата, като се регистрира и максимално намаляване на валежните суми.
- **Преходно-средиземноморска зона:** Регистрират се най-малки стойности на промените на температурата, а също се наблюдава и увеличение на валежите – единствената зона с позитивен тренд на валежите.
- **Планинска зона:** Темпът на затопляне е умерен и засушаването е по-слабо изразено.
- **Черноморска зона:** Висок темп на затопляне и среден темп на засушаване, въпреки близостта до морето.

Всички райони в България показват тенденция към затопляне, а валежите намаляват във всички климатични зони, с изключение на преходно-средиземноморската, където има слабо увеличение.

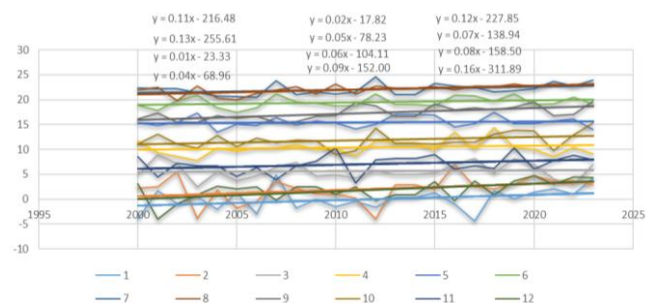
Измененията на температурата и валежите в различните хипсометрични зони показват следните тенденции:

- **Температура:** Затоплянето е по-силно изразено в низините и по-слабо в планините. Разликата между ниските и високите райони е умерена, но планинските райони все пак показват устойчивост срещу повишаване на температурни увеличения.
- **Валежи:** Най-голямо намаление на валежите се наблюдава в равнинните райони (особено преходно-континенталната зона). Във високите планини намаляват снеговалежите.

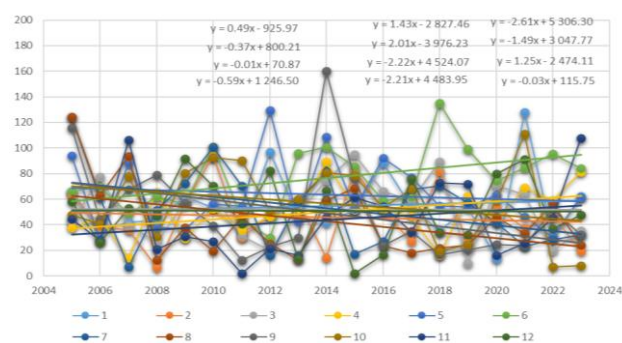
Тези тенденции подчертават по-голямата уязвимост на низините към засушавания и затопляне, докато планините се променят малко по-бавно.

Измененията в сезонността и пиковите стойности на тенденциите са представени на фиг. 3 и 4. Установяват се следните особености:

- **Температура:** Всички месеци показват увеличение на средните температури през годините, което е в съответствие с глобалните тенденции на затопляне. По-бързо затопляне за този период се наблюдава през зимата: зимните месеци (особено декември) се затоплят по-бързо в сравнение с летните. Това води до по-кратки и по-меки зими, както и до по-горещи и сухи лета.
- **Валежи:** Пролетните месеци (май и юни) показват както най-високи количества валежи, така и положителни трендове. Август и септември се характеризират с най-ниски валежни суми, които показват тенденция към намаление. Пролетта и началото на лятото стават по-влажни, докато есента става по-суха. Анализът на данните подчертава променливостта на валежите по сезони и изместването на по-големите есенни количества валежи към м. ноември.



Фиг. 3 Изменения и пикови стойности средно за страната – тенденции за температурата [°C]



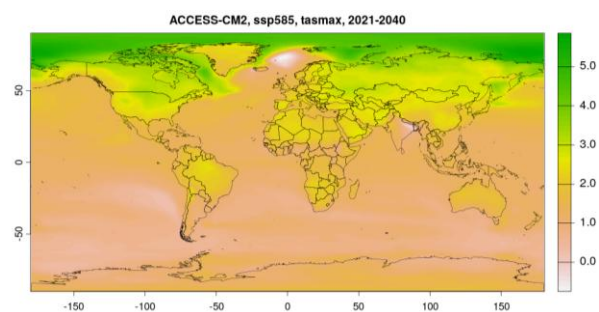
Фиг. 4 Изменения и пикови стойности средно за страната – тенденции за валежите [mm]

Уравненията на регресия, записани в горната част на фиг. 3 и 4, са по колони отгоре надолу по четиримесечия – в първата колона са януари, февруари, март и април и т.н. От значение са коефициентите пред x , като положителните стойности показват

повишаване, отрицателните – намаляване. Колкото по-голям по абсолютна стойност е коефициентът, толкова по-значителна е промяната за изследвания период.

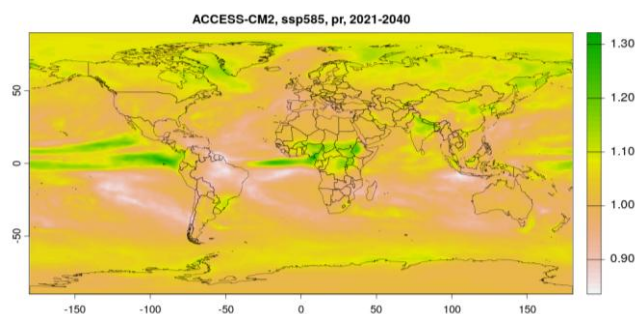
На база използваните за експеримента данни и получените средни стойности при екстраполация към бъдещ период от 15 години се очаква температурата да се повиши до 2040 с 1°C и валежите да намалят с 60 mm.

За оценка на тенденциите и определяне на най-вероятни климатични сценарии в следващите десетилетия е направена съпоставка с модели, генерирани от [7]. На фиг. 5 е представена карта на симулиран климатичен модел ACCESS-CM2 (Australian Community Climate and Earth-System Simulator – Climate Model 2), чрез който е пресъздадено изменението на температурата в краткосрочен план, до 2040 г., част от набора модели в рамките на CMIP6 (Coupled Model Intercomparison Project Phase 6), които се използват за оценка на миналото, настоящето и бъдещото състояние на климата в глобален мащаб. Моделът използва атмосферен, океански и биогеохимични компоненти и прогнозира глобалните температури, ветрове, влажност и атмосферно налягане. Избраният сценарий е SSP 5-8,5 (Shared Socioeconomic Pathway 5 – Representative Concentration Pathway 8,5), базиран на високи емисии на парникови газове. Симулирана е средната стойност на дневните максимални температури за периода 2021-2040 г. Този модел показва, че за територията на България се очаква повишаване на температурата с 2°C. При положение, че за последните 24 години температурите са се повишили с 1,5°C, то този модел изглежда реалистичен за следващите 15 години.



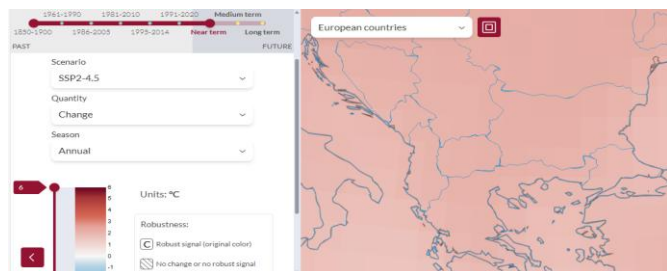
Фиг. 5 Карта на очакваните промени в максималната температура [°C], симулирана с модел ACCESS-CM2, сценарий SSP 5-8,5 [7]

На фиг. 6 е представена карта на симулиран климатичен модел ACCESS-CM2 (Australian Community Climate and Earth-System Simulator – Climate Model 2), чрез който е пресъздадено изменението на количествата на валежите също в краткосрочен план – до 2040 г. Избраният сценарий отново е SSP 5-8,5. Симулирано е количеството на валежите за периода до 2040 г. За територията на България се очаква понижаване на валежите на около 0,95 (95%) от сегашните количества. Предвид, че за последните 19 години валежите средно са намалели с около 80 mm, то и този модел изглежда реалистичен за следващите 15 години.



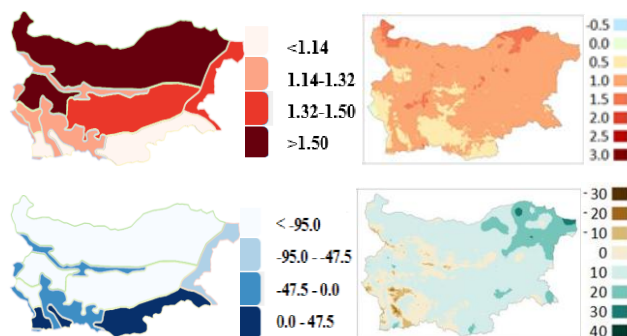
Фиг. 6 Карта на очакваните относителни промени в количествата на валежите, симулирана с модел ACCESS-CM2, сценарий SSP 5-8,5 [7]

На фиг. 7 е представена и визуализация за промените в средната годишна температура, генерирана чрез [8] – и тук, въпреки избора различен климатичен сценарий промяната в температурата е от порядъка на 1-2°C. Според [9] в новия вариант 6 на глобалните климатични модели всички сценарии достигат 1,5 °C затопляне в сравнение с базовата линия от 1850–1900 г. през втората половина на текущото десетилетие, като периодът от време между бавното и бързото затопляне обхваща между 20 и 27 години от настоящето.



Фиг. 7 Карта на очакваните промени в температурата на годишна база до 2040 г. – сценарий SSP 2-4.5 [8]

Направена е и съпоставка на полученото пространствено разпределение на тенденциите на изменение на температурата и валежите по климатични зони с данни на НИМХ [10].



Фиг. 8 Съпоставка на полученото пространствено разпределение на тенденциите на изменение на температурата и валежите по климатични зони с данни [10]

Тук трябва да се отбележи това, че разликите в пространствено разпределението стойности на НИМХ са изчислени от осреднени температури и валежи в два последователни 30-годишни интервала – 1961-1990 и 1991-2020. В случая за температурата тенденциите се потвърждават, но при валежите няма съответствие. Това може да се дължи на факта, че в настоящото изследване се разглеждат само 16 години от втория 30-годишен интервал (1990-2020), както и на ускорените климатични промени и промените атмосферни циркулационни модели в последното десетилетие и на влиянието на орографията. За изясняване на различията са необходими допълнителни анализи, към които ще бъде насочена бъдещата работа на авторите.

4. Заключение

Изследването анализира климатичните промени в България чрез ГИС-базирано моделиране с използване на метеорологични данни и съпоставка на получените резултати с актуални глобални климатични модели.

Изводите са следните:

Тенденция на затопляне във всички климатични зони, особено в равнинните райони на умерено- и преходно-континенталната зона. Зимите се затоплят по-бързо от летата, наблюдават се по-кратки зими и по-дълги топли периоди.

Намаление на валежите в почти всички зони, с изключение на преходно-средиземноморската, където има леко увеличение. Пролетта става по-влажна, а есента – по-суха, което увеличава риска от суши.

Установено е съответствие с глобалните проекции на климатичните модели (напр. ACCESS-CM2), според които затоплянето ще е с около 2 °C до 2040 г. и валежите ще намалят до 95% от сегашните нива.

България следва глобалните климатични тенденции, но с отчетливи регионални и сезонни различия, което подчертава нуждата от регионални и локални анализи, продължаващо наблюдение и устойчиво планиране. Климатичните промени изискват адаптивни политики, особено за уязвимите равнинни райони.

В заключение може да се каже, че ГИС технологията доказва своята ефективност като инструмент, който допринася за оценка на климатичните рискове и планиране на адаптивни мерки на локално и национално ниво. Продължаващото наблюдение и моделиране на тези промени е ключово за устойчивото развитие и минимизиране на рисковете за околната среда, икономиката и обществото.

5. Благодарности

Авторите на публикацията изказват благодарност за финансовата подкрепа на ЦНИП при УАСГ в рамките на проект „ГИС-базиран анализ на въздействието на климатичните промени върху пътната инфраструктура за изграждане на адаптивен капацитет“, Договор № БН-307/2024 година.

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Оценка на климатичните тенденции в България и тяхното влияние върху строителството и експлоатацията на сгради и пътнотранспортна инфраструктура

Тамара Илиева¹, Стоянка Иванова¹, Евелина Иванова¹, Симеон Матев²

Университет по архитектура, строителство и геодезия¹

Софийски университет „Св. Климент Охридски“²

ilieva_fgs@uacg.bg, siva_fce@uacg.bg, eivanova_fte@uacg.bg, smatev@gea.uni-sofia.bg

Резюме: Настоящата публикация представя актуалните климатични тенденции, идентифицирани на територията на България, въз основа на метеорологични данни за минали периоди, с фокус върху оценката на тяхното потенциално влияние върху строителството и експлоатацията на сгради и пътнотранспортна инфраструктура. Изследването анализира основните промени в температурите и валежите през последните десетилетия, както и очакваните бъдещи изменения в контекста на глобалните климатични модели. Тези промени трябва да бъдат интегрирани в строителните норми и стандарти, тъй като могат да доведат до сериозни последици за строителния и транспортен сектор. Специално внимание е обърнато на устойчивостта на сградите и пътнотранспортната инфраструктура спрямо екстремни метеорологични явления. Заключениеето подчертава необходимостта от включване на климатичните прогнози в процесите на планиране и управление на строителството, както и разработването на адаптивни стратегии за минимизиране на рисковете и повишаване на устойчивостта на инфраструктурата. Публикацията предлага насоки за институции и специалисти в областта на строителството с цел подобряване на готовността за справяне с климатичните промени.

Ключови думи: КЛИМАТИЧНИ ПРОМЕНИ, ТЕНДЕНЦИИ, СТРОИТЕЛСТВОТО, ЕКСПЛОАТАЦИЯ, СГРАДИ, ПЪТНОТРАНСПОРТНА ИНФРАСТРУКТУРА

Assessment of climatic trends in Bulgaria and their influence on the construction and exploitation of buildings and road transport infrastructure

Tamara Ilieva¹, Stoyanka Ivanova¹, Evelina Ivanova¹, Simeon Matev²

University of Architecture, Civil Engineering and Geodesy¹

Sofia University "St. Kliment Ohridski"²

ilieva_fgs@uacg.bg, siva_fce@uacg.bg, eivanova_fte@, smatev@gea.uni-sofia.bg

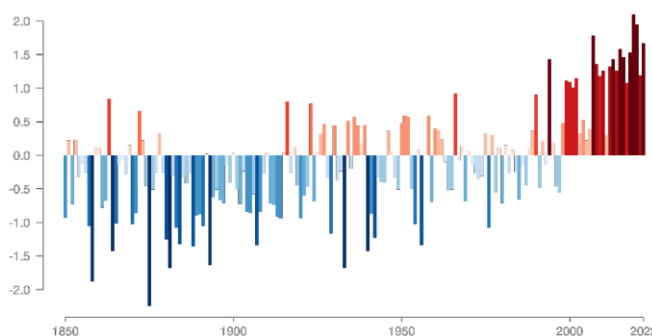
Abstract: This publication presents the current climate trends identified on the territory of Bulgaria, based on meteorological data for past periods, with a focus on the assessment of their potential impact on the construction and operation of buildings and road transport infrastructure. The study analyzes the main changes in temperatures and precipitation in recent decades, as well as the expected future changes in the context of global climate patterns. These changes must be integrated into building codes and standards, as they can have serious consequences for the construction and transport sectors. Special attention is paid to the resilience of buildings and road transport infrastructure against extreme weather events. The conclusion emphasizes the need to incorporate climate forecasts into construction planning and management processes, as well as the development of adaptive strategies to minimize risks and increase infrastructure resilience. The publication offers guidance for institutions and construction professionals to improve climate change preparedness.

Keywords: CLIMATE CHANGES, TRENDS, CONSTRUCTION, OPERATION, BUILDINGS, ROAD TRANSPORT INFRASTRUCTURE

1. Въведение

Климатичните промени се превръщат във все по-значим фактор, който оказва влияние върху всички аспекти на човешката дейност, включително строителството и транспортната инфраструктура. В контекста на нарастващата честота и интензивност на екстремните метеорологични явления, осъзнаването на климатичните тенденции и тяхното въздействие върху сградите и пътната мрежа става критично. България, със своята географска и климатична специфика, също е обект на съществени промени в температурните режими (Фиг. 1) и разпределението на валежите, което налага адаптиране на подходите при проектиране, строителство и управление на инфраструктурата.

Влиянието на климатичните промени върху проектирането на сгради и съоръжения в България е било изследвано и по-рано. В [1] се изследват промените на слънчевата радиация за България и несъответствието с нормативните соларни стойности. В [2] се обсъждат насоки за проектиране на сгради, съобразени с бъдещите климатични сценарии, отразени в глобални и регионални климатични модели. В [3] се разглежда проект на сграда в София, проектирана по настоящите климатични норми в България и изследвана в симулация за климатични условия след 50 години, като се установява значително увеличение на потребността от енергия за охлаждане в бъдеще.



Фиг. 1. Относителни температурни промени за България от 1850 до 2022 г. спрямо средните за периода 1971 – 2000 г. в °C [4].

Настоящата статия изследва основните климатични промени в страната, като анализира тяхното потенциално влияние върху устойчивостта и експлоатационните характеристики на строителните съоръжения и пътнотранспортната мрежа. Целта е да се подчертае необходимостта от интеграция на климатичните прогнози и климатични сценарии в националните строителни стандарти и стратегиите за управление на инфраструктурата, като се предложат конкретни насоки за повишаване на готовността и устойчивостта на сектора спрямо бъдещи предизвикателства.

2. Климатични промени и тенденции на територията на България – връзка със строителните норми

Климатичните промени са глобално явление, но техният ефект върху България е ясно изразен. Анализът на метеорологичните данни за последните две десетилетия разкрива следните тенденции:

2.1. Оценка на климатичните промени

Повишаване на температурите: Средните годишни температури в страната нарастват, като се наблюдава тенденционно затопляне през зимата и по-честа поява на екстремни горещини през летните месеци. Това води до:

- Увеличаване риска от засушаване.
- Увеличаване на риска от пожари.
- Повишена честота на екстремни температурни амплитуди, които създават натоварване върху строителните материали.

Изменение на валежния режим: Валежите стават все по-непредвидими, с ясно изразени тенденции:

- Намалване на общото количество валежи в някои райони, което води до повишен риск от ветрова ерозия на почвата.
- Увеличение на краткотрайните, но силни валежи, които предизвикват наводнения.

Екстремни метеорологични явления: Нараства честотата на градушки, бури и ураганни ветрове, особено в Дунавската равнина и Тракийската низина, а това създава пряка опасност за сградите и пътната инфраструктура.

2.2. Проявление на климатичните промени в различните зони на България

За климатичните промени и тенденциите по отношение на температурните и валежни режими е установено, че в различните части на страната имат различно проявление. При предходни проучвания на авторите е установено, че принадлежността на териториите към дадена климатична зона има значение и тенденциите за всяка от тях са следните:

- Умерено-континентална зона: Най-висок темп на затопляне и повишен риск от засушаване.
- Преходно-континентална зона: Висок темп на повишаване на температурата, като там се регистрира и максимално засушаване.
- Преходно-средиземноморска зона: Регистрират се най-малки стойности на промените на температурата и валежите.
- Планинска зона: Темпът на затопляне е умерен и е налице засушаване (намалване на снеговалежите).
- Черноморска зона: Висок темп на затопляне и среден темп на засушаване, въпреки близостта до морето.

Измененията на температурата и валежите по височина, като се разгледат зоните, които обхващат различни надморски височини, показват следните тенденции:

- **Температура:** Затоплянето е по-силно изразено в низините и по-слабо в планините. Разликата между ниските и високите райони е умерена, но планинските райони все пак показват известна устойчивост срещу по-високите температурни увеличения.
- **Валежи:** Най-голямо намаление на валежите се наблюдава в равнинните райони (особено преходно-

континенталната зона). Високите планини са относително по-малко засегнати от тази тенденция, но има видимо намаляване на снеговалежите.

Тези тенденции подчертават уязвимостта на низините към засушавания и затопляне, докато планините запазват по-благоприятни климатични условия, макар че и те се променят.

Всички райони в България показват положителна тенденция на затопляне, а валежите намаляват във всички климатични зони, с изключение на преходно-средиземноморската, където има слабо увеличение.

2.3. Влияние на климатичните промени върху подходите при проектиране и експлоатация

Настоящите климатични тенденции изискват преосмисляне на подходите при проектиране и експлоатация на сградите и пътнотранспортната инфраструктура:

За сградите:

- Топлинните вълни изискват нови стандарти за топлоизолация и охлаждане. Те влияят и върху термичните деформации на материалите.
- Екстремните валежи налагат подобрения в системите за отводняване на покриви и фасади, а също и проектирането на системи за дренаж и влагоустойчиви конструкции.
- Необходимост от по-здрави конструкции, устойчиви на динамичните натоварвания от силни ветрове и градушки.
- Конструкцията на сградите трябва да се проектират устойчиви срещу силни до ураганни ветрове.

За пътнотранспортната инфраструктура:

- Високите температури предизвикват деформации на асфалтовите настилки.
- Наводненията увреждат пътната основа и водят до ерозия на склоновете около пътищата, затова е необходимо да се осигури устойчива основа на пътната настилка.
- Устойчивостта на мостовете и тунелите срещу наводнения и преливания трябва да бъде подсилена.
- Пътната инфраструктура трябва да отчита риска от ветрови ефекти, особено при мостове.

3. Действащи строителни норми

Климатичните фактори – температура, валежи, вятър, сняг и екстремни явления – оказват значително влияние върху проектирането, строителството и експлоатацията на сгради и пътна инфраструктура. Българските нормативни документи отчитат тези фактори чрез регулации, стандарти и указания, които целят да осигурят безопасност, дълготрайност и устойчивост на строителните обекти.

Климатичните фактори са интегрирани в българските нормативни документи и прилаганите международни стандарти, използвани у нас:

3.1. За сгради

- Наредба № РД-02-20-2 от 2012 г. за проектиране на сгради и строителни конструкции [5] – тя отчита снегонатоварвания, ветрови натоварвания и сеизмична устойчивост, както и посочва зонирването на територията на България по снежни и ветрови карти.
- Наредба № РД-02-20-3 от 9.11.2022 г. за техническите изисквания към енергийните характеристики на сгради [6] – това е относително нов нормативен документ,

който регулира изискванията за изграждане на енергийно ефективни сгради. Обаче той е базиран на климатични и соларни данни, публикувани за първи път в Наредба № РД-16-1058 от 10.12.2009 г. за показателите за разход на енергия и енергийните характеристики на сградите [7], като са определени на база на измервания на температурата в метеорологични станции на територията на България в предходния 30-годишен климатичен период (1961 – 1990 г.).

- БДС EN 1991:2004 Еврокод 1 [8]: Въздействия върху строителните конструкции – регулира въздействията от сняг, вятър, температури и други климатични натоварвания.

3.2. За пътна инфраструктура

За нуждите на анализа е важно да се отбележи, че при съставянето на нормативната уредба в България, която се отнася до пътната инфраструктура и транспортните съоръжения към нея, няма изградени практики, да се съобразяват проектите параметри с климатичните тенденции. Разбира се, препоръките в отделните части на стандартите и наредбите са приети, така че да отчитат специфики на околната среда и климатичните за съответната национална територия, но като цяло са с високо ниво на консервативност при съставянето им. Това означава, че разписаните разпоредби, които ги съставят, осигуряват проектни параметри на трасетата при стандартни експлоатационни условия и заложено ниво на пътна безопасност. Тази характеристика в комбинация с продължителните времеви периоди на преразглеждане на наредбите ги прави нерелевантни на скоростта, с която се развиват климатичните рискове.

По-важните нормативни документи, с които се обезпечават пътищата и транспортните съоръжения към тях са:

- Наредба № РД-02-20-2 от 28 август 2018 г. за проектиране на пътища от 27 септември 2018 г. – в обхвата ѝ фигурират препоръки към частите трасе на пътя, пътно платно, земно тяло и други, които имат отношение към осигуряването на експлоатационните показатели на пътните участъци и по отношение на влиянието на климата [9]. Действието ѝ е в границите на неурбанизираните територии.
- Наредба № РД-02-20-2 от 20 декември 2017 г. за планиране и проектиране на комуникационно-транспортната система на урбанизираните територии от 27 ноември 2018 г. – в обхвата ѝ фигурират препоръки към комуникационно-транспортните системи, проектирането на пешеходни, велосипедни и улични трасета, и други [10]. Действието ѝ е в границите на урбанизираните територии.

И двата нормативни документа съдържат препоръки за укрепителни и стабилизиращи елементи, отводняване, видимост, снегонавявания и други.

- Наредба № РД-02-20-2 от 21 декември 2015 г. За технически правила и норми за проектиране на пътни тунели. Документът съдържа препоръки за проектиране, които изискват съобразяване с инженерно-геоложките условия, въздействия на околната среда от климатично провокирани събития и други [11].
- Техническа спецификация от 2014 г. и Технически правила и изисквания за поддържане на пътища от 2009 [12, 13]. Това са документи от нормативната база, съставена от Агенция пътна инфраструктура, насочени към изпълнението и поддръжката на пътищата и транспортните съоръжения към тях.
- Ръководство за оразмеряване на асфалтови пътни настилки от 2003 [14]. Документът използва методика, с

която се проектират пътните настилки, включително съобразно елементи на околната среда.

- Национални стандарти: БДС EN 1317 [15]: Ограничителни системи за пътища и националното приложение към тях. В него са регламентирани изисквания за оценяване на дълготрайността във връзка с атмосферните условия като част от елементите на климата, с които взаимодействат по време на експлоатация.
- БДС EN стандарти за проектиране на транспортни съоръжения – всички части на системата Еврокод от 0 до 9 и националните приложения към тях. По отношение на въздействията, всички видове, включително климатично провокираните от тях, са залегнали в БДС EN 1991:2004 Еврокод 1: Въздействия върху строителните конструкции.

3.3. Международни стандарти

- Системата от стандарти на CEN Еврокод с номера от 0 до 9 [16] са международен регламентен пакет, в който специфичните особености на съответната страна членка са регламентирани в групата на Националните приложения към дадената част [17]. Деветте части обхващат проектирането на всички сгради и съоръжения, включително част Геотехника и част Сеизмично осигуряване. По отношение на въздействията, всички видове са залегнали в EN 1991 2002.
- ISO 14001 и ISO 14090 – за адаптация към ефектите и смекчаване на изменението на климата.

4. Насоки за устойчиво проектиране и адаптация към климатичните промени.

Променящите се климатични условия налагат обновяване и разширяване на строителните норми. Необходими са следните мерки:

- Устойчивост на екстремни явления: сгради, устойчиви на бури, градушки и наводнения.
- По-строги стандарти за изолация и енергийна ефективност: материали с висока термична устойчивост за справяне с топлинни вълни и променливи температури.
- Пасивен сграден дизайн: подходяща ориентация, засенчвания, зелени покриви, усъвършенствана изолация, естествена вентилация и зелена околна среда за намаляване на прегряването и енергийните загуби.
- Активни мерки: PV панели в засенчващи устройства, интелигентни стъкла, адаптивни фасади, адаптивна архитектура и фазово-променящи се материали.
- Адаптивни технологии: зелени покриви, устойчиви материали и системи за рециклиране на водите.
- Регионално зонироване: стандарти, съобразени с климатичните рискове в различни части на България.

Адаптирането на сградите към променящите се климатични условия чрез устойчиви материали, ефективен дизайн и адаптивни технологии ще осигури по-голяма сигурност, енергийна ефективност и устойчивост на строителните обекти в България.

5. Предложения за промени в нормативните документи, предвид тенденциите в изменението на климата

Съществуващите строителни норми и стандарти в България все още не отразяват напълно климатичните тенденции. За да

се гарантира устойчивостта на строителните обекти към новите климатични реалности, е необходимо да се интегрират следните ключови аспекти:

1. Обновяване на нормативите: Въвеждане на параметри, които отразяват очакваните екстремни температури, интензивността на валежите, както и изисквания за устойчивост към силни ветрове и наводнения. Това ще осигури по-добра защита на сградите и инфраструктурата срещу климатичните промени и ще намали риска от разрушения.

2. Приспособяване към регионалните различия: В райони с чест риск от наводнения е необходимо прилагане на по-високи стандарти за отводняване, включително ефективни дренажни системи. В зони с висока влажност трябва да се използват материали, устойчиви на корозия и влага, за да се гарантира дълготрайността и ниските разходи за поддръжка на сградите.

3. Интеграция на адаптивни решения: Внедряване на зелени технологии като покривни градини и вертикални зелени фасади за намаляване на температурния ефект и подобряване на микроклимата в урбанизирани райони. Създаване на устойчиви системи за управление на дъждовните води, включително задържащи резервоари и възможности за рециклиране на водата за вторично използване, като например поливане на зелени площи.

Тези предложения ще допринесат за по-ефективно справяне с климатичните промени, като увеличават устойчивостта на строителните обекти, намаляват риска от щети и осигуряват по-дългосрочна ефективност на инвестициите в строителството.

6. Заключение

Интегрирането на климатичните прогнози в строителните норми е от ключово значение за повишаване на устойчивостта на сградите и инфраструктурата в България. Прилагането на адаптивни стратегии ще намали риска от бъдещи щети, ще намали загубите от влиянието на климатичните промени върху икономиката и ще осигури дълъг живот на строителните обекти и ще подобри готовността за справяне с климатичните промени.

Климатичните промени са критичен фактор, който трябва да оказва съществено влияние върху проектирането, строителството и експлоатацията на сгради и пътнотранспортна инфраструктура в България. Анализът на температурните и валежните тенденции разкрива ясно изразено затопляне и промяна в разпределението на валежите, които изискват интегриране на адаптивни стратегии и нови стандарти в строителните норми.

Основните изводи от изследването включват:

- Необходимост от актуализиране на нормативните изисквания с оглед на бъдещите климатични сценарии, които отразяват очакваните екстремни температури, валежи и екстремни метеорологични явления.
- Въвеждане на устойчиви и адаптивни решения в проектирането на сгради и инфраструктура, включително зелени технологии, интелигентни системи и повишена устойчивост на екстремни явления.
- Значение на регионалното зонироване за отчитане на специфичните климатични особености на различните райони в страната.

Изводите от изследването подчертават нуждата от координирани усилия между научните среди, институциите и строителния сектор с цел създаване на устойчиви и дълготрайни инфраструктурни решения. Действията по адаптация към променящите се климатични условия ще намали риска от бъдещи щети, загубите от влиянието на климатичните

промени върху икономиката и ще допринесат за по-висока енергийна ефективност, икономическа устойчивост и по-добра жизнена среда за бъдещите поколения.

7. Благодарности

Авторите на публикацията изказват благодарност за финансовата подкрепа на ЦНИП при УАСГ в рамките на проект „ГИС-базиран анализ на въздействието на климатичните промени върху пътната инфраструктура за изграждане на адаптивен капацитет“, Договор № БН-307/2024 година.

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Technologies for additive manufacturing of metal structures

Adelina Miteva¹, Gyunver Hodjaoglu²

Space Research and Technology Institute, Bulgarian Academy of Sciences, Sofia, Republic of Bulgaria¹

Institute of Physical Chemistry, Bulgarian Academy of Sciences, Sofia, Republic of Bulgaria²

ad.miteva@gmail.com¹, gyunver@ipc.bas.bg²

Abstract: Additive manufacturing (AM) of metal structures is transforming industries by enabling the creation of complex, efficient, and customizable components. This article explores key AM technologies for metals, including Powder Bed Fusion (PBF), Directed Energy Deposition (DED), Binder Jetting, Metal Extrusion, and Sheet Lamination. Each is analyzed in terms of principles, strengths, limitations, and applications. A comparative evaluation highlights factors like precision, scalability, cost, and environmental impact to identify optimal technologies for various industries. Despite its advantages, challenges remain in material quality, process reliability, cost, and certification. Emerging trends such as hybrid manufacturing, AI-driven process optimization, advanced materials, and sustainable practices hold promise for overcoming these barriers. By examining current technologies and future opportunities, this article provides valuable insights for advancing metal AM in diverse applications.

Keywords: ADDITIVE MANUFACTURING, METAL STRUCTURES, POWDER BED FUSION (PBF), DIRECTED ENERGY DEPOSITION (DED), BINDER JETTING, METAL EXTRUSION, SHEET LAMINATION, HYBRID MANUFACTURING, SUSTAINABLE MANUFACTURING

1. Introduction

Additive manufacturing (AM), commonly known as 3D printing [1-3], has emerged as a transformative technology in modern manufacturing, enabling the layer-by-layer construction of complex and intricate geometries directly from digital models. This approach contrasts with traditional subtractive methods, offering significant advantages such as material efficiency, design flexibility, and reduced lead times. Over the past two decades, AM has advanced beyond its initial use for rapid prototyping and evolved into a robust method for producing functional components across various industries.

Metal additive manufacturing [4-7], in particular, has gained prominence due to its ability to produce high-performance parts with superior mechanical properties and lightweight designs. Industries such as aerospace, automotive, medical, and construction have embraced AM for metals to address demanding requirements for strength, durability, and precision. In aerospace, AM enables the production of lightweight but structurally strong components, reducing fuel consumption. Automotive manufacturers leverage AM for rapid design iterations and custom parts, while the medical sector benefits from personalized implants and prosthetics. In construction, metal AM offers solutions for creating complex architectural structures and infrastructural components with minimal waste.

This review aims to provide a comprehensive exploration of key additive manufacturing technologies specifically tailored for metal structures. It examines their working principles, advantages, limitations, and suitability for various applications. Technologies covered include Powder Bed Fusion (PBF), Directed Energy Deposition (DED), Binder Jetting, Metal Extrusion, and Sheet Lamination. A comparative analysis highlights the strengths and weaknesses of each method across critical performance metrics such as precision, scalability, cost, and environmental impact.

The article also discusses the current challenges faced by metal AM, including material quality, process reliability, certification, and economic constraints. Emerging trends such as hybrid manufacturing, artificial intelligence (AI) integration and sustainable practices are explored as potential solutions to these barriers. By focusing on the present state and future directions of metal AM, this article seeks to guide researchers and industry professionals in advancing the adoption of this transformative technology across diverse fields.

2. Classification of AM Technologies for Metals

The development of additive manufacturing (AM) technologies for metals [4-7] has led to a range of methods optimized for specific applications. These methods enable the creation of metal components with varying complexity, precision, and performance. AM technologies for metals can be classified based on material

type, energy source, and process flow, offering a systematic understanding of the available approaches.

1. Classification by Material Type

AM methods for metals are designed to handle different forms of feedstock, including:

- **Powders:** Common in Powder Bed Fusion (PBF) and Binder Jetting, where metal powder is fused or bonded layer by layer.
- **Wire:** Used in Directed Energy Deposition (DED) processes that employ wire as the primary feedstock for building parts.
- **Filaments:** Found in metal extrusion techniques, where a metal-polymer composite filament is extruded and subsequently sintered.
- **Sheets:** Utilized in Sheet Lamination, where thin metal sheets are bonded and shaped layer by layer.

Each material type offers unique advantages, such as high material utilization (powder and wire) or cost efficiency (sheet and filament-based methods).

2. Classification by Energy Source

The energy source plays a crucial role in determining the process mechanisms and applications of metal AM technologies. Key categories include:

- **Laser-Based Systems:** Common in PBF (Selective Laser Melting, SLM) and DED, lasers provide high precision and control for melting or sintering metal feedstock.
- **Electron Beam Systems:** Used in processes like Electron Beam Melting (EBM), electron beams deliver high energy levels for melting metal powders in a vacuum environment.
- **Arc-Based Systems:** Often used in wire-based DED, electric arcs provide a cost-effective and scalable energy source for metal deposition.
- **Binder and Chemical Processes:** Found in Binder Jetting, where binding agents solidify metal powder layers without requiring direct melting.
- **Ultrasonic Energy:** Utilized in Sheet Lamination, where ultrasonic welding bonds metal sheets into a cohesive structure.

Each energy source offers trade-offs in terms of precision, build speed, energy efficiency, and part quality.

3. Classification by Process Flow

The workflow of AM technologies for metals can be categorized into distinct stages, affecting the final part's quality and application. Key classifications include:

- **Powder Bed Processes:** Methods like PBF involve spreading a layer of powder over a build platform, followed by selective fusion using lasers or electron beams. These processes are known for high precision and excellent mechanical properties but have slower build rates.
- **Directed Deposition Processes:** DED and similar methods deposit material directly onto a surface in a controlled manner, offering versatility in repair and large-scale applications.

- **Binder-Based Processes:** Techniques like Binder Jetting use a liquid binder to join metal powder particles layer by layer, with sintering or infiltration required to achieve final part strength.
- **Extrusion-Based Processes:** Metal extrusion methods rely on the deposition of a composite filament, followed by debinding and sintering steps to create functional parts.
- **Sheet-Based Processes:** Sheet Lamination techniques involve bonding and cutting metal sheets layer by layer, offering high speed and material efficiency but limited geometrical complexity.

By organizing metal AM technologies into these categories, we can better understand the trade-offs and applications of each approach, laying the groundwork for selecting the most suitable method for specific industrial needs.

3. Key Technologies

Additive manufacturing (AM) for metals includes various key technologies designed to meet specific needs in material properties, precision, and application. These methods allow for the production of complex metal structures, offering design flexibility and material efficiency, though they also present challenges in cost, speed, and scalability. Below is an overview of the main technologies used in metal AM.

3.1. Powder Bed Fusion (PBF)

Techniques: Selective Laser Melting (SLM) - Uses a laser to melt and fuse metal powder particles, producing fine details and excellent mechanical properties; Electron Beam Melting (EBM) - Uses an electron beam to melt metal powders, effective for high-melting-point metals like titanium. **Mechanisms:** Metal powders are spread across a build platform, melted layer by layer by a laser or electron beam, bonding them to the layer below. **Applications:** Used in aerospace, medical implants, and automotive industries for producing complex geometries. **Advantages and Limitations:** Advantages - High precision and complex part production; Limitations - High equipment costs, slow build rates, and need for post-processing.

3.2. Directed Energy Deposition (DED)

Techniques: Laser-Based DED - Uses a laser to melt metal powder or wire, forming the structure layer by layer; Arc-Based DED - Uses an electric arc to melt metal wire, depositing it onto the build surface. **Mechanisms:** Energy is directed at the material, melting it and allowing it to deposit layer by layer. **Applications:** Used for large parts, such as turbine blades, and for repairs in aerospace and defense [8-12]. **Advantages and Limitations:** Advantages - Flexibility in material use and part size; Limitations - Lower resolution and surface finish compared to PBF.

3.3. Binder Jetting

Mechanisms: Metal powder is layered, with a binder selectively applied, followed by sintering to remove the binder and fuse the metal. **Applications:** Ideal for medium-sized parts in industries like automotive and aerospace. **Advantages and Limitations:** Advantages - Fast and cost-effective, suitable for complex geometries; Limitations - Lower strength and density compared to PBF and DED, requiring additional post-processing.

3.4. Metal Extrusion

Techniques: Bound Metal Deposition (BMD) - Metal-polymer composite filament is extruded, followed by heating and sintering; Fused Filament Fabrication (FFF) - Similar to BMD but uses a metal filament mixed with polymer binder. **Mechanisms:** The filament is extruded layer by layer, followed by debinding and sintering to achieve full metallization. **Applications:** Primarily for prototyping and low-volume production of metal parts. **Advantages and Limitations:** Advantages - Cost-effective, simple setup, suitable for prototyping; Limitations - Limited material options, requires post-processing.

3.5. Sheet Lamination

Techniques: Ultrasonic Additive Manufacturing (UAM) - Uses ultrasonic welding to bond metal sheets layer by layer. **Mechanisms:** Metal sheets are bonded together and machined to achieve the desired shape. **Applications:** Used for lightweight structural components in aerospace and automotive industries. **Advantages and Limitations:** Advantages - Fast and low-cost for

large parts; Limitations - Limited material options and lower resolution.

These key technologies serve different industrial needs, based on factors such as material, part complexity, and production speed. Understanding the advantages and limitations of each method is critical for selecting the most appropriate technology for specific applications.



Fig. 1 An image of a metal turbine blade

Figure 1 shows an image (made by AI) of a metal turbine blade designed for aerospace applications, manufactured using additive manufacturing. The intricate cooling channels and polished surface demonstrate the advanced engineering and precision achievable with this technology.

4. Comparative Analysis

Selecting the appropriate additive manufacturing (AM) technology for metal structures requires evaluating performance metrics, application suitability, and environmental impact. This section compares key technologies based on accuracy, material properties, build speed, cost, scalability, and environmental factors.

Performance Metrics

- **Accuracy:** PBF (Selective Laser Melting and Electron Beam Melting) provides high precision, suitable for complex geometries; DED offers lower resolution but is ideal for large-scale parts or repairs; Binder Jetting and Metal Extrusion have lower accuracy, often requiring post-processing.

- **Material Properties:** PBF delivers parts with superior mechanical properties (high tensile strength); DED is good for repairs but lacks the precision of PBF; Binder Jetting and Metal Extrusion produce parts with lower mechanical strength, requiring post-processing.

- **Build Speed:** DED has the fastest build times for larger parts; Binder Jetting is also quick for medium-sized parts; PBF is slower due to the scanning process; Metal Extrusion and Sheet Lamination are the slowest.

- **Cost:** PBF has high upfront and operational costs due to expensive materials and equipment; DED is more affordable than PBF but still involves high costs for equipment; Binder Jetting is cost-effective for medium volumes, using cheaper materials; Metal Extrusion and Sheet Lamination are the least expensive but have trade-offs in material properties.

- **Scalability:** DED is highly scalable for large parts or repairs; PBF is best for low to medium-volume, high-precision production; Binder Jetting scales well for medium-volume production of less-critical parts; Metal Extrusion and Sheet Lamination are better for low-volume or prototyping.

Application Suitability

- **Aerospace:** PBF is ideal for lightweight, high-performance parts; DED suits large components and repairs; Binder Jetting is used for prototypes but not for high-strength parts; Metal Extrusion and Sheet Lamination have niche uses in lightweight structures.

- **Automotive:** PBF is used for high-performance parts with complex geometries; DED works for larger automotive components and repairs; Binder Jetting is suitable for prototypes and medium-

sized parts; Metal Extrusion and Sheet Lamination are used for low-volume production and lightweight parts.

- **Medical:** PBF is favored for biocompatible implants and prosthetics; DED is used for repairs and custom prosthetics; Binder Jetting is less common due to material limitations; Metal Extrusion and Sheet Lamination are not widely used in medical applications.

Environmental Considerations

- **Energy Consumption:** PBF requires high energy for laser or electron beam melting; DED is more energy-efficient, especially with arc-based systems; Binder Jetting is the most energy-efficient; Metal Extrusion and Sheet Lamination are relatively low in energy use.

- **Waste Generation:** PBF generates excess powder, but it can be recycled; DED produces minimal waste, mainly excess material; Binder Jetting and Metal Extrusion also create waste, but recycling is possible; Sheet Lamination generates minimal waste from cutting and machining.

- **Recyclability:** PBF and DED can recycle unused powder or wire; Binder Jetting parts can be fully recycled post-sintering; Metal Extrusion and Sheet Lamination are harder to recycle due to binder content.

In conclusion, the choice of AM technology for metal structures depends on factors like performance, cost, scalability, and environmental impact. PBF and DED are ideal for high-precision and large-scale parts but come with higher costs, while Binder Jetting and Metal Extrusion offer cost-effective solutions for lower-performance applications. Environmental considerations, such as energy consumption and recyclability, should also influence the selection process.

5. Challenges and Limitations

Additive manufacturing (AM) for metal structures offers promising advancements but faces several challenges across technical, economic, environmental, and regulatory domains. These factors affect its broader adoption, particularly in industries demanding high precision and performance.

5.1. Technical Challenges

Material Availability and Quality: Limited availability and inconsistent quality of metal powders and filaments are significant hurdles. Properties like particle size and flowability impact part integrity and performance, with variations leading to defects.

Process Reliability and Repeatability: Ensuring consistent outcomes across production runs is challenging due to variability in machine calibration, material quality, and environmental conditions. Reliable process control is critical for applications in aerospace and medical fields [13-15].

Resolution and Surface Finish: Some methods, like Powder Bed Fusion (PBF), offer high resolution but often require post-processing for better surface finish. Technologies like Directed Energy Deposition (DED) or Metal Extrusion have lower resolution, adding to the overall time and cost.

5.2. Economic Challenges

High Costs: Metal AM requires significant upfront investment in machines and materials. Technologies like PBF and DED are expensive, both in capital and operational costs, limiting accessibility for smaller companies.

5.3. Environmental Challenges

Energy Use and Material Waste: Energy-intensive processes, particularly PBF, require high-powered lasers. While some metal powders are recyclable, not all are recoverable, leading to material waste. Efficient recycling and waste management remain key concerns.

5.4. Regulatory Challenges

Certification and Standardization: Obtaining certification for metal AM parts is a slow and costly process, especially in industries like aerospace and healthcare. The lack of established standards complicates regulatory approval and industrial adoption.

In summary, AM for metal structures faces challenges including material quality, process reliability, high costs, environmental impact, and regulatory hurdles. Addressing these issues requires ongoing innovation and collaboration across industries.

6. Emerging Trends and Future Directions

Additive manufacturing (AM) of metal structures continues to evolve, driven by advancements in materials, integration with other manufacturing methods, automation, and a growing emphasis on sustainability. These emerging trends are shaping the future of AM, enabling broader applications and improving its efficiency and environmental impact.

New Materials [18]

- **Alloys and Composites:** The development of specialized metal alloys tailored for AM processes, such as lightweight titanium-aluminum alloys or high-strength steel, is expanding the range of applications. Advanced composites combining metals with ceramics or polymers are being introduced to enhance properties like wear resistance, thermal stability, or conductivity.

- **Advanced Metals:** Efforts are underway to create functionally graded materials (FGMs) that offer varying properties within a single part, enhancing performance in critical applications like aerospace and energy.

Hybrid Manufacturing

- **Integration with Subtractive Methods:** Hybrid manufacturing, which combines AM with traditional machining methods, is gaining traction. For example, AM can produce complex geometries, while CNC milling provides high-precision finishing. This integration allows manufacturers to leverage the strengths of both techniques, enabling faster production cycles and improved part quality.

- **Repair and Retrofit Applications:** Hybrid systems are increasingly used to repair and refurbish high-value components, such as turbine blades, where AM builds new material onto worn areas, followed by precision machining for final touches.

Automation and AI

- **Process Automation:** The integration of sensors, robotics, and automated control systems is streamlining the AM process, reducing human intervention, and ensuring consistent quality. Automated powder handling and part removal systems are improving throughput in high-volume production environments.

- **AI-Driven Optimization:** Artificial intelligence (AI) and machine learning algorithms are enhancing design optimization, defect prediction, and real-time monitoring. AI can help identify optimal process parameters, reducing trial-and-error experimentation and improving efficiency.

Sustainability Initiatives

- **Eco-Friendly Practices:** Efforts to reduce the environmental footprint of AM include developing recyclable metal powders, minimizing energy consumption, and improving powder recovery systems. Binder jetting and metal extrusion processes are increasingly recognized for their energy efficiency compared to more intensive methods like PBF.

- **Green Materials:** Researchers are exploring the use of bio-derived binders and low-energy sintering techniques to reduce environmental impact. Additionally, closed-loop recycling systems for unused powders are becoming standard practice in AM facilities.

Large-Scale Additive Manufacturing

- **Construction and Infrastructure:** Large-scale AM technologies are moving beyond aerospace and automotive applications into the construction sector. Techniques such as Wire Arc Additive Manufacturing (WAAM) are being used to fabricate structural components like bridges and building frameworks, offering faster build times and reduced material waste compared to traditional methods.

- **Energy Sector Applications:** AM is being applied to produce large, high-performance parts for wind turbines, pipelines, and other infrastructure, where cost-effectiveness and customization are critical.

In conclusion, the future of metal additive manufacturing is being shaped by advancements in materials, hybrid manufacturing approaches, and the integration of automation and AI. Emphasis on sustainability and scalability is further expanding its applications, positioning AM as a transformative technology across industries.

7. Conclusion

Additive manufacturing of metal structures represents a transformative shift in manufacturing, offering unparalleled design freedom, material efficiency, and the ability to produce highly customized and complex parts. Key technologies such as Powder Bed Fusion (PBF), Directed Energy Deposition (DED), Binder Jetting, Metal Extrusion, and Sheet Lamination each bring distinct advantages and limitations, making them suitable for specific applications across industries such as aerospace, automotive, and healthcare.

Despite its promise, the broader adoption of metal AM is hindered by persistent challenges. Technical obstacles, including material quality, process reliability, and surface finish, remain critical concerns. Economic barriers, such as the high initial investment and operational costs, particularly for advanced machines and specialized materials, further limit accessibility. Environmental impacts—notably high energy consumption and material waste in some processes—require continued innovation to align with global sustainability goals. Additionally, regulatory challenges, particularly in the standardization and certification of AM processes, pose hurdles for industrial use in critical applications.

Overcoming these challenges necessitates a coordinated effort among researchers, industry stakeholders, and policymakers. Investment in the development of new materials, hybrid manufacturing approaches, and sustainable practices will be crucial. Furthermore, collaboration between industry and academia can drive innovation, while harmonized standards and certification frameworks can accelerate adoption in regulated sectors.

In conclusion, while the technologies for metal additive manufacturing have achieved significant milestones, addressing the remaining technical, economic, and regulatory challenges will be pivotal for its broader application. By fostering collaboration and investing in research, the potential of AM to revolutionize manufacturing can be fully realized, unlocking new opportunities for innovation and growth.

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Параметризиране за анализ на влиянието на климатично провокирани рискове върху пътната инфраструктура

Евелина Иванова¹, Стоянка Иванова¹, Тамара Илиева¹
 Университет по архитектура, строителство и геодезия¹
 ilieva_fgs@uacg.bg, siva_fce@uacg.bg, eivanova_fte@uacg.bg

Въведение: Изменението на климата се превръща в елемент на принципите за управление на системата потребител-транспорт-пътна инфраструктура. Това ежегодно засилва необходимостта от създаване на методики за оценка на влиянието на климатичните въздействия. За да са резултатни и да допринасят за оценката на рисковете през жизнения цикъл на пътната инфраструктура, те трябва да са съставени с определена структура. Публикацията представя идеен вариант за параметризиране на такъв системен работещ модел за проследяване и анализ.

Ключови думи: ТРАНСПОРТНА ИНФРАСТРУКТУРА, ИЗМЕНЕНИЕ НА КЛИМАТА, КЛИМАТИЧНО ПРОВОКИРАНИ РИСКОВЕ, ПАРАМЕТИЗИРАНЕ, АДАПТИВЕН КАПАЦИТЕТ

Parameterization for the analysis of the impact of climate-induced risks on road infrastructure

Evelina Ivanova¹, Stoyanka Ivanova¹, Tamara Ilieva¹
 University of Architecture, Civil Engineering and Geodesy¹
 Sofia University "St. Kliment Ohridski"²
 ilieva_fgs@uacg.bg, siva_fce@uacg.bg, eivanova_fte@uacg.bg

Abstract: Climate change is becoming an element of user-transport-road infrastructure management principles. This annually reinforces the need to create methodologies for assessing climate impacts. In order to be effective and to contribute to the assessment of risks during the life cycle of the road infrastructure, they must be drawn up with a certain structure. The publication presents a conceptual option for the parameterization of such a system working model for tracking and analysis.

Keywords: TRANSPORT INFRASTRUCTURE, CLIMATE CHANGE, CLIMATE-INDUCED RISKS, PARAMETERIZATION, ADAPTIVE CAPACITY

1. Въведение

Изменението на климата е глобален проблем с регионални специфики в рамките на отделните сектори на икономиката. В отговор на това държавите, членуващи в Европейския съюз приеха регламенти за адаптация към изменението на климата по сектори на икономиката, като процесът стартира през 2013 година с разписване на „Стратегия за адаптиране към изменението на климата [1]. През февруари 2021 година Европейската комисия прие оптимизация на стратегията като акцентът беше изместен от дефиниране на проблемите и планове за решения в посока към изпълнението на конкретни мерки.

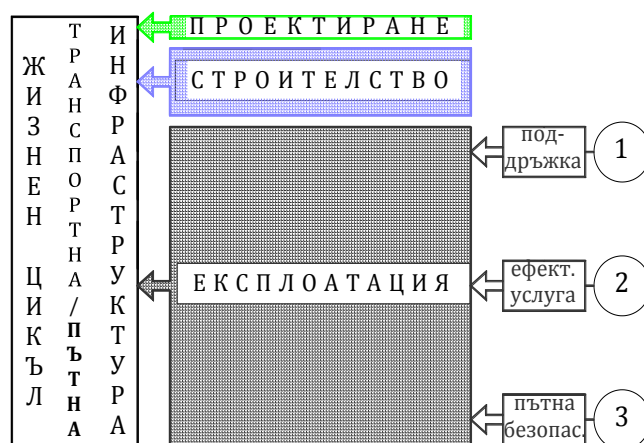
България прие своите документи за адаптация към изменението на климата (АИК) през 2019 година [2, 3]. Пет години по-късно, по отношение на сектор „Транспорт“, мерките по адаптация практически не са планово разработени, съответно не може да се премине и към практическото им прилагане [4-6]. В същото време транспортът е изключително чувствителен към климатично провокираните рискове, като това се отразява на качеството на услугата и на експлоатационните показатели на провеждащата инфраструктура [4, 7-11]. Трябва да се обърне внимание и на зависимостта между пътната безопасност и климатичните рискове от тип 1 и тип 2 [10-12] като ключов показател от експлоатацията на пътната инфраструктура. По отношение на АИК фокусът е върху изпълнителя на услугата и критичността на провеждащата инфраструктура, но за българския транспортен сектор пътната безопасност се оформя като отделен проблем, който в бъдеще трябва да се разглежда отделно от икономическата и социалната значимост на сектора.

2. Идеен вариант на методически подход за работещ адаптивен капацитет

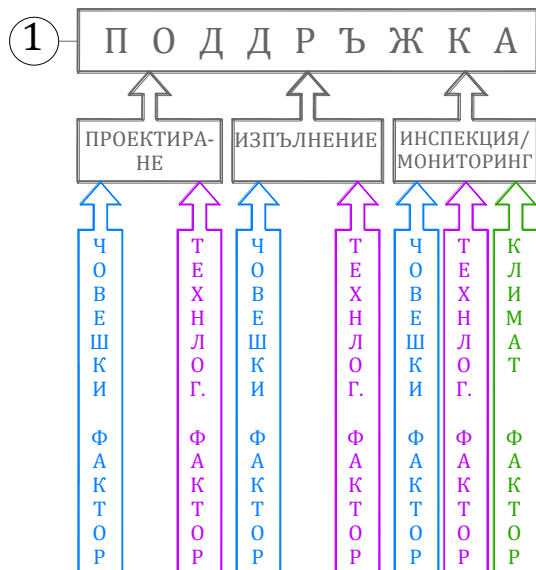
Обект на АИК: Предвид значимостта на пътната инфраструктура от степен на критична на национално ниво, ако се изгради адаптационен капацитет по климатични събития, ще се реши и проблема с негативните ефекти с транспортната услуга.

Обхват на АИК: Основата на структурата на анализа за изграждане на модела и параметри за прилагането му – фиг. 1:

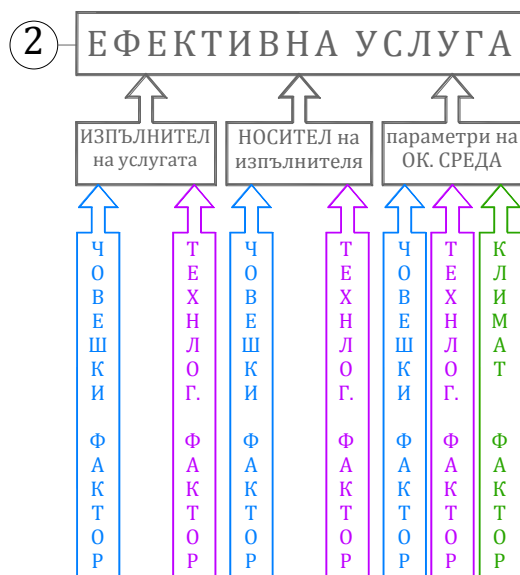
- Транспортната инфраструктура е уязвима към рискови събития в следствие от изменението на климата през всички основни етапи на жизнения ѝ цикъл (проектиране, строителство, експлоатация);
- Етап с най-висока степен на риска – експлоатацията. Това се дължи на съчетание между време ползване и необходимостта от адаптиране на структурно-изграждащите я компоненти (поддръжка, ефективна услуга, пътна безопасност);
- Групиране на параметрите, които определят степента на чувствителност на поддръжката, ефективността на услугата и пътната безопасност към ефектите от климатичните събития тях – фиг. 2;
- Определяне на факторите които определят адаптационния капацитет на параметрите, изграждащи структурно-изграждащите компоненти на експлоатацията на пътната инфраструктура. Според извършения анализ, те формират три основни групи: човешки, технологични и климатични фактори – фиг. 3.



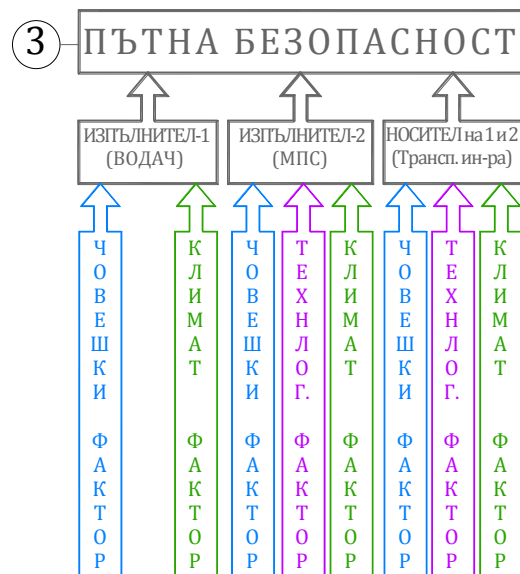
Фиг. 1 Обхват на АИК за пътната като част от транспортната инфраструктура през етапите на жизнения ѝ цикъл



Фиг. 2а



Фиг. 2б



Фиг. 2в

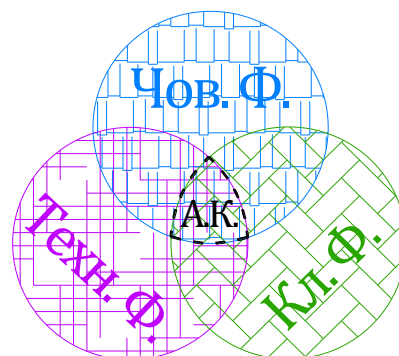
Фиг. 2 Зависимост между структурно-изграждащите компоненти на транспортната инфраструктура, параметрите, които определят чувствителността им към ефектите от климатични събития и факторите, които определят адаптационния им капацитет

Мерки по АИК по групи фактори: В България няма утвърдени процедури и добри практики за въвеждане на адаптационни мероприятия във връзка с АИК в сектор „Транспорт“. От друга страна, параметрите, чието съчетание определя експлоатационните показатели на пътната инфраструктура в рамките на този времеви период от жизнения цикъл (фиг. 1) проявяват различна степен на зависимост от трите групи фактори.

Липсата на методология за търсене на припокриваща се област на едновременно противодействие на климатичните рискове в рамките на трите групи, ограничава ефективността им като обхват в сектора и то само в рамките на краткосрочна перспектива. Следователно, за да се получи работеща методическа последователност, трябва да се изгради структура на модел, при който крайните резултати от анализа да са в обхвата на взаимно действие на групите фактори, респективно адаптационният капацитет да е комплексно решение на проблема.

3. Елементи на групите фактори, определящи модел на взаимодействие

Взаимното влияние на развитието на човешките, технологичните и климатичните фактори може да бъде определено като парадигма при дефиниране на модела. За да се заложи обхват на модела, с който да дефинираме общата област на взаимно влияние може да използваме постановка за задачите, които трябва да бъдат решени като се прилагат постижения в научната област [11-19].



Фиг. 3 Определяне на факторите които определят адаптационния капацитет на параметрите и област на взаимодействие.

Постановка на задачите по групи фактори, които да се решат с научни и технологични нововъведения:

- **Човешки фактори**, адаптацията трябва да съдържа мерки, осигуряващи осведоменост* (включително в реално време [13]) и дисциплиниране на субектите**;
- **Технологични фактори**, адаптацията трябва да бъде базирана на въвеждане на практически мерки*** (нанотехнологии и интелигентни транспортни системи) и технологично обезпечаване**** (подходяща софтуерна платформа и прилагане на изкуствен интелект) [14-19];
- **Климатични фактори**, адаптацията изисква събиране на данни и използването на прогнозно климатични модели, с които да е възможно проследяване на взаимното влияние на климатични събития от тип 1 (екстремно действие) и тип 2 (с постепенно нарастващ ефект или с последващо действие)****, за да може да се предвидят комплексни адаптационни мерки [10, 12, 14];

От фиг. 2 и фиг. 3 ясно се вижда, че промяна в обхвата на влияние върху всяка една от трите групи, променя моментната ситуация на другите две. Това отражение до момента остава недостатъчно изследвано и анализирано, като съответно това

дава отражение върху мерките по адаптация. Следователно ако мероприятията се предвиждат в рамките на пресечната област, то те може да бъдат по ефективни от гледна точка на резултати.

За да се илюстрира това, може да се даде следния общ пример за прогнозиране по тип климатично събитие:

Моделът задава информация за потенциален климатичен риск, това активира системата за ранно предупреждение, към нея в реално време стартира вхвърляне на данни за климатичния фактор в системата. Тези данни „веднага“ се обработват (технологичен фактор). Тази обработка променя времевата рамка на ранното предупреждение, за което се подава обратна връзка за корекция към органите за управление на сектора (включване на институционалния управленчески ресурс). Активирането на превантивни дейности (например чрез ИТС) ще осведоми и последващо ще дисциплинира човешкия фактор. Следователно моделът ще е работил в адаптационната област и мерките ще са прецизирани за съответната територия, транспорт и климатично събитие.

4. Структура и параметризиране на системен модел за проследяване, анализ и изграждане на адаптационен капацитет при транспортната инфраструктура

Предвид анализа в точка 3, може да се приеме, че при изпълнение на тези задачи при гореизредените подходи, те ще станат използвани в петстепенния модел на взаимодействие (показан на фиг. 4 и фиг. 5) като адаптационният капацитет, който ще се получи на изхода след етап 5 се очаква, че ще попадне в областта на взаимодействие на факторите от фиг. 2 и фиг.3.

Предлаганата структура на модела е изградена в пет основни етапа:

Етап 1: Събиране и обобщаване на бази с данни на елементите на околната среда, климата и транспортната инфраструктура в рамките на обща софтуерна платформа (пр-р: [6, 13, 17-19]), където може да се изгради област, в която да бъдат присъединени един към друг (независимо дали са входни променливи или са ефекти и последици) – фиг. 4.

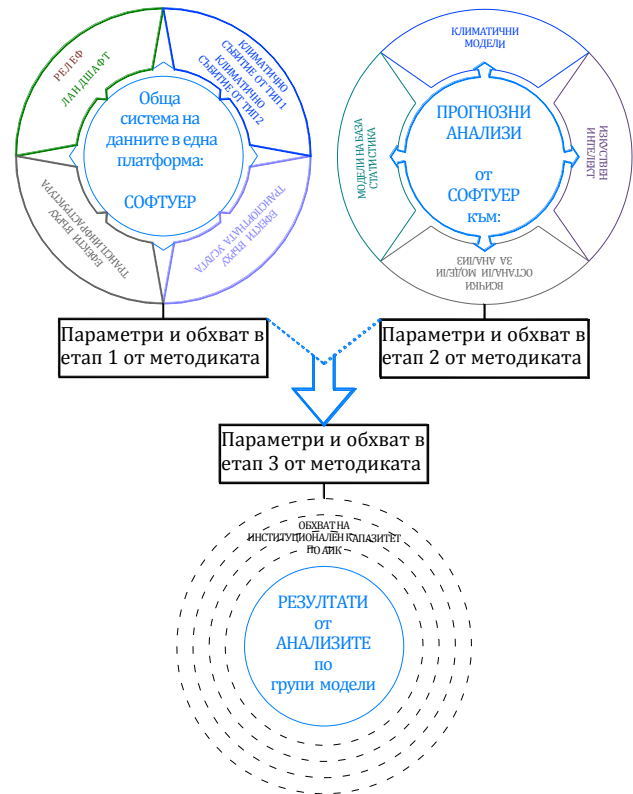
Етап 2: Получената информационна мулти база от данни в софтуерната обща област от етап 1, да бъде изследвана с поне три групи модели, основани на научни методи ([4, 8-11, 15-16]), за да се получат прогнозни резултати. Тези резултати и мулти данните от етап 1 би трябвало да предоставят достатъчно информационни параметри, с които да се работи в етап 3.

Етап 3: Параметрите от етап 1 и 2 по групи модели на анализа трябва да бъдат съхранени и предоставяни в споделена платформа с достъп до всички сектори, отговарящи за управлението на транспортната инфраструктура по отношение на поддръжката, ефективността на услугата и пътната безопасност.

В този етап всеки сектор, който изгражда административен капацитет по АИК може да получи информация, с която да оцени посоките, в които да се разработват и прилагат мерки по групите фактори (човешки, технологични, климатични), [4-5, 12, 15-16].

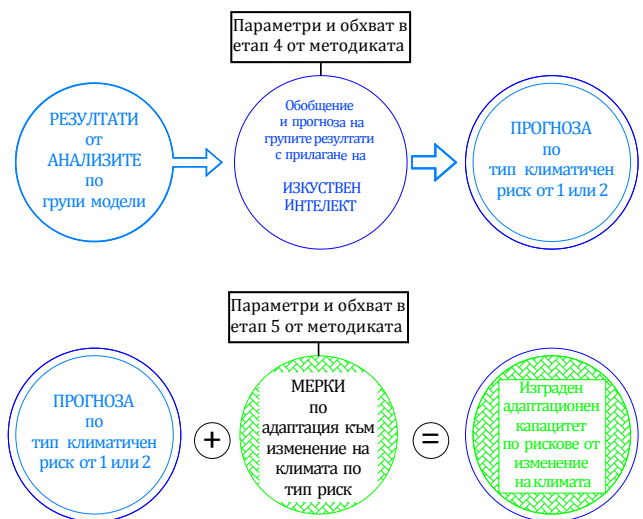
Етап 4: Резултатите от анализите в етап 3 да се обследват с изкуствен интелект, за да се получи необходимата прогноза за случаите на климатичните рискове от тип 1 или тип 2, за които да се изпълняват мерките по адаптация в рамките на етап 5.

Етап 5: Изграждане на адаптационен капацитет за климатичните рискове за съответната критична транспортна инфраструктура и осъществяване на ефективна превенция и управление на рисковите елементи по време на експлоатацията в рамките на жизнения ѝ цикъл.



Фиг. 4 Структура на системен модел за проследяване, анализ и изграждане на адаптационен капацитет при транспортната инфраструктура.

Етапи от 1 до 3 (осигуряване на мерките по осведоменост*, технологично обезпечаване****, взаимно влияние на климатични събития тип 1 и 2****)



Фиг. 5 Структура на системен модел за проследяване, анализ и изграждане на адаптационен капацитет при транспортната инфраструктура.

Етапи от 4 до 5 (осигуряване на практическите мерки**** и тези по дисциплиниране**). Резултат от методиката след етап 5 – изграждане на адаптационен капацитет в областта на взаимодействие

5. Изводи и заключение

Настоящата публикация разглежда значимостта на климатичните промени и тяхното въздействие върху транспортната инфраструктура, като подчертава необходимостта от системен подход при изграждането на адаптационен капацитет. Анализирани са основните етапи от жизнения цикъл на инфраструктурата, като е идентифициран най-високорисковият етап – експлоатацията. Това определя

ключовата роля на мерките за поддръжка, ефективност на услугата и безопасност, които трябва да бъдат адаптирани спрямо климатичните събития.

Разработената методология включва параметризиране и групиране на факторите, които определят уязвимостта на транспортната инфраструктура. Особено внимание е отделено на взаимодействието между климатичните, технологичните и човешките фактори, представено в рамките на петстепенен модел за проследяване и анализ. Този модел предлага структуриран подход за определяне на мерки, които могат да смекчат негативните ефекти от климатичните промени и да гарантират дългосрочната устойчивост на инфраструктурните системи. Прилагането на разработената методика има потенциала да се превърне в основа за вземане на информирани решения на национално ниво. Това ще подпомогне въвеждането на конкретни мерки за адаптация и ще подобри координацията между различните институционални и технически звена. Освен това, прилагането на моделите за прогнозиране и анализ ще позволи по-добро планиране и оптимизация на ресурсите за поддръжка на транспортната мрежа.

Разработеният системен подход за изграждане на адаптационен капацитет предлага значителен принос към устойчивото управление на транспортната инфраструктура. Той осигурява необходимите инструменти за анализ и адаптация, които са съобразени с регионалните специфики и нуждите на националната транспортна мрежа. Устойчивостта на тази мрежа е от ключово значение за икономическото и социалното развитие, както и за минимизиране на рисковете, породени от климатичните предизвикателства.

6. Благодарности

Авторите на публикацията изказват благодарност за финансовата подкрепа на ЦНИП при УАСГ в рамките на проект „ГИС-базиран анализ на въздействието на климатичните промени върху пътната инфраструктура за изграждане на адаптивен капацитет“, Договор БН-307/2024 г.

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ПРОЕКТИРОВАНИЕ АВТОМАТИЗИРОВАННОЙ СИСТЕМЫ УПРАВЛЕНИЯ ПРОЦЕССОМ ЛАЗЕРНОГО ПОВЕРХНОСТНОГО УПРОЧНЕНИЯ ИНСТРУМЕНТАЛЬНЫХ СТАЛЕЙ

DESIGN OF AN AUTOMATED CONTROL SYSTEM LASER SURFACE HARDENING PROCESS TOOL STEELS

В.Ф. Коростелев*, В.А. Хайназарова**

* д.т.н., профессор кафедры АМиР Владимирского Государственного университета

E-mail: giess300@mail.ru

** аспирант кафедры АМиР Владимирского Государственного университета,

старший преподаватель кафедры УЭиП Покровского филиала Московского педагогического государственного университета

E-mail: v.khainazarova@ya.ru

Abstract: In mechanical engineering, the quality and cost of manufactured products largely depend on solving the problem of durability of metal-cutting tools. The possibilities of alloying and heat treatment of high-speed steels have been largely exhausted. The dispersion mechanism of hardening of high-speed steels with carbides Ti, V, Mo, W is insufficiently studied and is not used effectively in practice. As a new approach to solving the problem of tool durability, it is proposed to increase the hardness of the working surface by 5...6 HRC. The indicated increase in surface hardness on P18 steel samples was achieved during laser beam treatment with a high concentration of energy. Special attention is paid to determining the heating temperature of the hardened surface in the vicinity of the focal spot. It has been found that, unlike carbon steels, the hardness of high-speed steels depends on the interaction of carbides with the base, which is a solid solution of carbon in γ -Fe. This base is plastically deformed during laser radiation under the influence of emerging thermal stresses, which qualitatively changes the mechanism and kinetics of dissolution of carbides at the heating stage and their release during cooling. Tool blades, surface-hardened to a hardness of ~ 70 HRC, are able to withstand higher contact loads and higher thermal stresses, and their durability is increased by increasing the value of the temperature critical for each specific tool. The critical temperature is the temperature at which plastic deformation occurs. The combination of simultaneous effects of temperature, thermal stresses and contact loads leads to plastic shifts in the crystal lattice, to abnormally intense softening compared to softening under isothermal conditions.

KEYWORDS: LASER ENERGY EFFECT, THERMAL STRESSES AND DEFORMATIONS, HARDENING AND SOFTENING OF HIGH-SPEED STEELS, TEMPERATURE CONTROL, DATABASE, STABLE PARAMETERS OF THE THERMAL CYCLE.

1. Введение

С развитием автоматизации производственных процессов проблема повышения стойкости металлорежущих инструментов приобретает возрастающее значение, потому что от стойкости зависит исправность и непрерывность надежной работы станков с программным управлением, автоматических линий и целых автоматизированных производств. Частые и непрогнозируемые сбои в работе инструментов разывают информационные и физические процессы, осложняют работу цифровых производственных систем, приводят к значительным затратам потерям все видов ресурсов.

Общеизвестно, что на этапе разработки принципов легирования и определения содержания компонентов быстрорежущих сталей (БРС) лабораторные испытания опытных образцов на разупрочнение проводились в условиях изотермической выдержки, в то время как материал инструмента в процессе резания подвергается не только нагреву, но и воздействию контактных давлений и термических напряжений.

В работах [1,2] установлено, что сжимающие напряжения снижают температуру полиморфных и фазовых напряжений, что в процессе перестройки кристаллической решетки сопротивление металла пластическим деформациям значительно снижается.

В этой связи значительный интерес представляет возможность повышения стойкости за счет сочетания дисперсионного упрочнения БРС частицами термостойких карбидов с интенсивным нагревом концентрированным потоком энергии лазерного излучения.

2. Отличие лазерного поверхностного упрочнения от поверхностной закалки

Лазерное поверхностное упрочнение (ЛПУ) это уже не новый, а вполне распространенный процесс, не имеющий дотнастоящего времени определенного названия. На

практическом уровне, как и в публикациях без какого-либо обоснования процесс известен как «Лазерная закалка», «Лазерная термообработка», «Лазерное термическое упрочнение». В этих названиях просматривается только термическая составляющая, и не учитывается влияние термических напряжений, которые возникают вследствие градиента температурного поля в окрестности зоны лазерного воздействия. В работах [3,4] рассмотрено влияние температуры и термических напряжений на снижение предела текучести, что дает основание называть ЛПУ лазерным термомеханическим поверхностным упрочнением (ЛТ-МПУ). Отличительными признаками ЛТ-МПУ являются:

- скорость нагрева, несопоставимая ни с печным, ни с индукционным нагревом, достигающая при плотности мощности $1 \times 10^5 \dots 1 \times 10^8$ Вт/см² нескольких тысяч градусов в секунду;
- продолжительность термического воздействия сотые...тысячные доли секунды;
- уровень термических сжимающих напряжений на глубину 0,1...0,3 мм, превышающий предел текучести;
- в интервале температур полиморфного превращения, когда происходит растворение углерода в γ -Fe, металл пластически деформируется пластически.

Нагрев при термической обработке предполагает выдержку, продолжительность которой измеряется секундами и минутами, необходимыми для диффузии атомов углерода.

Отсюда следует, что никакого сходства ЛПУ с термообработкой нет.

Рассматривать ЛПУ через призму образования аустенита при нагреве и протекания мартенситного превращения при охлаждении означает не учитывать названные отличительные признаки.

3. Поведение карбидов в структуре БРС во время лазерного поверхностного нагрева

Наличие в БрС дисперсной карбидной фазы создает значительные трудности с обоснованным выбором значений параметров лазерного упрочнения. Так, в работе [5] установлено, что даже незначительное увеличение плотности мощности с $1,3 \times 10^4$ до $1,4$ Вт/см² приводит в стали P18 к снижению микротвердости с 9,8 ГПа до 8,6 ГПа, а в стали P6M5K5 - с 9,6 ГПа до 8,5 ГПа.

Известно также, что быстрорежущие стали чувствительны к скорости трехкратного нагрева и охлаждения в процессе отпуска [6]. И дело заключается не столько в количестве остаточного аустенита, сколько в снижении содержания легирующих элементов в мартенсите.

Вправе предположить, что лазерный нагрев до температуры, близкой к температуре плавления, может оказывать влияние на соотношение легирующих элементов в мартенсите и в карбидах и повышать или понижать твердость. Поэтому в дополнение к факторам множественного влияния на твердость таких как температура и скорость нагрева, перепады температур, напряжения, деформации и фазовые превращения следует взять в рассмотрение растворимость легирующих элементов в железе в конкуренции с образованием карбидов и их устойчивостью.

Перечисленные факторы не поддаются корректному описанию и тем более количественной оценке. По степени значимости ведущая роль принадлежит тепловым процессам в то время как качественная характеристика влияния отдельных факторов и их взаимодействий необходима для формирования соответствующих баз данных и их использования в решении конкретных задач повышения твердости и красностойкости БрС.

4 Определение температуры поверхности при лазерном нагреве

В целях исследования зависимости твердости поверхности от температуры нагрева и связанной с ней растворимостью легирующих элементов в γ -Fe важное значение приобретает определение критического значения температуры лазерного нагрева (КТЛН), превышение которого приводит к аварийному снижению работоспособности режущего инструмента.

Исследования тепловых процессов ЛПУ проводятся расчетно-аналитическим методом [7], который предоставляет возможности осуществлять оценку влияния различных факторов не только на температуру поверхности, но и на распределение температурных полей в трех направлениях, включая и распределение температуры вглубь от поверхности. Однако метод распространяется на решение ограниченного числа задач к тому же с упрощениями, существенно снижающими практическую ценность в процессе автоматизации управления процессом упрочнения.

В каждом конкретном случае необходимо достоверно и оперативно зафиксировать температуру поверхности при лазерном нагреве. Осуществить это экспериментальным путем затруднительно по ряду причин:

- пирометр, наведенный на фокальное пятно, регистрирует температуру плазмы на уровне больше 2000 °C;
- в процессе обработки лазерным лучом нагрев происходит с нарастанием температуры со скоростью $1...2 \times 10^4$ К/с в течение сотых долей секунды, что может быть измерено пирометром и зарегистрировано компьютером, но при этом возникают ошибки, связанные с запаздыванием.

В качестве компромисса предлагается, как и в работе [8], измерять температуру поверхности на удалении 1,2 мм за фокальным пятном с интервалами между замерах 2...5 с.

Расположение пирометра на корпусе оптической головки лазера позволяет проводить замеры на всех участках траектории обработки.

Экспериментальные исследования выполнены на роботизированном лазерном комплексе (ЛРК), включающем на итербийевый волоконный лазер ЛС-5, в Инжиниринговом Центре во Владимирском государственном университете (ВлГУ).

Результаты исследований представлены на рис. 1- 3.

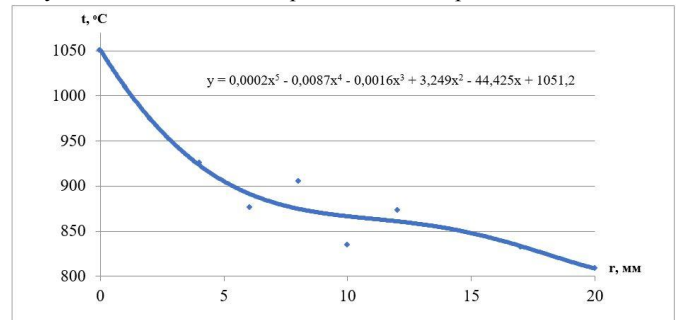


Рис. 1. Зависимость температуры, измеренной оптическим пирометром, от расстояния точки измерения до фокального пятна.

Измерения на удалении ~1 мм дают возможность с ошибкой не более 5 % от измеряемой температуры проводить оценку влияния параметров излучения на температуру нагрева

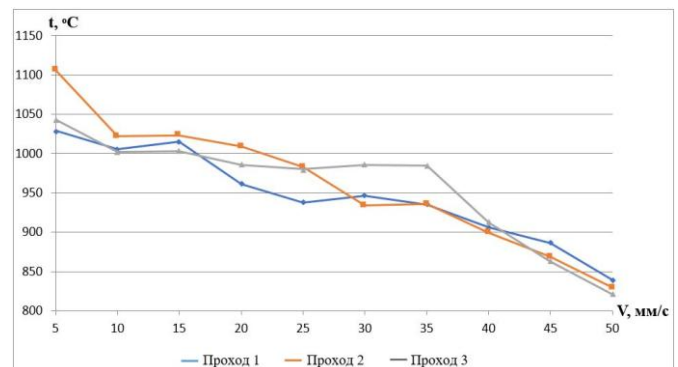


Рис. 2 Оценка влияния скорости обработки на температуру поверхности в зоне воздействия лазерного излучения.

График показывает, что измерение температуры может быть использовано в контуре обратной связи при автоматическом управлении лазерным поверхностным упрочнением.

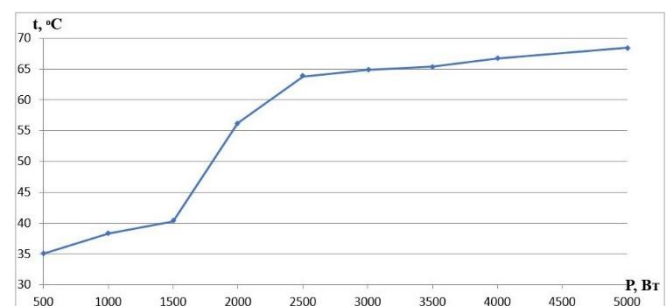


Рис.3. Влияние мощности излучения на температуру нагрева упрочняемой поверхности.

Из графика следует, что зависимость твердости поверхности от мощности излучения имеет сложный не аддитивный характер. Измерения выполнялись пирометром повышенной точности Optiris CTPlazer LT DCI. Фокусное расстояние F=350 мм. Упрочняемый материал Сталь У8. Исследуемым параметром является температура t , варьируемые параметры - мощность излучения лазера N и скорость обработки v .

При всех трудностях выполнения измерений установлено, что уровень достигаемой температуры достаточно четко реагирует на изменения параметров N и v .

Предложенный подход к оценке температуры не предназначен для непрерывного измерения температуры лазерного нагрева, но может быть использован в процессе настройки мощности и скорости при ЛПУ конкретного изделия или инструмента. В данном случае температура может выступать в качестве контролируемого и управляемого параметра взамен параметра – твердость HRC, который не является управляемым.

5. Заключение

На основании анализа и использования информации из литературных источников и результатов выполненных исследований можно сделать следующие выводы.

1. Лазерное поверхностное упрочнение сталей, включая и инструментальные, является особым видом обработки, в котором тепловые процессы играют ведущую роль наряду с механическими, с напряженно-деформированным состоянием и структурно-фазовыми превращениями. Этот вид обработки предложен называть «Лазерное термомеханическое поверхностное упрочнение» - «ЛТ-МПУ».
2. Инструментальные стали, упрочняемые дисперсными термостойкими карбидами, чувствительны к температуре нагрева, влияющей на растворимость легирующих элементов в мартенсите и в остаточном аустените, поэтому определение критического значения температуры нагрева, может быть использовано в процессе настройки режимных параметров лазерной обработки.
3. Предложенный метод контроля обеспечивает возможность определить значение температуры, которое устанавливается за фокальным пятном; значение температуры, обеспечивающее повышение твердости на 5 ед.HRC, т. е. до 70 HRC может быть занесено в Базу Данных и в дальнейшем использовано практически.

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Investigation and analysis of tested plastic films according to ASTM D6992 Standard Test Method for Accelerated Tensile Creep using the Stepped Isothermal Method

Chukalov, Konstantin¹, Sabev, Savi²
Technical University Sofia, Bulgaria, branch Plovdiv
chukalov@tu-plovdiv.bg, sabi_sabev@tu-plovdiv.bg

Abstract: In the article, experimental results according to ASTM D6992 standard test method for accelerated tensile creep of plastic films were investigated and analyzed. A regression model was created based on the obtained results. Real and theoretical data were compared in order to determine deviations of the model and what is the reliability of the theoretical data.
Keywords: CREEP, PLASTIC TESTING, STEPPED ISOTHERMAL METHOD, REGRESSION ANALYZE.

1. Introduction

Materials creep is a process of slowly increasing plastic deformation at constant temperature and applied stresses below yield strength [1]. Creep deformation depends on several factors - temperature, applied load and specific characteristics of material. The process of material creep is not yet fully studied [2].

Plastics are widely used in mechanical engineering, construction, automobile manufacturing, etc [3]. Plastics are increasingly used as a structural material, as well as part of composites that are subjected to long-term loads. Studies of the creep process in plastics is very current, because it characterizes dependability of materials in long-term applications.

The test to determine creep limit has a long duration - up to 10,000 hours, therefore accelerated creep of materials is often used, as well as various mathematical models with estimated values, [4], [5]. Through these methods, duration of the test is reduced and resources are spared without compromising results.

2. Materials and methods

HDPE-mixture was chosen as test material because it is one of the most used plastics, so the obtained results and data are significant for manufacturers. Polyethylene has high mechanical-physical properties and is not affected by moisture [6]. Polyethylene is used for pipes, tanks, insulation, packaging, etc. Polyethylene is a recyclable material, which contributes to its even wider use, in addition to being a virgin material, but also as a recycled one.

The test was performed according to ASTM D6992-Accelerated tensile creep and creep-rapture of geosynthetic materials based on time-temperature superposition using the stepped-isothermal method [7]. Stepped isothermal method (SIM) consists of defined temperature steps and dwell time in order to accelerate testing process. Deformation and dead weight are presented as a function of time. The duration of the test according to the standard is a not less than 60,000 seconds.

The test was carried out on a calibrated universal creep testing machine, which has an appropriate range of values - temperature, dead weight and linear deformation according the standard and the selected material. The results are generated automatically, and the error of the measured values is less than 0.5% according the calibration data atmospheric conditions are controlled according to the standard requirements.

Suitable gripping jaws were chosen, which, on one hand, do not allow sample slipping, and on the other hand, do not apply excessive load on sample, which would rapture it. Mechanical system of the lab stand is stable and minimizes errors of the sample's alignment. The insulation of the stand does not permit fluctuations in temperature. The stand, including the dead weight system and gripping is shown in fig. 1.

The selected test program is shown in Fig.2 and Table. 1. Six temperature steps, each of 10 000 seconds are selected in order to meet the requirement for a minimum duration of 60,000 seconds.



Fig.1 Universal creep testing stand

Table 1: Temperature steps and dwell times

Steps	1	2	3	4	5	6
Dwell Time (min.)	170	170	170	170	170	170
Temperature (C°)	23	30	37	44	51	58

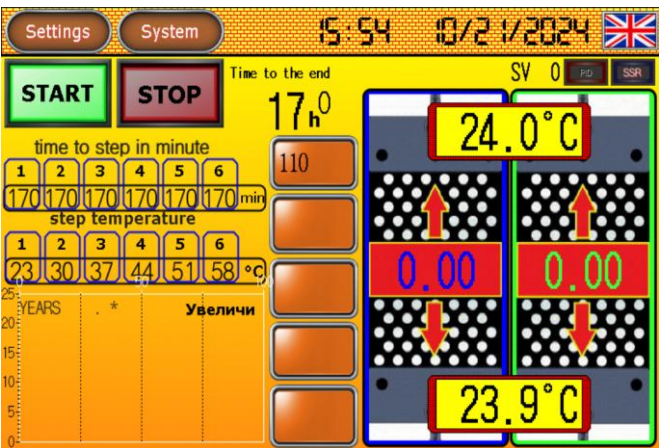


Fig. 2 Test program

The calibrated dead weights used for tensile creep stresses are 4(3 discs of 10 kg and 2 discs of 5kg) The samples have dimensions - length 120 mm, thickness 1.3 mm, width 100 mm. The sample is textured and contains six holes-diameter of which is 20 mm. Accelerated creep testing of the materials means using equivalent times [8]. Each minute of testing at a certain temperature determines equivalent time according to the standard shown in

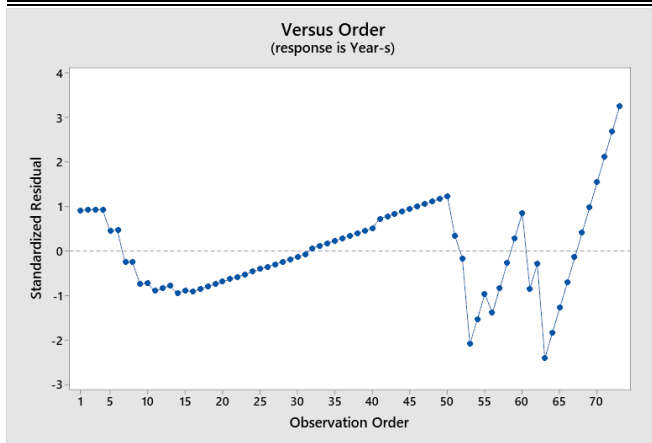


Fig. 7 The standardized residuals in order of obtains

Analysis of residuals is performed using plots in Fig. 6,7. The values of the standardized residuals should be within ± 2 [13].

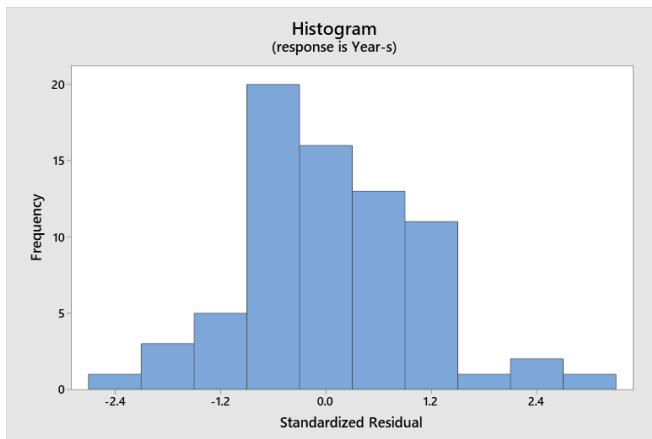


Fig. 8 Histogram of standardized residuals

Figure 8 shows a diagram of the standardized residuals, which shows that the normal distribution is right-skewed.

4. Conclusions

From the obtained regression model, the relative elongation according to equivalent years can be predicted with an accuracy of 98.4%.

The verification of the results obtained from the model show that they are statistically significant, which proves the mathematical dependence between the variables. The use of a regression model leads to obtaining adequate results and eliminating random errors caused by various factors. The model can also be used for creep tensile testing of other materials in order to reduce duration of the test. It is possible to use other mathematical models in order to optimize test duration and used resources.

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Frost resistance of hollow ceramic structural elements for ceramic beehives

Todorka Lepkova*, Lyuben Lakov, Bojidar Jivov, Marieta Gacheva

Bulgarian Academy of Sciences, Institute of Metal Science, Equipment and Technologies with Hydro- and Aerodynamics Centre
"Acad. A. Balevski", 67 "Shipchenski prohod" Blvd., 1574 Sofia, Bulgaria, e-mail: lepkovatodorka@ims.bas.bg

Abstract: In laboratory conditions, the frost resistance of hollow ceramic samples (constructive elements of ceramic beehives) was examined by applying a standardized methodology for assessing the reliability of ceramic products. For both sample types that were investigated (each with different phase compositions), the result for the frost resistance coefficient K_{fr} is above 84%. The products retain their structural integrity and high resistance in an extreme temperature environment. It was not observed any significant damage that could disrupt their functionality. The obtained results prove the assumptions that the ceramic beehives are appropriate for use in vast geographical regions characterized by critical temperatures and high diurnal and seasonal temperature amplitudes. At the same time, the experimental data can serve for further optimization of the recipe compositions, the technological regime, and for improvements of the construction characteristics of the ceramic elements that build the ceramic beehive.

Keywords: CERAMIC BEEHIVE, FROST RESISTANCE, MARL, KAOLIN, MOISTURE ABSORPTION

1. Introduction

There are various natural, anthropogenic, and complex factors causing moderately negative to fatal effects on the normal development and survival of bee families [1-3]: diseases typical for the brood and the adult bees; impact of natural enemies of the honey bee (mainly various insects, birds and others); environmental pollution from growing industrial activity; increasing use of toxic insecticides for plant protection in the agricultural sector; intensive noise pollution (transport traffic, industrial production, construction, and others); annual fires with extensive localization, global climate changes and many other.

Bee farms nowadays are widely using several basic systems of beehives [4] made of different materials (wood, polystyrene, and others).

Due to its suitable workability, wide availability, natural origin and environmental friendliness, wood is a predominant and relatively cost-effective raw material for the production of beehives [2]. The use of wood as the main construction material allows the use of various technological methods of processing, accurate implementation of the designed construction options, and preparation of a wide assortment of products [4]. Spruce, pine, fir, pine, linden and others are used in the production of various beehive systems [2, 4]. The existing experience in the practice shaped the opinion that coniferous resinous trees are better raw materials for beehives as they can provide higher resistance to the impact of destructive cyclic weather factors (mainly during the winter season).

At the same time, in the course of active exploitation of the widely spread standard wooden beehives, it is observed a critical disadvantage [4] - the relatively low resistance under dynamic extreme climate conditions.

To effectively overcome some of the existing main problems in the beekeeping sector, an innovative beehive was created. Its construction consists of hollow ceramic elements that form air chambers providing thermal insulation of the hive. [5].

For materials with a porous structure (such as many types of ceramics), frost resistance is a key factor in their durability. The moisture that has penetrated the material's pores freezes at low temperatures, which leads to the expansion of water and, accordingly, to an increase in the internal tension in the pores. Repeated freezing and thawing causes: microcracks, widening of existing cracks, reduction of mechanical strength, damage to the surface layer, and other damages.

The frost resistance of the material depends on its porosity, capillary structure, absorption properties, and strength. Various tests and analyses determine how well a material can retain its properties and structure under continuous exposure to freeze-thaw cycles.

The study of frost resistance of hollow ceramic structural elements composed of anorthite ($\text{CaAl}_2\text{Si}_2\text{O}_8$) - marl clay and washed kaolin ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$) is of key importance for creating resistant and long-lasting materials suitable for use in

beehives. Ceramic elements created on the basis of these minerals combine good mechanical strength and a specific microstructure with porosity that supports their thermal insulation properties. Despite these advantages, the porous structure is still vulnerable to climate influences, such as freezing and thawing, which can lead to the accumulation of water deposits in the hollow of the material. Over time, this process causes micro-level expansion and contraction, leading to microcracks and structural deterioration of the material.

The present work aims to study the degree of resistance of ceramic structural elements (for the production of ceramic hives) to freezing and thawing cycles and to analyze their impact on the microstructure and the strength of the elements. The obtained results are intended to be used for improvements of the material so that it provides reliable protection and comfort for bee colonies and their owners.

2. Experimental procedures

For the purpose of the study and the examination of the frost resistance of hollow ceramic elements were used the following methods:

2.1. Preparation of the samples:

- There were prepared two types of samples and from each type were prepared 5 elements. The types are respectively: from a mixture of marl clays - anorthite ($\text{CaAl}_2\text{Si}_2\text{O}_8$), with dimensions of 162 mm x 75 mm x 25 mm with a cavity of 66%; and from a mixture of washed kaolin ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$) with dimensions of 310 mm x 156 mm x 25 mm with a cavity of 66%.
- The samples were produced according to a previously established technology for the production of elements for hives by slip casting.

2.2. Initial measurement and analysis:

- Marl clay samples - anorthite ($\text{CaAl}_2\text{Si}_2\text{O}_8$), size 162mm x 75mm x 25mm with a cavity of 17mm or 66% cavity;
- Washed kaolin samples ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$) measuring 310 mm x 156 mm x 25 mm with a cavity of 17 mm or 66 % cavity;

To register results for changes in the pores and possible microcracks, we performed an initial microstructural analysis of the samples (fig. 1,2, and 3). For this, we used a scanning electrical digital microscope, Wireless Microscope HiView, version 1.4, 2000 c USB 1600x, Windows 2000/2003/XP/Vista/7, Linux.

The main physical properties of the samples were determined at the beginning of the study, as follows:

- Compressive strength - 2550 kg/cm² washed kaolin; compressive strength of marl clay (anorthite) - 2250 kg/cm²;
- Moisture absorption - of the washed kaolin sample - 2,65%; moisture absorption of the marl clay (anorthite) sample - 3,4%.

2.3. Exposure to freeze-thaw cycles [6]:

The samples are exposed to frost-thaw cycles according to the following procedure:

- The samples are dried in a dryer at $105 \pm 5^\circ\text{C}$ to a constant mass and after that their weight is measured. They are cooled to an ambient temperature of 25°C and the mass is measured again. [Md]
- After that, the samples are immersed in a tank of tap water at room temperature and the water is heated in the vessel to $80^\circ\text{C} \pm 3^\circ\text{C}$ for 2 hours. At cool saturation, water enters only the fully open pores, while at 80°C water temperature, it is assumed that it enters the semi-closed pores.
- The water-saturated samples are weighed with an electronic scale with accuracy ± 1 gram and the results are recorded [Mw]. Then the samples are left to air for 20 minutes and weighed again [Ms]
- They are placed in a freezer chamber at temperature of $-18^\circ\text{C} \pm 3^\circ\text{C}$. Each freezing cycle is at least 5 hours, counted from the moment of reaching the set temperature -15°C .
- Follows a rapid thawing by blowing warm air at temperature of $105^\circ\text{C} \pm 5^\circ\text{C}$ for 20 minutes and subsequently leaving at room temperature 25°C for 20 minutes.
- Each subsequent cycle starts by pouring over with tap water for minimum 2 minutes, weighing them immediately and after resting for 20 minutes. After that they are placed in the freezing chamber for the next freezing.

The first freezing period lasts 6 hours, each subsequent freezing period must last minimum 5 hours in the chamber after reaching the set temperature. A cycle of defrosting and subsequent humidification follows. This freeze-thaw cycle is repeated 51 times.

3. Results and Discussion

3.1. Monitoring of the microstructural changes:

- We are monitoring for cracks on the sample surface.
- Using a scanning microscope, we scan the surface of the samples for cracks and capillaries after cycles 35 and 50.
- After cycle 35 and cycle 50 for all the anorthite samples ($\text{CaAl}_2\text{Si}_2\text{O}_8$), there is no change in dimensions, nor capillary cracks (fig.1). For the samples of washed kaolin ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$) there is no change in dimensions. After cycle 50, on one of the parts of a kaolin sample is identified a crack of 1 mm – 2 mm (fig.3) with a length of about 50 mm. The crack is observed in the funnel area. After cycle 50 capillaries are noticed on the surface layer of the same sample (fig.3). For the rest of the samples are not observed any defects or cracks (fig. 2).



Fig. 1 A marl clay sample from left to right: at the beginning; after cycle 35; after cycle 50



Fig. 2 The surface of a washed kaolin sample at the beginning; after cycles 35; and after 50 cycles (from left to right)

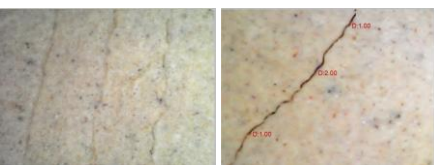


Figure 3 Surface capillaries and a crack on one of the washed kaolin samples

3.2. Measurement of physico-mechanical properties after freezing and thawing cycles:

After the 35th and the 50th cycles, the key physico-mechanical parameters are measured again: sample sizes, and compressive strength. The results of these measurements are presented in tables 1 and 2 respectively for marl clay and washed kaolin.

Table 1. Marl clay samples.

No of cycle	Marl rock sample dimensions anorthite ($\text{CaAl}_2\text{Si}_2\text{O}_8$),	Moisture absorption coefficient [%]	Compressive strength [kg/cm^2]	Defects/ presence of capillaries and cracks
1	162 mm x 75 mm x 17mm	3,40	2250	No
35	162 mm x 75 mm x 17mm	3,35	2200	No
51	162 mm x 75mm x 17 mm	2,22	2150	No

Table 2. Washed kaolin samples.

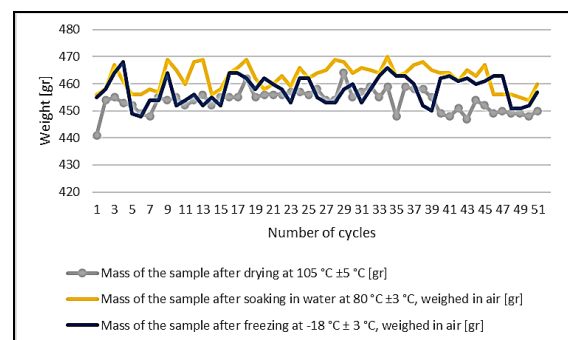
No of cycle	Dimensions of the washed kaolin sample ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$)	Moisture absorption coefficient [%]	Compressive strength [kg/cm^2]	Defects/ presence of capillaries and cracks
1	310 mm x 156 mm x 25 mm	2,65	2550	ne
35	310 mm x 156 mm x 25 mm	2,00	2450	ne
51	310 mm x 156 mm x 25 mm	0,68	2400	ne

The results we obtained show that after 50 frost-thaw cycles of the samples, a crack with the size of 1 mm is observed on the surface of only one of them. This defect is located in the area of the technological holes, which are the result of the casting process. This is probably one of the weakest areas of the element, where the tension concentration is higher and the structural resistance is lower.

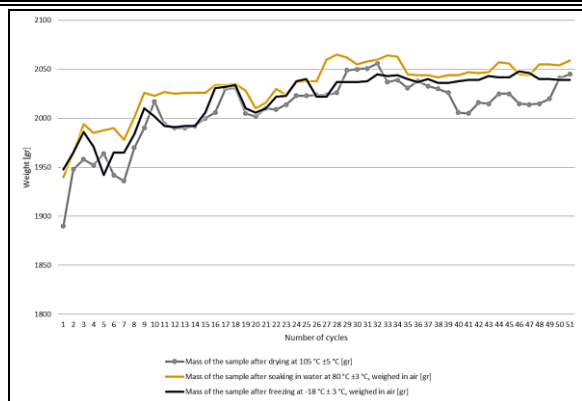
We observe that the compressive strength decreases both for the samples from kaolin (5,88%) and marl clay (4,44%).

The experimental method we have applied allows us to get a holistic and comprehensive view of the effect of freezing and thawing cycles on the structural and mechanical resistance of hollow ceramic elements composed of marl clay and glass ceramics.

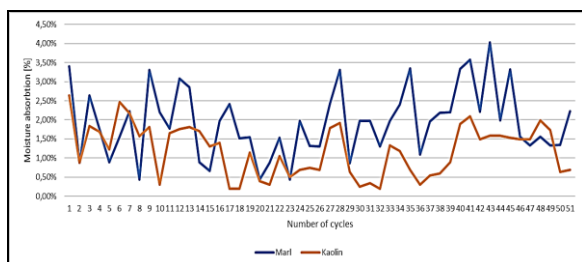
The focus of the analysis is the change of the weight of the samples when they are watered, dried, frozen, and defrost. All measurements are included in a table. Based on the obtained results we present the following graphs: Graph 1 Shows the mass of the marl clay samples after drying, after soaking in water, and after freezing. Graph 2 contains the same information but for the kaolin samples. Graph 3 displays the information about the water absorption of the two types of samples over the 50 cycles.



Graph 1. Mass change of marl clay samples



Graph 2. Mass change of washed kaolin samples



Graph 3. Moisture absorption of marl clay and washed kaolin samples

3.3. Evaluation of frost resistance and analysis of results:

The frost resistance coefficient was calculated for the samples of marl clay anorthite: $K_{mr}=84.45\%$ and washed kaolin $K_{mr}=84.30\%$. According to the standard, the coefficient should be smaller than 85% for a product to be considered frost-resistant. In the case of our experiment, both sample types can be considered frost-resistant.

For the samples of washed kaolin we found that the material shows stability under existing conditions (drying, soaking in water, and after freezing). Weight changes are minimal, indicating high resistance to freeze/thaw cycles. The location of the crack is around the technological openings related to the casting process: The crack is concentrated around the technological opening, indicating that this area is more susceptible to microstructural defects in cold due to the different density of the material in this area. Another reason may be the accumulation of internal pressure during the casting and baking of the element. Such pressure becomes a reason for a higher degree of water absorption by the pores leading to freeze expansion. Lower water absorption of the kaolin samples is connected to less pores. During the cycles of watering, water can not be spread evenly on the surface and while freezing uneven tensions are created. This is the reason why for these samples we observe capillary structural changes on the surface.

For the samples of marl clay, we observe relatively higher water absorption and weight change, especially after soaking in water and freezing. We connect this observation to the higher porosity of the material which would generally mean it shall be more prone to defects. We observe that for the course of 50 frost-thaw cycles, there are no changes of the structure on the surface of the samples, no cracks, nor capillaries which means that the higher porosity contributes to an even distribution of inner tensions.

4. Conclusion

Our analysis shows that for both types of examined samples, a sufficient level of frost resistance is reached. They passed successfully through 50 frost-thaw cycles without significant changes which can damage their functionality. This leads us to the conclusion that the selected casting mixtures (marl clay (anorthite) and kaolin) have physicommechanical properties that make them appropriate for use in places with variable or extreme temperature conditions.

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Failure analysis of the pelton hidro-turbine buckets damaged in the exploitation conditions

Sveto Cvetkovski¹, Nazif Jashari²,

Faculty of Technology and Metallurgy, Ss Cyril and Methodius University, Skopje Republic of North Macedonia¹ State University Tetova, Republic of North Macedonia²
sveto@tmf.ukim.edu.mk

Abstract: Pelton mini hydro-turbine, more concretely its turbine circle buckets was completely damaged during exploitation conditions i.e. working time of about two years and half. Because turbine was ensured in ensured company, representatives of the company engaged court expert prof Cvetkovski to perform investigations (analysis) and to determine the reasons for these accidents. Normally working time of the Pelton turbine is about ten years, but there is examples that it can work even twenty years if construction and maintains of turbine was properly done. Therefore, the purpose of the conducted expert examination is to analyze the causes, effects and potential solutions for the damaged Pelton turbine. This report covers the technical aspects, the mechanisms that contribute to the appearance of defects, that is, damage of the buckets of the Pelton turbine. In order to find the reason of failure of the turbine buckets, as first complete visual inspection of the turbine wheel was performed. As additional investigation was performed chemical analysis of the buckets, measuring of its hardness and metallographic investigation (determination of type and quantity of non-metallic inclusion and microstructure).

KEYWORD: PELTON TURBINE, BUCKETS, EROSION, WATER JET, VISUAL INSPECTION, HARDNESS, SEDIMENTS

Introduction

This expertise, from the field of technological engineering, was made at the request of the insurance company UNIKA A.D. Skopje. The subject of the expertise is a turbine (stream turbine wheel) mounted on the Topolka river, Macedonia. It is mini, hydro Pelton turbine (PT), which was in operation for about 2.5 years. During the exploitation, serious damage occurred to the buckets of the turbine (turbine wheel) due to which it had to be replaced with, and a new turbine wheel was installed. The damaged turbine wheel was dislocated after disassembly. The same was seen by the representatives of UNIKA AD Insurance company, and after taking over the case by the authorized court expert Prof. Sveto Cvetkovski. From the court expert was performed visual inspection of the dismantled turbine wheel. In addition, a piece of turbine bucket was taken to analyze the chemical composition, to perform hardness measurement and metallographic analysis of the microstructure, as well as checking the purity of the material, i.e. the presence of non-metallic inclusions in it.

In the technical literature is well known that three main reasons contribute to the occurrence of defects, and finally, breakdowns in Pelton turbines [1, 2]. These factors are clearly stated. It is obvious that the buckets are most susceptible to damage only during the operation of the turbine. The usual reasons for the occurrence of defects in the Pelton turbine are:

- Erosion: Occurs because of hitting a water jet moving with great speed and suspended particles.
- Cavitation: Formation of steam bubbles that collapse and cause damage to the surface of the turbine.
- Fatigue of the material: Repetitive stress cycles that lead to cracks and eventual collapse.
- Operational problems: improper maintenance, overloading and difficult working conditions.

1 Material and investigations

1.1 Pelton turbine overview

Description:

Pelton turbines used in hydroelectric power plants are high voltage. These are essentially impulse turbines used for hydroelectric energy production.

Operating principles of the turbine:

The water jet hits the turbine buckets, converting the kinetic energy of the water into mechanical energy and then into electrical energy. Schematic presentation of operating principles of Pelton turbine is given in figure 1a. Complete turbine wheel with buckets is presented in the figure 1b.

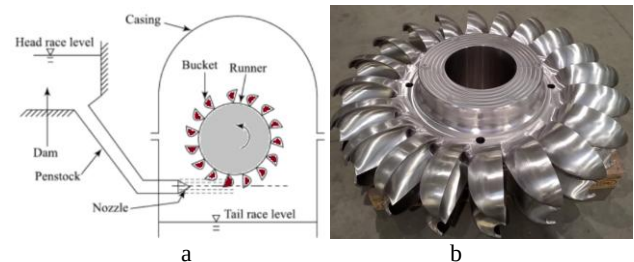


Figure 1. Pelton turbine overview a. Operating principles of Pelton turbine b. Pelton turbine circle with a buckets

2. Performed investigations of the turbine wheel buckets

2.1 Inspection of the condition of the dismantled turbine wheel (Visual inspection)

During dismantling, the turbine wheel was cut into two halves and left in the appropriate location figure 2. A visual inspection of the cut halves of the turbine wheel (Pelton turbine) was performed on site. It was ascertained that there was huge damage of the buckets, which prevented the normal functioning of the feet, in fact, there was an intense perforation of the buckets. From the on-site inspection, it was established that the turbine wheel has 14 buckets on which the water jet hits. The documentation says that 18 buckets are installed.



Figure 2 Cut turbine wheel halves with a buckets

It is immediately noticeable that the damage (perforation) is noted only on one side B of the buckets, figure 3. Therefore, there is drastic damage. This is somewhat incomprehensible, because the water jet should hit the middle of the bucket (figure 4) so that the water jet should be distributed evenly on the two halves of the bucket. It is noted that the outer surfaces of the buckets that are not in contact with the water jet are not damaged at all, which is quiet normal. With the visual inspection, it was established that there are no signs of corrosion on the wheels, as they were cleaned and painted before putting them into operation. In addition, possible

cracks on the inner surfaces are not recorded. According to the information, the turbine wheel was in use for about two and a half years. This something indicates that it takes a very short period of time to damage the buckets from exploitation. Almost all turbine buckets have traces of erosion on the inside, which occurs due to hitting particles carried by the water jet and roll out the buckets.

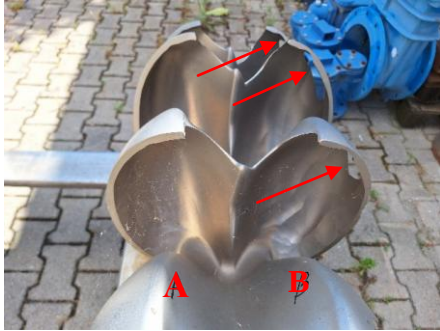


Figure 3 Damaged buckets but only on one side (B) while on the side (A) there are practically no perforations

The same conclusions can be reached from figure 4.

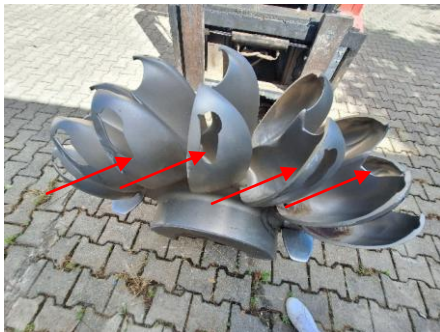


Figure 4 Perforation of the buckets but only from one side

According to technical knowledge water jet has to hit any bucket in the middle, figure 5, but it is not such case in this situation. It is obvious that water jet is not properly directed [3, 4].

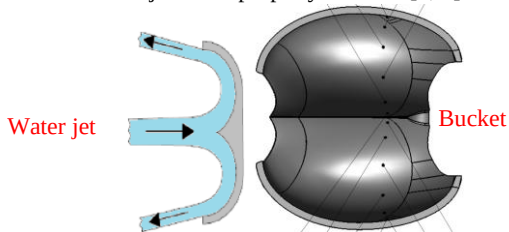


Figure 5 Schematic presentation regular water jet hitting the bucket

This is somewhat incomprehensible, because the water jet should hit the middle of the bucket so that the water jet should be distributed evenly on the two halves of the bucket. It is noted that the outer surfaces of the buckets that are not in contact with the water jet are not damaged at all, which is always normal.

Figure 6 show how particles are arranged in water jet when they hit the bucket depending of their size and weight [5].

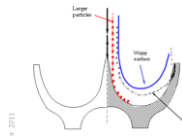


Figure 6 Distribution of particles in waer jet before hiting the bucket

With the visual control, it was confirmed that there are no signs of corrosion on the wheels, because they were cleaned and painted before putting them into operation. Corrosion of the buckets was not noticed. Cracks was not noticed too.

From the figure 7 could be noticed locations on the buckets where their perforations start, arows and circles with yellow colour. It is possible that besides erosion cavitation on the buckets appear too.



Figure 7 View of bucket from the inner side Pozitions where perforation starts

Figure 8 presents roll out material (buckets) during the exploitation as results of erosion from the particles sediments. The reason is erosion that appear as result of hitting the buckets with water jet together with hard particles. Depending from a particles size, they hit the bucket at different locations and lower the thickness of the bucket.



Figure 8 Erosion roll out of the bucket surface during exploitation

In figure 9, one can see traces of erosion on the inside of the buckets. Visual inspection showed that practically all buckets were affected by erosion. Such images can be found in many scientific and technical papers on Pelton hydro-turbine buckets in different parts of the world. It was confirmed in our case too.

What is erosion? Erosion is caused by small debris particles passing through the turbine system. The rapid movement of particles can deform metal surfaces. Over time, when this process is repeated, material is removed and the surface of the parts becomes worn. The level of erosion depends on several factors: the amount of debris, the type of debris, the material of the turbine and the location of the section. Often the worst erosion occurs on high head turbines such as the Pelton. Where water moves very quickly through the valve, erosion can result in turbine equipment failures. In all turbines, over time repetitive contact between silt, sand and small stones with a metal surface will lead to wear.



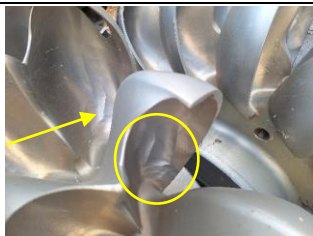


Figure 9 Traces of erosion on the inner side of buckets

Conclusions from the visual review were compared with literature data i.e. schematic overview of erosion. It is obvious that low angle hitting of the particles on the surface of the buckets appear, denoted with red color, figure 10.

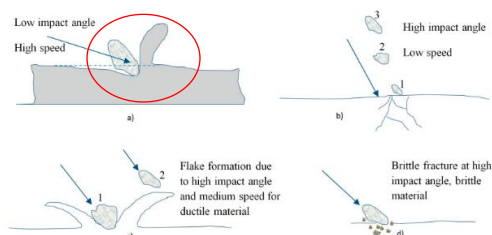


Figure 10 Different types of erosion depending of hiting angle

2.2 Additional investigations on turbine buckets

After the visual control of the turbine circuit (buckets), additional investigations were perforated on the turbine circuit, such as determination of the chemical composition, measurement of the hardness HB and metallographic investigations.

2.2.1 Determination of the chemical composition

The results of determining the chemical composition of the buckets is given in table 1. For comparison, the table also lists values for the chemical composition for X3CrNiMo13-4 steel according to the EN 10250-4 standard. Determination of the chemical composition was carried out in an accredited laboratory. For determination of the chemical composition was used emission spectroscopy device SPECTRO type.

Table 1 Chemical composition of X3CrNiMo13-4 steel

element	Standard X3CrNiMo13-4	measured
C	max 0.05	0.0492
Si	<0.7	0.302
Mn	<1.5	0.67
P	<0.04	0.0142
S	<0.015	0.001
Cr	12-14	12.71
Ni	3.5-4.5	3.54
Mo	0.4-0.7	0.445

Chemical analysis confirmed that the material used to make the buckets is soft martensitic steel X3CrNiMo13-4. It can be noted that the maximum concentration of carbon in this steel is 0.05%. The purpose of the test was to check whether the chemical composition of the incorporated material for making the buckets corresponds to the one declared in the offer, namely X3CrNiMo13-4, number 1.4313. So martensitic stainless steel which is subject to quenching and tempering. This means that the steel after quenching and tempering has a rather low hardness, which is insufficient to prevent erosion, i.e. perforating the buckets.

2.2.2 Measuring the hardness of the buckets

Hardness is considered the most important factor affecting erosion. The higher the hardness, the greater the resistance to erosion. According to the standard, the hardness for this steel can be 320 HB

if it is in the annealed state or about 300 HB if it is delivered in the quenched and tempered state. The measured values for strength are given in table 2. The measurements were performed on cut pieces of the buckets. The hardness was measured in order to see why we have bucket erosion and perforation.

Table 2 Measured bucket hardness

	1	2	3	4	5	6	7
Тврдина HB	255	271	262	257	262	271	249

As can be seen from table 2, the values for hardness range from 249 to 271 HB. It should be noted that this steel is not supplied in the annealed (A) condition, but in the quenched and tempered (Q&T) condition. The material in the annealed state has a hardness of 320 HB in the quenched and tempered state its hardness is about 300 HB. The general rule is that the higher the hardness, the greater the resistance to erosion. The measured hardness of the buckets is quite low. I assume the buckets are delivered in a quenched and tempered condition. In quenched and tempered steels, the hardness varies depending on the tempering temperature and time. When choosing the material for making the buckets, the erosion situation should have been taken into account. It must be mentioned here that erosion is considered as the biggest problem that occurs during the operation of Pelton turbines. It was also confirmed in this case. It is obvious that the buckets are one of the most vital parts for the normal operation of the turbine. Damage to the buckets from the turbine contributes to its being thrown out of operation, which means big stoppages due to replacements and thus big financial losses. It is incomprehensible that the manufacturer of the turbine did not take into consideration the possible defects of the buckets due to erosion, which, together with cavitation and fatigue, certainly contribute to the failure of the buckets. It is assumed that no water analysis was done at all.

2.2.3 Metallographic investigations

Metallographic tests were performed on a cut piece of one of the buckets. A standard metallographic preparation of the sample was done. So, after sanding and polishing, the sample was etched with Nital (3% sol. HNO₃). An analysis of the purity of the material, i.e. the presence of non-metallic inclusions, was performed on a polished and unetched sample. From the photographs, it can be concluded that the material is very clean as far as the presence of non-metallic inclusions is concerned (Figure 7). The microstructure consists of quenched martensite indicating that the steel used to make the buckets was tempered and quenched, Figure 11.



Figure 10 Non-metallic inclusions in steel

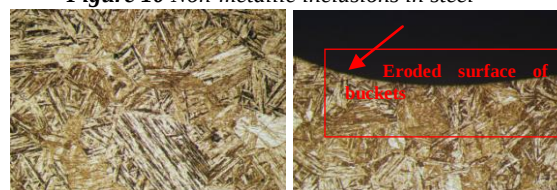


Figure 11 Microstructure of steel for bucket production, x500

What is erosion? Erosion is caused by small debris particles passing through the turbine system. The rapid movement of particles can deform metal surfaces. Over time, when this process is repeated,

material is removed and the surface of the parts becomes worn. The level of erosion depends on several factors: the amount of debris, the type of debris, the material of the turbine and the location of the section. Often the worst erosion occurs on high head turbines such as the Pelton. Where water moves very quickly through the valve, erosion can result in turbine equipment failures. In all turbines, over time repetitive contact between silt, sand and small stones with a metal surface will lead to wear.

Discussion

The on-site inspection was carried out on the dismantled turbine, i.e. the turbine circuit. Almost all the buckets were damaged or rather large holes were observed on them. It is obvious that this is serious damage to the buckets that impairs the basic function of the turbine. Visual inspection clearly showed that these holes (perforations) occur only on one side of the bucket. On the inside of the buckets, typical traces caused by erosion of the material of the buckets were observed too, while on the outside, no such errors were observed. The buckets themselves are painted as outlined in the specification. During the inspection, one bucket was cut and samples were taken from it to determine the chemical composition of the material, metallography and to measure the strength.

The measurement of the hardness of the bucket showed that the hardness of the surface of the bucket is quite low, or rather lower than declared for this type of material. The maximum hardness for this type of steel is 320 HB when it is in the annealed state, but in the quenched and tempered state, the hardness should be about 300 HB when it is in the quenched and tempered state, according to the technical literature (standard EN 10250-4). The hardness in that case will depend on temperature and tempering time. In addition, in this case we have a relatively low concentration of carbon. Carbon increases the hardness of steel, and hardness is known to be the primary factor affecting the material's resistance to erosion [6].

Erosion occurs when the particles present in the jet hit the buckets, but only on one side. This indicates that the jet is not hitting the buckets evenly. A high-speed jet hits the turbine buckets. The higher the speed of the jet, the higher the speed of the particles hitting the surface of the buckets (fine sand particles and small debris/particles). The angle at which the particles hit the bucket surface also affected the erosion damage [7]. Certain research shows that the size of the particles depends on which parts of the buckets will be damaged [8]. As was pointed out earlier, the speed of the jet also has its own effect on erosion, because the speed with which the particles (substrates) hit the inner surface of the buckets also depends on the speed of the water jet. Otherwise, according to the literature and technical knowledge, ordinary steel, high-alloy martensitic steel and even bronze are used as materials for making the [9]. In certain cases, coatings with (chromium or tungsten carbides) are also applied to the buckets. The martensitic steel used has a relatively low carbon concentration, and it is well known that carbon is the main factor that increases hardness and therefore erosion resistance [10]. The maximum measured blade hardness is 271 HB. Obviously, this strength is insufficient to affect erosion resistance. I believe that no care was taken to prevent direct contact between particles and buckets.

Conclusion

The tests conducted in this research work confirmed that the main reason for the appearance of holes (perforations) on the buckets is their erosion. Because of the presence of abrasive particles in the water jet hitting their inner surface in direct contact with water jet. Practice has shown that the buckets of Pelton turbines suffer the most from erosion [11]. The higher the concentration of the particles (mil, sand, gravel, coarse particles, etc.), but also the higher the speed of the water jet, the greater the damage will be. We must not forget the influence of the shape, the strength as well as

the chemical composition of the particles. Otherwise, this phenomenon is not unknown when it comes to Pelton hydro-turbines [12].

Scientific and technical research is still being carried out in this field. Precisely because of this, it is incomprehensible why the manufacturer of the turbine did not take measures to analyze the water and, accordingly, give the optimal solution to erosion. It is indicative that the manufacturer of the turbine, i.e. its constructors and designer, did not check the composition of the water, i.e. the presence of particles. Otherwise, appropriate measures would have to be taken [13]. The material chosen for making the buckets is quite good and used for this purpose, however the effort should have been affected as it affects the erosion resistance to a certain level. Martensitic steel - soft martensitic steel X3CrNiMo13-4 was used for making the turbine. Practice shows that carbon steel and even buckets made of brass can be used. It will primarily depend on the danger of erosion. In addition to the choice of material, care should also be taken to install filters that would prevent the contact of particles, substrates from the water jet with the fire surfaces of the buckets. Therefore, the water entering the turbine had to be analyzed, and filters (sieves) should be selected according to the size of the particles. If it was physically prevented, the contact between the substrates and the buckets would be much longer. Then the lifetime of the buckets would be much longer. According to the technical data, the Pelton turbines can achieve a service life of twenty years. In this case, the working life is about two and a half years. There is also a question as to whether the training of the personnel for operating the turbine as well as its maintenance has been done. As I previously pointed out, it was necessary to install filters to prevent erosion of the buckets from the particles, but also to make a special design of the buckets that directly affects their resistance to erosion. The speed of the water jet, but also the angle at which the water jet hits the buckets are also very important. If the representatives of the manufacturer had come to the site after the accident, they would have been able to see all the facts I am talking about. It is known that there are three basic types of failures in Pelton turbines, namely fatigue, cavitation and, above all, erosion. Preventing erosion in Pelton turbines is critical to maintaining their efficiency and longevity. Here are some strategies that would help mitigate the danger of erosion:

1. Material selection: Use erosion-resistant materials for baskets and other components. Materials such as stainless steel or special alloys can withstand the abrasive action of water and particles better than standard materials.
2. Surface Coatings: Apply protective coatings to turbine components. Coatings such as hard chrome, tungsten carbide or ceramic can provide a barrier against erosion [14].
3. Water quality management: Ensure that the water used in the turbine is as clean as possible. Installing sediment traps or filters can help reduce the amount of abrasive particles in the water.
4. Optimal design: Design turbine components to minimize areas where erosion is likely to occur. This includes optimizing the shape and angle of the buckets to reduce the impact of water jets.
5. Regular maintenance: Conduct regular inspections and maintenance to detect early signs of erosion. This allows for timely repair or replacement before significant damage occurs.
6. Operational adjustments: Adjust turbine operation to reduce water jet velocity when possible, as lower velocities may reduce erosive force.

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Fabrication of electrospun poly (3-hydroxybutyrate) materials with controlled fibers alignment and desired mechanical properties

Vladimir Krastev, Mariya Spasova, Olya Stoilova
Laboratory of Bioactive Polymers, Institute of Polymers, Bulgarian Academy of Sciences, Sofia, Bulgaria,
v_krastev@polymer.bas.bg

Abstract: The fibrous materials produced by electrospinning offer unique properties and enormous applications. Nevertheless, despite progress in the electrospinning process, it is still an important challenge to find possible adjustments and improvements to the mechanical properties of these materials. In this regard, the study focuses on the preparation of electrospun poly(3-hydroxybutyrate) materials with controlled fiber alignment and desired mechanical properties.

Among aliphatic polyesters derived from renewable sources, poly(3-hydroxybutyrate) (PHB) stands out as a promising hydrophobic, thermoplastic polymer with physical properties similar to polypropylene. However, unlike polypropylene, PHB is both biocompatible and biodegradable. Despite these advantages, PHB presents processing challenges: it is brittle, with high crystallinity, leading to poor mechanical properties. This work explores innovative approaches to enhance the mechanical properties of electrospun PHB materials. One approach examines the effect of collector geometry and rotation speed on fiber alignment and mechanical properties of the obtained fibrous materials. Another approach applies coatings of natural polysaccharides (such as chitosan and cellulose derivatives) to the PHB fibers, using solvents that preserve fiber structure.

KEYWORDS: ELECTROSPINNING, POLY(3-HYDROXYBUTYRATE), PATTERNED COLLECTORS, COATING, MECHANICAL PROPERTIES

Acknowledgements:

Part of the research equipment of distributed research infrastructure INFRAMAT, part of the Bulgarian National Roadmap for research infrastructures, supported by the Bulgarian Ministry of Education and Science was partially used in this study.

Quo Vadis industry? Critical and strategic raw materials, environment-friendly WEEE mining and REE reuse

Zara Cherkezova-Zheleva^{*1}, Daniela Paneva¹, Radu Robert Piticescu², Guido Heunen³, Olivier Jay⁴
 Institute of Catalysis, Bulgarian Academy of Sciences, Sofia, Bulgaria¹,
 National Research and Development Institute for Nonferrous and Rare Metals-IMNR, Ilfov, Romania²
 SIRRIIS, rue du bois Saint-Jean 12, BE-4102 Seraign, Belgium/Wallonia³
 FADDTORY SPRL, rue Albert 1er, nr42, 5380 FERNELMONT, Belgium/Wallonia⁴

^{*}Corresponding author

E-mails: zzhel@ic.bas.bg; daniela@ic.bas.bg, rpiticescu@imnr.ro, guido.heunen@sirris.be, oj@faddtory.com

Abstract: Critical Raw Materials (CRMs) are raw materials that combine high importance to the EU economy and high risk associated with their supply due to their production only in a few countries or in countries with unstable regimes. In this regard the renewed industrial EU strategy is focused on stimulation of the production of CRMs by enhancing new mining and recycling activities in the EU, as well as on fostering efficient use and reuse of critical raw materials, a priority area in the EU circular economy action plan. In parallel, the attention is currently focused on the Strategic Raw Materials, which are a vital Resource for various industries having unique properties and challenging to replicate. Strategic raw materials help make Europe more independent in the production of strategic products, especially in the area of green energy production, digital technology and defence. Both critical and strategic raw materials play a crucial role in modern technology, quality of life, and clean technology initiatives.

Currently, the importance of rare earth elements (REE), both heavy and light REEs, continuously increase on a global level due to their significance both as critical and strategic raw materials, having an additional high demand connected with the Green transition. REEs are irreplaceable in applications such as wind turbines, electric vehicles, automotive catalysts, energy-efficient lighting, electric batteries, solar panels, mobile phone and computer displays, glass additives, metallurgy, etc. Therefore, the sustainable solution to address the high demand and the straitened supply of REEs is to accelerate the scientific and innovative investigations focused on the closing of the loop of their life cycle.

On the other hand, mechanochemical treatment of waste materials has been recognized as a green and sustainable method for waste management and pollution remediation.

The presented investigation is focused on treatment of EoL small magnets from hard discs based on their degree of damage, toward preparation of standardized batches of Fe-Nd-B-containing materials.

The performed laboratory experiments revealed the possibilities for the design of mechanochemical reactions toward environmentally friendly, sustainable and economical recycling of target materials. The study includes multidisciplinary analysis of the obtained data based on detailed physical-chemical characterisation using XRD, Moessbauer spectroscopy, Electron Microscopy and EDS. Special attention is paid to follow the changes of material composition at different stages of the treatment. The paper is also a step forwards the development of the scientific foundations of mechanochemistry by studying the multidirectional processes that take place during the material treatment, toward the selection of mechanochemical reactions with potential application in practice.

Acknowledgements:

This article is based on the project activities of H2020 ERA-MIN3 Project № KII-06-ДO02-3/06/06/2022: Microwave enhanced recovery of REEs and plastic from WEEE and re-use in Additive Manufacturing of novel magnetic components (MW4REMAM).

Digital transformation and corporate culture: shaping work-life balance and employee well-being – A systematic literature review

Natália Mišíková^{1,*}, Nadežda Jankelová²
 University of Economics Bratislava, Slovakia¹
 University of Economics Bratislava, Slovakia²
 natalia.misikova@euba.sk

Abstract: This article provides a systematic literature review to explore the relationship between digital transformation and corporate culture, focusing on their impact on employees' work-life balance and well-being. In today's dynamically changing work environment, the rapid adaptation of businesses to digital technologies figures prominently in changing corporate practices. This transition to the digital era has a significant impact on employees' personal and professional lives, which must also remain a key area of research interest. This review will focus on two key research areas: (1) the role of digital technologies and teleworking in shaping work-life balance, and (2) corporate culture in the context of digital transformation. Within the research findings, there is considerable current literature on how companies can use digital technologies to their advantage while shaping a strong corporate culture to improve work-life balance and employee well-being.

Keywords: DIGITAL TRANSFORMATION, REMOTE WORKING, CORPORATE CULTURE, WORK-LIFE BALANCE, JOB SATISFACTION

1. Introduction

The current era of Industry 4.0 is related to the relentless and dramatically rapid development of technology on the one hand and the development of socio-economic factors on the other. With the advent of the latest production technologies, working conditions and lifestyles of the human population have historically changed. Industry 4.0 is a turning point that is putting an end to conventional production. It is the result of merging the boundaries of the physical and virtual worlds to create cyber-physical systems. It is a change in the way industry can respond to the changing needs of human society [1]. The fourth industrial revolution has changed the information age. Since this moment, for the first time in the history of mankind, the emerging new technologies that allow us to control everything around us, in a much more intelligent way, have brought society to the possibility of rethinking the current practices and processes, for the re-execution of anything that is as autonomous and intelligent as possible [2]. As Mariette DiChristina [22] said: "Technologies that are emerging today will soon be shaping the world tomorrow and well into the future - with impacts to economies and to society at large. Now that we are well into the Fourth Industrial Revolution, it's critical that we discuss and ensure that humanity is served by these new innovations so that we can continue to prosper". Digital transformation has therefore become inevitable for all sectors within the global economy. Its domain is the adoption of digital technologies to increase operational efficiency, expand markets of operation and improve business competitiveness [4].

The digital era has enabled the ubiquity of the work environment. Employees have much more freedom to choose to work anytime, anywhere in this environment. Historically, work has had clearly defined boundaries in the work environment. The confined spaces of the office were separated from personal life. Today, however, there is a change in the established trend. In recent decades, these boundaries have become less and less visible, and this is mainly due to the increasing interconnectedness brought about by technological advances [5]. Work-life balance is a key idea when trying to achieve work-life balance for employees. Individuals must individually manage their workload, adapting to flexible working hours on the one hand, and managing their family and social commitments on the other, to maintain the operation of this balance. Organizations can facilitate this effort for employees precisely by offering them adaptable work patterns, supportive policies and psychosocial support [6]. Digital development has brought several new opportunities for companies to achieve sustainable human resource management in many ways, including teleworking as a means of achieving work-life balance for employees. Digitalization is improving the skills of employees in both the public and private sectors. However, private companies are using work in much greater numbers to achieve work-life balance

for employees. Digitalization helps employees in many areas. For example, in learning, development, achieving work-life balance, or job well-being [7].

Change and adaptability, two concepts in the era of Industrial Revolution 4.0 and Society 5.0. All businesses, including universities, need to demonstrate the ability to adapt to the dynamic environment around them in order to survive in it. Institutions need to be sufficiently equipped with information technology to face today's global competition. Corporate culture is a coherent system of norms, rules, beliefs, values, patterns of behavior and interactions across a company. Corporate culture is a collaborative means through which the vision, goals and development of a company can be achieved [8]. As Katherine Kostereva mentions: "Digital transformation is a business discipline or company philosophy, not a project" [23]. Digital transformation aims to help companies understand and seize the opportunities presented by the digital era, improve efficiency and competitiveness through innovation, and ultimately achieve continuous sustainable development. Corporate culture represents a company's identity, its core values, and influences communication, collaboration and decision-making. Corporate culture therefore plays a key role in the development and success of companies. It is rooted in shared values and beliefs that reflect the principles and norms of behavior of employees and management. Corporate culture is unique. It must be derived from the strategic goals and values of the organization. A strong and positive corporate culture can positively influence employee empowerment, increase employee satisfaction and loyalty, and help businesses achieve long-term success [9].

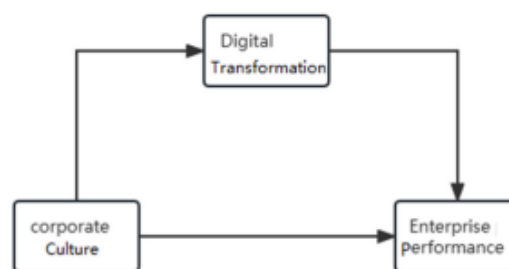


Figure 1 The Theoretical Framework [9]

2. Methods

This study follows the systematic literature review process adopted by Xiao and Watson [2]. The systematic literature review process is illustrated in the following figure.

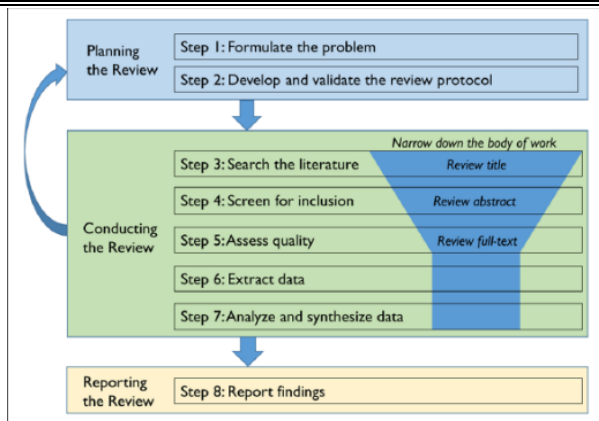


Figure 2 Process of systematic literature review [2]

The first step was to formulate the research problem through research areas or research questions that framed the entire literature review process. The next step was the development of the research protocol, which was designed to reduce the subjectivity of the authors and clarify the selection of the literature used through criteria that include the purpose of the study, the research areas, the literature search strategy, or the method of data processing.

Subsequently, we conducted a literature review. The fourth step was accompanied by the need to evaluate the literature and decide whether or not to include individual publications in our analysis. The first step was a rough reading of the abstracts of each study, followed by a detailed assessment of their quality based on a full-text study. We set our selection criteria based on our study areas. In assessing the quality of the articles, we were able to perceive the differences of the selected literature and the subsequent possibility of extracting less relevant literature through synthesis of the data obtained from the literature used. We used induction and deduction in the data extraction process so that the findings could be interpreted in a sufficiently relevant way in the conclusion of the article. After completing the data extraction process, we organized the data through a spreadsheet. For a clearer output, we chose a segregated design that handles qualitative and quantitative studies separately and produces a combination of them in the final text. The last part of the systematic literature review was the final clear and rigorous output of our paper. It focuses on key areas of research. It is included in the results and discussion section of the paper [2].

3. Research results

The following tables provide an overview of the sources and relevant literature related to two chosen areas of investigation (1) the role of digital technologies and telework in shaping work-life balance, and (2) corporate culture in the context of digital transformation. The tables are divided separately and respond separately to the issues under investigation. From the key information for each area, we have created a discussion and output of our paper.

Table 1 Review of the research results first study area

Author, author's collective	The role of digital technologies and teleworking in shaping work-life balance
Stephen A. and et al, 2024	Flexibility, autonomy, transparent communication - tools for remote working. More time, collaboration, efficiency
Aydinli and Erkasap, 2023	They reduce work-related stress levels. Automation, flexibility, efficiency of the working environment
Schongen S. 2023	Creation of new working models

	(flexible working hours, increased control and work), autonomy, increased productivity, automation, positive social impact
Vyas L. 2022	Flexibility of work, hybrid work, improving employee well-being, increasing the psychological well-being and health of employees
Chatterjee S. and et al, 2023	Increased work performance, flexible working options, changes in work processes and social interaction
Gálvez A. and et al, 2012	Autonomy, organizational support, performance improvement

Table 2 Review of the research results second study area

Author, author's collective	The role of corporate culture in the context of digital transformation
Gálvez A. and et al, 2012	Applying digital technologies and measures for teleworking opportunities. Autonomy, work flexibility, support
Fahmi T.A. and et al, 2023	Flexibility of working conditions, development of digital skills, openness to change
Hamdani N.A. and et al, 2021	Ensuring flexible and skilled human resources for the current market environment
Rathi and Srivastava, 2024	Supportive work environment, psychological safety, communication, flexibility
Bozkus K, 2023	Cultural shift in organisations, integration of new technologies, adaptability and development, new trends (functioning, shaping, communication)
Khanzad and Gooyabadi, 2022	Shift in corporate culture, integration of new technologies, role of leaders, emergence of a culture of adaptability, development and growth

4. Discussion

Digital technologies bring with them new opportunities in the context of work-life balance. They enable greater flexibility in work and work planning, open and transparent communication, autonomy, efficient planning and help employees to have more time available for their personal activities. At the same time, they enable collaboration on a global scale with the elimination of geographical boundaries. However, from the employer's perspective, there is a need to assist employees in establishing work-life boundaries and incorporating an organizational culture that will serve to support this pull [10]. Work-life balance, work stress and digital transformation are interconnected elements. There is a significant link between digital transformation and maintaining work-life balance. The change brought about by digital transformation does not have a direct negative impact on work-life balance. Digital transformation, through state-of-the-art technology, streamlining of processes and flexible working conditions, alleviates the pressure that is associated with work commitments [6]. According to research by Sebastian Schongen, digitalisation brings positive results for work-life balance. Digital technologies improve working conditions for employees, offer increased autonomy in the choice of where and when to work, and allow for increased labour productivity through the digitisation and automation of work processes, freeing up time for individuals' other activities. Although the boundaries between work and private life are constantly blurring and work stress is increasing at the same time, it has been shown that technological change can have a desirable positive impact on this balance. However, one of the negatives remains the difficulty of social inclusion in the workplace [11]. The role of digital

technologies is therefore also a contribution to hybrid working conditions, teleworking, flexible working hours, increased employee productivity, all elements that go hand in hand with technological advances. It has been found that the benefits of digital technologies are also based on improving the psychological well-being of employees and increasing their health. At the same time, research also points to possible negatives such as the impossibility of defining work-life boundaries in teleworking, or the assumption of being constantly connected to work. That is, based on the current hyperconnectivity, employees may experience work overload [12]. People who work occasionally in a hybrid or telecommuting environment have the best job quality and work-life balance [15].

Digital technologies provide tools that can have a positive impact on work-life balance. However, these tools can only be used if the corporate culture is set up to do so. It is not so much important to implement specific measures such as hybrid jobs or teleworking, but rather to change the organisational culture of companies so that there is a willingness to put these measures into practice. Corporate policy cannot be divided into one where it is compulsory to always be present in the workplace and one where it is not. In such a case, the consequence will be a negative impact on employees' social relations, conflicts and an imbalance in work-life balance. Therefore, the support that teleworkers have from the organization and management, autonomy, flexibility of working hours are extremely important within the organizational culture [14]. A company culture that supports work flexibility and adaptation to digital change positively shapes employees' attitudes and their overall well-being at work. The company culture must therefore be set up in a way that supports the development of digital skills that will have a positive impact on work-life balance and employee well-being. Such a supportive corporate culture opens a positive attitude towards change among employees. This is a key aspect for their psychological well-being during transition periods [16]. When the need arises to apply digital transformation in an enterprise, according to research Chernyavskaya S.A. and et al, in order to achieve the greatest effect from the organization's digital transformation, it is necessary to develop its strategy, increase the digital skills of employees, change the organizational culture to a digital one, and attract talent [17]. Digital transformation in the context of corporate culture has a huge impact. It requires a shift towards innovation, empowerment, collaboration and adaptability of employees and company leadership. In order to overcome the challenges and take full advantage of the opportunities offered by the digital era, organisations need to identify and address this impact on culture. Employee engagement and investment in digital skills development is needed. The link between corporate culture and digital transformation is underlined in addressing the challenges of the digital era together. Continuous adaptability, learning and humanity is required for the long-term sustainability and success of organizations on a global scale [20].

5. Conclusion

The current digital era and remote working has brought new opportunities for companies to operate. It has brought new opportunities and challenges to companies around the world. These opportunities include increased flexibility, autonomy, efficiency and the removal of geographical barriers, which encourages global collaboration. However, to take full advantage of these benefits offered by digitalisation, it is essential to gradually introduce a supportive corporate culture that helps to establish boundaries between personal and professional life, is adaptable to digital change, is supportive in the context of transformational change, is transparent, engages employees sufficiently and develops them in a direction in which employees can increase their digital skills. Only then can corporate culture play a role that enhances employee well-being, performance, motivation and overall work-life balance. At the same time, it reduces stress, improves productivity and the psychological well-being of employees. To thrive in the digital era, companies need to invest in building a culture that is willing to embrace change and that fosters adaptability and resilience. If

companies can find synergies between digital transformation and building a coherent corporate culture in the coming era, they will be able to create the conditions for enhancing employee work-life balance and well-being. They will become more competitive in a global environment.

6. Acknowledgement

This work was supported by VEGA 1/0010/23 Adaptability of corporate culture – a factor supporting resilience and sustainability of enterprises in Slovakia in the post-covid period.

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Conceptual Model for Increasing Production Efficiency in Bulgarian Industrial Enterprises

Tanya Panayotova^{1*}, Denis Sherifov¹
 Technical University Varna, Bulgaria¹
 t_panayotova@tu-varna.bg, d_sherifov@tu-varna.bg

Abstract: *In a world of constant change, there is an increasing need for tools and methods that help organizations become more efficient and competitive. Overcoming traditional thinking in business management requires organizations to quickly adapt to market innovations and fully focus on "processes, results, and customers." Otherwise, many traditionally operating organizations may struggle to survive in a dynamic business environment. The modern concept of production efficiency is no longer limited to individual production units but focuses on the entire value chain, i.e., the "delivery of value" to all stakeholders. Despite the existence of various practices, methods, approaches, or theories that identify and deliver value to different stakeholders, the implementation of improvements within enterprises remains a subjective process. Based on the achievements of existing methods, tools, and best practices for realizing rapid-response and low-cost production processes, this publication proposes a conceptual model for increasing production efficiency in industrial enterprises in Bulgaria. The model takes into account the new realities of the Fourth Industrial Revolution and its logical continuation into Industry 5.0 by identifying and delivering value to all stakeholders.*

Keywords: PRODUCTION, EFFICIENCY, PROCESSES, CONCEPTS, MANAGEMENT, KEY INDICATORS

1. Introduction

In today's economic environment, characterized by intense global competition and ever-increasing dynamics of market demands, the behavior of the enterprise's production system is a key factor for its sustainability and competitiveness. Changing global market conditions and advances in technology require new approaches to the management of production processes. The development of production systems today is closely linked to increasing the efficiency, flexibility and quality of production, which brings into focus the need for an in-depth analysis of the underlying concepts and principles that determine their behaviour and interaction.

With the increasing role of technology and innovation, modern enterprises are striving not just for production but also for optimization of their resources, which allows the creation of quality products at minimum cost. This aspect of production system management is crucial to remain competitive and to achieve sustainable growth in today's economic environment.

The production system in an enterprise is a set of resources, technologies, processes and organizational mechanisms that aim at transforming raw materials and resources into value-added finished products. This system includes not only tangible resources (machinery, equipment, raw materials) but also immaterial aspects such as process management, quality control, logistics and planning. The efficiency of the production system depends on the ability of the enterprise to synchronise and manage all its components so as to achieve an optimal balance between productivity and resource utilisation. Understanding the nature and characteristics of the production system is a prerequisite for considering the factors determining its behaviour.

The purpose of this publication is to explore and present a conceptual model for the application of Industry 5.0 principles in Bulgarian industrial enterprises to ensure higher production efficiency and sustainability.

2. Conditions and methods of solving the problem

Various methods and approaches exist in the literature to analyze the efficiency and productivity of manufacturing systems. Classical approaches such as production capacity analysis, resource management and quality assessment remain fundamental to the optimization of manufacturing processes. However, modern demands require the application of innovative models such as Lean Production, Just-in-Time and Total Quality Management. These approaches are designed to increase efficiency by minimizing waste, rationalizing the use of resources and integrating Quality principles into the overall production process. Through the analysis of these methods and concepts, the main aspects of the behaviour of

the production subsystem necessary to ensure sustainability and competitiveness in today's economic environment are clarified.

Technology and innovation are crucial in determining the behaviour of modern production systems. Progress in automation, robotics and digitalisation is transforming traditional production models and creating new opportunities to increase efficiency and reduce costs. Concepts such as Industry 4.0 and the Internet of Things (IoT) allow enterprises to collect and analyse data in real time, which makes manufacturing processes more flexible and adaptable to changing market demands. The role of technology and innovation is not limited to the efficiency of production processes, but also includes aspects related to the quality and sustainability of production, as well as the optimisation of resource management. It is not possible to achieve long-term business success without exploiting the advantages of information and communication technologies in this digital age. Companies must take a reasonable price to achieve this success because using an innovative approach to business strategy, hiring highly skilled IT professionals and making the right decisions at the right time is a prerequisite for business success. [3]

Today's industrial enterprises are faced with the need to implement optimization approaches to ensure quick response to market changes and minimize production costs. Kaizen, Lean and Six Sigma are the most widely used and well-established methods for achieving these goals. These methods are designed to efficiently manage resources, reduce waste and improve the quality of production.

Kaizen is a Japanese philosophy of continuous improvement that focuses on small but continuous improvements in all aspects of the organization. The word "Kaizen" itself means "improvement" and is widely accepted as an approach to engaging all employees, regardless of their position, in the process of optimizing production. Kaizen is based on the idea that sustainable improvements in quality and efficiency can be achieved through small but regular changes that lead to long-term results. Through its philosophy of continuous improvement, Kaizen facilitates rapid adaptation to change and reduces costs by eliminating waste and improving process quality. Continuous small improvements reduce production time and operational costs while improving production efficiency. [4]

Lean manufacturing is a management philosophy focusing on minimizing waste and optimizing the manufacturing process by improving the flow of materials and information. Originally developed at Toyota, Lean uses a series of techniques and practices that reduce the resources required for production without compromising product quality. The primary goal of Lean is to maximize value for the customer with minimal expenditure of resources.

Lean manufacturing enables businesses to quickly adapt to changes in demand, reducing lead times and increasing

production flexibility. By eliminating unnecessary activities and waste, Lean achieves low costs and higher efficiency, which is essential for manufacturing competitiveness. [6]

Six Sigma is a methodology focused on improving quality by reducing defects and variation in manufacturing processes. The method is based on statistical analysis and the application of structured problem-solving methods, with the objective of achieving a defect rate that is less than 3.4 per million opportunities. Six Sigma, developed at Motorola and widely adopted in various industries, follows the DMAIC (Define, Measure, Analyze, Improve, Control) cycle, which provides steps for identifying and eliminating the causes of inefficiencies. [8]

Six Sigma minimizes variation and defects in production, resulting in better process predictability and stability. As a result, organizations can respond quickly to market demands and reduce costs associated with waste and poor quality production. Also, through its strong focus on data analytics, Six Sigma optimizes manufacturing costs and supports the long-term sustainability of quality. [7]

In the last decades, the industrial environment in Bulgaria has experienced significant changes under the impact of global digitalization and the introduction of automation and related technologies. However, Bulgarian industrial enterprises often face challenges in adapting to the rapid changes, especially in the context of the constraints of the local economy and market dynamics. Industry 5.0, presented as the next stage of the industrial revolution, places emphasis on human-machine interaction, sustainable production and social responsibility. This concept offers new opportunities for optimisation and humanisation of production processes, which is essential for Bulgarian enterprises in their drive to increase efficiency and competitiveness.

3. Conceptual model for increasing production efficiency in Bulgarian industrial enterprises.

Publication presents a conceptual model for increasing the efficiency of production in Bulgarian industrial enterprises. The model consists of three main components: Technological Transformation, Humanisation of the Production Process and Sustainability and Resource Efficiency.

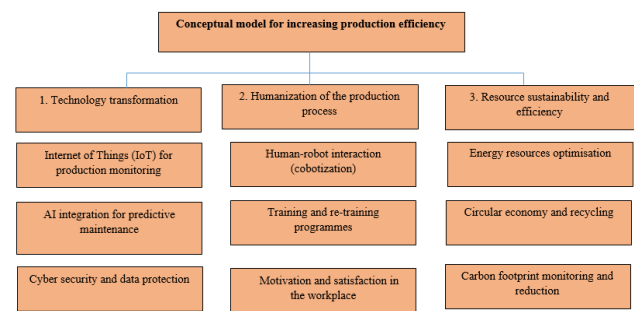


Fig. 1 Conceptual model for increasing production efficiency in Bulgarian industrial enterprises

3. 1. Technological transformation

Technological transformation involves the integration of automated and digital technologies that increase productivity, collect data for analysis and support decision-making. Depending on the characteristics of their business, organisations generate, use or process data that is diverse in type, content and structure. It is up to each organization to determine which data are vital to its operations and which are secondary or supporting. [1] :

3.1.1 Internet of Things (IoT) for production monitoring

Implementation of IoT sensors that monitor real-time key metrics such as machine efficiency, energy consumption, and task

turnaround time. Data can be collected in a centralized platform for analysis and optimization.

3.1.2 Artificial intelligence (AI) integration for predictive maintenance

AI algorithms can analyze historical data and predict failures and maintenance service needs. It will reduce equipment downtime and optimize repair costs.

3.1.3 Cyber security and data protection

As digitalization continues to increase, cybersecurity is becoming a priority, especially in industries with high data sensitivity. Implementing secure protocols and personnel training will minimize the risks of information loss and protect industrial systems.

3.2. Humanisation of the production process

The second key element relates to increasing employee motivation and productivity by enabling collaborative working with robotic systems and promoting skills. This includes:

3.2.1 Human-robot interaction (cobotisation)

Implementation of collaborative robots (cobots) that work side by side with humans. Cobots can perform tasks requiring precision or physical strength, while operators focus on control and decision-making. This will improve the quality of work and reduce the risk of injury.

3.2.2 Training and retraining programmes

Develop adaptive programs to train personnel in the skills to work with new technologies. Retraining will enable the people employed to use new technologies more effectively and create a more flexible and skilled workforce.

3.2.3 Motivation and job satisfaction

Introduce motivational programmes and flexible working arrangements that increase employee engagement. Research shows that higher employee satisfaction has a positive impact on productivity.

3.3. Sustainability and resource efficiency

The third key priority relates to increasing resource efficiency and minimising waste through sustainable practices and circular economy, which according to the authors includes:

3.3.1 Optimisation of energy resources

Implementation of energy efficient technologies and energy management systems. For example, intelligent systems can automatically adjust energy consumption according to production needs.

3.3.2 Circular economy and recycling

Introduce waste recycling and material reuse processes that will reduce costs and improve the sustainability of businesses. Particular attention could be paid to recycling raw materials and packaging in production.

3.3.3 Monitoring and reducing the carbon footprint

Using IoT and resource management software, enterprises can monitor and optimise their carbon footprint. Reducing CO2 emissions and other pollutants will increase competitiveness, especially for export markets..

Sustainable development is based on the idea and concern for economic growth that improves the well-being of people and society in the long term and is directly linked to the need to solve global problems related to climate change, economic, social, environmental and demographic crises. [2]

4. Conceptual model Key performance indicators.

The proposed conceptual model for increasing efficiency in Bulgarian industrial enterprises implies measuring progress through a set of Key Performance Indicators (KPIs) that reflect different aspects of the production process, human resources and sustainable resource management. Appropriate selection and monitoring of these indicators will allow enterprises to assess the results of the model implementation and identify areas for further improvement..

4.1 Indicators of technological transformation

4.1.1 Overall Equipment Effectiveness – OEE

Production Equipment Effectiveness measures the combined effect of machine availability, productivity and quality. OEE provides a summary indicator of equipment efficiency and reveals gaps in resource utilization and process optimization.

4.1.2 Production cycle speed

This indicator measures the time it takes to complete a production cycle from start to finish. Reducing turnaround time is an indicator of manufacturing process optimization and IoT and AI integration.

4.1.3 Level of process automation

The automation metric reflects the proportion of processes that are automated and executed by robots or IoT devices. Increasing automation leads to increased productivity and improved execution accuracy.

4.1.4 Speed of response to a technical problem

This metric evaluates the time it takes to diagnose and resolve technical issues, especially through AI-based predictive maintenance. Reducing response time reduces downtime and increases efficiency.

4.2 Manufacturing process humanisation indicators

4.2.1 Level of employee engagement and satisfaction

The engagement indicator measures the degree of employee participation in improvement suggestions and their satisfaction with working conditions. Higher levels of engagement are associated with improved motivation and productivity.

4.2.2 Number of employee suggestions for improvement

The number of suggestions for improvement is an indicator of the active involvement of personnel in the optimization of production processes. This indicator also reflects the culture of continuous improvement (Kaizen) and employee engagement in the production process.

4.2.3 Percentage of hours invested in training and retraining

This indicator measures the amount of time employees spend training and qualifying to work with new technologies. Increasing the percentage of training is linked to improving employee skills and professional flexibility.

4.2.4 Workplace safety and accidents indicator

The number of safety incidents and violations measures the level of safety and conducive work environment. A reduction in incidents indicates more effective risk management and collaborative working with robotic systems (cobots).

4.3 Sustainability and resource efficiency indicators

4.3.1 Energy efficiency of production

Energy efficiency is measured as the ratio of output production to energy used. Reducing energy costs without compromising output production is an indicator of sustainable resource management.

4.3.2 Percentage of recycled materials and waste

This indicator measures the percentage of materials that are recycled or reused in the production process. Increasing this percentage reflects the company's commitment to sustainability and circular economy.

4.3.3 Level of carbon emissions and environmental footprint

The carbon emissions indicator measures the total level of harmful emissions, including CO₂. Reducing emissions and the environmental footprint is a key factor for competitiveness in international markets, especially with environmental responsibility requirements.

4.3.4 Percentage of waste from the production process

The amount of waste as a percentage of total production reflects resource efficiency and sustainability of production practices. Reducing waste reduces costs and improves the sustainability of the enterprise.

These key performance indicators provide a comprehensive framework for assessing the effectiveness and results of the implementation of the conceptual model in Bulgarian industrial enterprises. Measuring these indicators will allow tracking progress

in technological transformation, humanisation of the working environment and sustainable resource management. Regular monitoring and analysis of these KPIs will support management in identifying areas for optimization and in implementing further corrective measures to increase the competitiveness and sustainability of Bulgarian industry.

5. Conclusion

In this publication a conceptual model for increasing the efficiency of production in Bulgarian industrial enterprises was proposed, which combines the three main pillars of Industry 5.0 - technological transformation, humanization of production processes and sustainable resource management. In the face of global competition and ever-changing market demands, Bulgarian industrial enterprises are faced with the need to adapt their strategies and operational practices to remain competitive and sustainable.

Technological transformation, which includes the implementation of automated and digital technologies such as IoT, artificial intelligence and cyber security, provides the basis for optimising production processes and increasing equipment efficiency. Artificial intelligence-based monitoring and predictive maintenance systems enable reduced maintenance costs and minimized machine downtime. By using data effectively, businesses can not only increase productivity but also achieve better control over their processes and ensure sustainable resource management.

Sustainability and efficient resource management, which constitute the third pillar of the model, reflect the critical role of enterprises in addressing global challenges related to climate change and environmental protection. The implementation of circular economy practices and energy efficiency optimisation contribute not only to reducing costs and increasing profitability, but also to reducing the environmental footprint of production activities. Resource monitoring and management systems allow companies to monitor emissions levels in real time and adapt their processes to meet the environmental demands of today's market.

The conceptual model also offers detailed performance measurement indicators that allow regular monitoring and evaluation of the progress of implemented changes. Key Performance Indicators (KPIs) provide a structured framework for tracking performance and identifying areas for improvement. Implementing this model and monitoring KPIs provides businesses with the ability to adapt and improve their processes in response to external and internal changes, increasing their operational agility and sustainability.

In conclusion, the conceptual model for improving production efficiency offers a strategic and operational approach for adapting Bulgarian industrial enterprises to the demands of the modern economic environment. By integrating technological innovation, humanization of the work environment and sustainable resource management, the model creates opportunities for achieving sustainable growth and high competitiveness.

In order to facilitate the procedure of tracking progress in technological transformation, humanization of the work environment and sustainable resource management, or at least to reduce subjectivism in making final decisions on the relevance of each pillar of the proposed model, it is recommended to use the right assessment methods and software [5]. A suitable method to realize this goal is the Analytic Hierarchy Process/ANP (Saaty, 1980). The ANR method is a useful tool for selecting an alternative when multiple criteria are used and especially when the criteria also have subcriteria. It is used to make choices based on the relative importance of the criteria in achieving the objectives of the production system and the extent to which the performers are satisfied.

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Increasing production efficiency through an innovative hybrid monitoring system

Konstantin Kostov¹, Krasimira Dimitrova²
 “Meta 8” LTD, Varna, Bulgaria¹
 Technical University Varna, Bulgaria²
 kostov@meta8.bg, krasimira.dimitrova@tu-varna.bg

Abstract—Globalization in the modern world covers all areas of life, economy and modern technology, politics and culture. The rapid development of information and communication technologies makes it possible to provide competitive advantages to business organizations. In recent decades, information systems have led to a dramatic increase in the productivity of large and small businesses. This enables an accelerated transition to climate neutrality and digital transformation of the economy, society and industry and requires new technologies, investments and innovations to ensure the sustainable development and competitiveness of every business and a resource-efficient and competitive economy as a whole. The integration of digital technologies in production processes plays an increasingly important role in shaping the competitiveness of enterprises and their sustainable development in the modern world.

Keywords—EFFICIENCY, SUSTAINABILITY, TECHNOLOGY, PRODUCTION, MONITORING

1. Introduction

Nowadays, production systems are subjected to more and more serious analyzes and effective solutions are sought to increase the production capacity and at the same time reduce the costs per unit of product. These measures are also in sync with the global circular and low-carbon economy policy. The development of scientific and technical progress has led to such technologies, through which it is possible to apply modern organizational forms in the transfer of information, as well as for coordination and constant control of the stages of development and production. The implementation of these forms creates an opportunity for flexible organization of production, shorter lead times, avoidance of duplication of effort, overall process control, consistent data documentation, integration of mechanics, electrical systems and automation [6]. To ensure business success in the future, every company must identify ways and means to increase the efficiency of its internal processes, resulting in achieving the most cost-effective quotations for it in the dynamic competitive environment [7].

The search for increasingly creative solutions to improve production practices and reduce energy consumption is developing in three main aspects - economic, social and environmental.

From an economic point of view, the aim is to achieve a higher competitiveness of the manufactured products. The reduction of energy required per unit of product leads to a reduction in production costs and thus creates a better position of the product in the market and a higher attractiveness for consumers. At the same time, this should not be at the expense of quality. Quality has become one of the decisive factors for increasing the efficiency and competitive advantage of manufactured products. [4] Uncertainty in global markets requires continuous innovation in enterprises, not only in terms of products, but also in business processes. It is particularly important to look for methods and techniques to increase production and increase energy efficiency by introducing systems for monitoring and controlling energy consumption. The advent of Industry 4.0 designs intelligent products through hyper-connected cyber-physical systems in environments where humans and machines collaborate to achieve goals and use mega data to generate value. This has fundamentally changed production and business models, creating conditions for greater flexibility and resource efficiency [3].

Industry 4.0 represents not only a technical challenge - the technological change that provides long-lasting organizational impact and creation of opportunities for new production, models, concepts and approaches, but also a new concept for a sustainable networked world [9],[5]. The introduction of Industry 4.0 technologies into enterprises and their gradual transformation into Industry 5.0 technologies will allow companies to further exploit the capabilities of machines and combine them with those of people to develop efficiency, sustainability and safety in all their processes. This industrial transformation prioritizes environmental protection. With Industry 5.0 will come new technologies and models aimed at higher business efficiency and sustainability.

From a social point of view, the creation of good practices for more efficient production would also generate more successful and

productive staff. The problem of labor is not something new in the labor market and is a universal problem for most manufacturing companies. Well-trained staff would be much more effective in companies' desire to reduce production costs and would create a stable environment for companies to develop. In addition to practical and professional training, training should increasingly focus on environmental prevention and energy saving, as well as the maximum degree of suitability of waste for recycling.

From an environmental point of view, green economy policies are applied by management in the overall function of enterprises. The corporate social responsibility of business to society, the quality of life of people, the protection of the environment and the achievement of the goals of sustainable development and the transition to a circular economy are increased [2]. The idea of manufacturing with minimal waste generation and repeated use and input of raw materials is in line with the idea of improving production efficiency [10], [8].

In summary, the main goals of the present study can be stated:

- Minimization of input raw materials per product unit;
- Full utilization of the technical capabilities of the available equipment;
- Minimal generation of technological waste;
- Analysis and optimization of human potential.

In order to achieve these goals, a thorough analysis of production in a number of industrial enterprises was made. Collaboration between experts in the field of information technology and business users in this field is aimed at developing models and applications that provide effective integration of people, information and other resources. The development and implementation of a system for monitoring and outputting results is set as the main task towards the achievement of the set goals. These results should provide the following information:

- Energy consumption for the respective production (per hour, work shift, day or month);
- Quantitative accounting of production by machinery and equipment and the relevant personnel engaged in the respective production operation;
- Qualitative accounting of the manufactured products.

2. Integrated hybrid system for reporting and analyzing the required information

As a result of the analysis, it is necessary to conclude that production enterprises need a universal type of effectively functioning monitoring system, applicable in any enterprise, regardless of its size and scope of business. Currently used conventional monitoring and control systems cannot successfully deal with a huge volume of information and data. The challenges are different depending on the size of the business. For smaller enterprises, control operations, information processing and storage are less complex, while for large companies they involve a large

number of processes, machines and personnel. Another problem is the time-consuming collection, systematization and analysis of data, where there is a very high chance of technical errors. It is not possible to achieve long-term business success without taking advantage of information technology in this digital age. This gives rise to the idea to develop an integrated hybrid system for reporting and analyzing data and information. This article presents a conceptual framework of an innovative hybrid monitoring system applicable in any type of manufacturing enterprise. This system is complex and combines automated systems with autonomous reporting of quantitative indicators and qualitative assessment according to certain indicators. Such a system makes it possible to report and analyze correlations between technical and informational indicators of production machines in the context of Industry 4.0 [1].

The proposed monitoring system for reporting the consumption of energy by machines is a specialized solution that is used to track, analyze and manage the consumption of electricity (if the machines are electric), fuels, special gases, water, heat, etc. in other types of machines. This system provides valuable data on the energy efficiency of machines and helps plant managers to identify opportunities to optimize costs and reduce energy losses.

The main characteristics and advantages of the proposed monitoring system are related to the accounting of electrical energy, which is one of the main resources used in the production process, can be summarized as follows:

- **Measurement of energy consumption:** The system reports the energy consumption of an individual machine or facility;
- **Data analysis:** The system processes the collected data and provides detailed information on energy consumption, including consumption by hours per day, day/days of the week, month, etc.;
- **Identification of inefficiencies:** By analyzing the data, the system can help the enterprise to understand, by machines or processes, how consumers actually spend electricity;
- **Improve maintenance:** By monitoring energy consumption, the enterprise can prevent accidents and unnecessary production stoppages by reporting various anomalies in the operation of a specific machine;
- **The implementation of the monitoring system** can contribute to the improvement of energy efficiency based on consumption analysis;

3. Quantitative reporting of expenditure of energy carriers

The proposed monitoring system for reporting the consumption of energy by machines is an integral part of the hybrid system and is a specialized solution that is used to track, analyze and manage the consumption of electricity (if the machines are electric), fuels, special gases, water, heat and etc. in other types of machines. This system provides valuable data on the energy efficiency of machines and helps plant managers to identify opportunities to optimize costs and reduce energy losses.

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- **Improve maintenance:** By monitoring energy consumption, the enterprise can prevent accidents and unnecessary production stoppages by reporting various anomalies in the operation of a specific machine;
- **The implementation of the monitoring system** can contribute to the improvement of energy efficiency based on consumption analysis.

Energy consumption monitoring is one of the steps to achieve maximum ecological production in modern enterprises. The construction of a sustainable monitoring system is the condition to then build a real control of the consumption of energy carriers.

The monitoring system can also be applied to older generation equipment, usually with the addition of hardware and software flow meters. Thus, this system could also be applied to existing production systems.

4. Quantitative reporting of production

Automated machine production reporting is a process that uses various technologies and automation systems to collect, report and analyze production data from machines in real time. This practice aims to improve the efficiency, control and management of manufacturing processes through automated information collection and report generation. Some of the main advantages of automated machine production reporting are:

- **Real-time data collection:** The automated system can collect production data from the machines in real-time, with each machine's counter connected to the overall production reporting system. If the machine is analog, a digital device must be implemented to record the output;
- **Data integration:** The automated production reporting system can be paired with other information systems in the enterprise (for example, different ERP modules), which facilitates and accelerates the exchange of data and allows managers to have real and reliable information about production processes;
- **Report generation and analysis:** The automated system can generate various types of production reports and analysis, such as production reports, machine efficiency, resource consumption, and other key metrics;
- **Improved efficiency:** Through automated machine production reporting, the enterprise can identify areas for improvement, optimize production processes and reduce waste of time and resources.
- **Increase control:** The automated reporting system facilitates the tracking of production processes, control over the amount of output produced. In this way, the real performance of a given machine and of the corresponding operator or work shift can be analysed;

The automated collection of performance information creates a robust information base from which the hybrid system will draw the relevant information it needs.

The system includes the ability to identify the operator of each machine. This is achieved by checking each machine before starting the work process (adjuster, operator, assistant operator, service personnel and others) by means of identification (chip, magnetic card or facial recognition). Thus, in the analysis of the data, there is information about each employee and the output produced by him or by a certain group of employees (for machines with more than one employed worker).

5. Qualitative reporting of the manufactured product

As a result of the increasingly competitive markets and high consumer requirements, the quality of individual products becomes an extremely important feature, and its control and implementation must be given due attention in production enterprises. In production, taking into account the quality of the produced units, a qualitative assessment of those employed in

the production processes is also made. The qualitative characteristic does not take into account quantitative values, but it is very important to evaluate the quality of work of equipment and workers. It can be added in a note to each order to have reverse traceability of the quality of the manufactured products. Qualitative analysis visualizes how different workgroups or individual workers handle the same equipment. Based on an analysis of the quality of the finished product, steps can be taken to improve the qualifications of workers.

The qualitative reporting of the manufactured products must be an invariable part of each individual order and the system must require mandatory completion of the quality characteristics. The system will not complete the full analysis of the manufactured product if the quality assessment of the product is not completed.

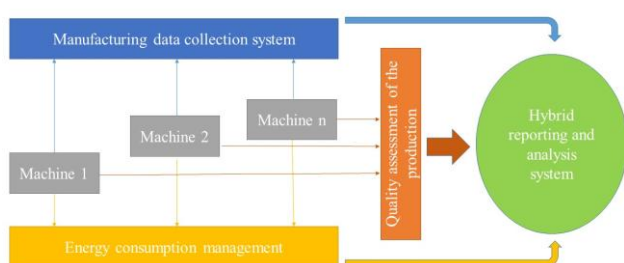
Ways to collect data and information on qualitative indicators:

- Protocols by quality managers and inspectors;
- Test results: Documentation of test results if the product involves any physical quality control tests;
- Defect Tracking: Documenting defects encountered during production or received as customer feedback;
- Audit reports: Results of internal or external quality audits.

The system makes it possible to fill in a field with complaints if there are any within a certain period after dispatch of the products. In this way, feedback on the quality of the products is created and actions will be taken to minimize the risk of recurrence of the relevant defects. On the basis of this feedback, the qualitative analysis of the work of individual groups or individual workers and the equipment used in production will be supplemented.

In Fig. 1 shows a schematic diagram of the concept of an integrated hybrid system for measuring the energy intensity of electric powered machines.

Fig. 1. Integrated hybrid reporting and data analysis system.



The hybrid system will be able to measure the consumption of different energy carriers. The system will be implemented after a thorough analysis of the used resources of each individual production, and then separate modules will be generated according to the specifics of the studied production - for example, for consumption of compressed air, technical gases, liquid and gaseous fuels and other energy sources used in production. Thus, this system will be flexible and modular enough to adapt to a greater percentage of production systems and to be able to quickly react to changes in production companies - replacement of equipment, changes in production technologies, replacement of main energy carriers, modernization and automation. This hybrid system will also be able to be used for benchmarking. For example, equipment similar in type and characteristics using different energy carriers, as well as machines and systems different in technology using the same energy carriers. Thus, it will be possible to compare different characteristics in real working conditions and to draw important conclusions about the actual performance and energy consumption of machines, systems and assemblies. It will be possible to compare the real efficiency of different technologies and methods for the production of a unit of product. The hybrid system will also be used in the

development activity as a finished product to support tests and trials of different types and applications of machines and systems. Through it, it will be possible to test in real production conditions and extract real data on performance, energy consumption and quality of the manufactured products. In addition to the fact that the system will provide information on how those employed in production exploit the available equipment, it will also be possible to take measures for the work and energy consumption of individual machines. An algorithm will be created to display a complete analysis of energy consumption during operation, in different modes of operation, as well as during downtimes. In this way, weaknesses in terms of energy saving will also be identified and improvements can be made in the automation of the equipment such as adding different hardware or software products to reduce energy consumption especially when the machines are idle or individual units of the machine are idle and engines, turbines, fans and others are idling.

Actually tested and implemented, the proposed system will lead to an increase in the efficiency of the production process, increase the reliability and safety of the monitored machines and technological equipment, as well as provide opportunities to increase the environmental friendliness and economy of the related processes. The software provision of the system includes the development of algorithms for early prevention, which characterizes the system as one of the most innovative in the field of automation and management of production processes. The system will generate a quantitative and qualitative assessment of the staff's performance. On this basis, the management will be able to plan the necessary trainings and ways to increase the qualifications of the employees.

6. Conclusion

Within the scope of the scientific research presented in this publication, the idea of a universal hybrid monitoring system, which has the potential to significantly increase the production efficiency of any business organization, has been developed at a conceptual level. At the moment, the system is in the test stage, being tested in a specific enterprise. Work is underway on a companion software product that synchronizes the operation of all parts of the system. As information and communication technology-based solutions continue to increase the productivity and efficiency of business operations and communications, businesses will continue to rely on evolving technologies well into the future. The expected results are aimed at generating and processing data and information in real time, achieving maximum flexibility and efficiency of the production process, system modularity and interoperability between individual modules, increasing the quality of products and processes, reducing resource and energy consumption.

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Prospects for the application of ceramic beehives in modern apiculture farms

Lyuben Lakov, Bojidar Jivov, Todorka Lepkova*, Marieta Gacheva, Gabriel Peev

Bulgarian Academy of Sciences, Institute of Metal Science, Equipment and Technologies with Hydro- and Aerodynamics Centre
“Acad. A. Balevski”, 67 “Shipchenski prohod” Blvd., 1574 Sofia, Bulgaria, e-mail: lepkovatodorka@ims.bas.bg

Abstract: A brief review of the design characteristics of the main construction types of standard movable frame and traditional beehives applicable in beekeeping farms is presented. The performance of a newly developed innovative movable frame beehive constructed of durable, heat-resistant hollow chamber ceramic structural elements is discussed. A comparison of the functional characteristics of prepared experimental ceramic hive prototypes and the prevailing types of standard beehives made of other materials is carried out. The existing requirements and prospects for equipping beekeeping farms with ceramic hives providing prolonged service life, higher yields and increased sustainability in diverse climatic environments and critical conditions are analysed.

Keywords: INNOVATIVE CERAMIC BEEHIVE, BEE FARMS, DADANT-BLATT

1. Introduction

Bee products find application in culinary practices, the food industry, cosmetics, pharmaceuticals, alternative medicine and many other fields [1]. At the same time, the natural life activity of wild and cultivated honey bees is an essential factor in the pollination process of various plant species [2, 3].

For millennia, the main source for the production of bee products was bee colonies growing freely in natural conditions or artificially colonized in primitive hives (skeps).

With the gradual development of beekeeping as an organized economic activity, different structural types of beehives were designed [4]. Some of the beehive systems developed in earlier periods have been further modified and upgraded to increase their efficiency.

Currently, there are several construction types of beehives made of different materials - wood, plastic, polystyrene and others - commonly in use [5].

The Dadant-Blatt beehive system is a structural type widespread across Europe. It comes in two main versions - for 10 or for 12 frames, which determines the specific sizes of hives of this type. It is characterised by the presence of one main brood box [6]. Volume expansion is achieved by installing honey supers above the brood box. The main disadvantages are the different sizes of the brood and store combs which do not allow their interchangeability, and the relatively limited volume of the hive [5].

In the case of the Langstroth Ruth hive system, volume reduction and increase is achieved by installing separate interchangeable supers [4]. The use of a single type of frame increases efficiency and labour productivity. The increase in the volume of multi-hull hives allows accelerated and full development of the colonies and creates conditions for higher yields. The design features of the Langstroth-Ruth hives make it possible to house several colonies in one hive.

Roger Delon hives are characterised by their relatively low weight, increased functionality of management and ease of transportation [6]. The limited volume makes it easier to maintain appropriate temperature conditions and low humidity during the natural life activity of the colonies throughout the overwintering period. The operation of the Roger Delon alpine hive follows a predominantly classical approach to multi-hull operation. Intensive spring colony development and high productivity are observed. At the same time, the installation of a larger number of supers forms a tall and unstable structure, making servicing difficult [4-5].

Farrar hives are applicable in a variety of climatic conditions. They are equipped with a detachable flat bottom board, compact and light supers of one and the same type and small frames. The supers are mounted frontally on the bottom. The supers are interchangeable, with the hive volume increasing in the vertical direction. This allows the application of the multi-super technology for breeding bee colonies [6].

Lezhak hives are relatively less common in the sector. Structurally, they allow a lateral expansion of up to 18 or 24 frames. Their main advantages are the use of a single frame size and the absence of sections or buildings. This allows for easier maintenance and higher efficiency. The relatively larger hive volume enables the

development of active and healthy colonies throughout the year. It is applicable for making colony increase, overwintering two or more colonies together and more [5]. Much of the hive volume has no functional role for most of the year. Lezhak hives have a relatively higher weight, making them difficult to transport.

To a limited extent, traditional hives (skeps) made mainly of natural plant materials and untreated natural clays are still in use. However, because their primitive construction is suboptimal and the combs are fixed, management of colony development is limited. Thus, the use of modern technological methods in the extraction of bee products is inapplicable and risks the integrity of the colony. This results in relatively low yields and limited purity of the bee products [7]. Due to the use of organic, flammable and combustible materials and thermally untreated clays for the main components, traditional reed hives are characterised by unreliability in the event of fires and relatively low resistance in long-term contact with water.

The aim of this paper is to present the main requirements and prospects for the potential application in the equipment of modern beekeeping farms of an innovative ceramic hive. A comparison of the performance characteristics of the prepared experimental ceramic hive prototypes and the prevailing design types of standard and traditional beehives made of other materials is made.

2. Discussion

A study of the current trends and issues in the beekeeping industry was carried out. The possibilities for increasing the long-term serviceability and productivity of the main equipment of beekeeping farms are analyzed. On the basis of the obtained data and long-term research, an innovative movable frame beehive made of ceramic structural elements with air chambers is designed [7-14]. The use of ceramic materials for the manufacture of various structural details of the developed beehive ensures their high durability, fire resistance and other superior characteristics.

Ceramic experimental prototypes of the Dadant-Blatt system (10-frame version) have been prepared, specialized primarily for operation by stationary beekeeping methodology (fig. 1, 2 and 3). The repositioning of the ceramic hives on the territory of the bee farms is carried out manually (using the hull-mounted carriers) or mechanically (by means of lifting equipment - forklift, etc.).

The relatively higher mass of ceramic hives (compared to standard hive types) makes their handling and transportation only slightly more difficult. At the same time, the greater weight of the developed ceramic hives provides significantly higher operational resistance to the impact of extreme environmental factors (strong wind gusts, hurricane winds, storms, etc.).

During prolonged torrential rains and intense floods, existing standard hives (wooden and others) move much easier from their stationary positions, in the direction of the movement of the main water mass. This creates significant risks of damage to the basic inventory of bee farms and irreversible destruction of colonies. In this respect, the higher mass of the ceramic beehives is mainly seen as a favourable characteristic ensuring their operational stability and durability. On the other hand, for the purpose of mobile beekeeping,

a separate modification of a ceramic movable frame beehive with a lower mass is being developed, allowing easier handling and transportation.



Fig. 1. A prototype of a ceramic beehive.



Fig. 2. A prototype of a ceramic beehive.



Fig. 3. A prototype of a ceramic beehive.

The standard hives (made of other materials) used in practice are characterized by a limited lifetime and accelerated depreciation (under the influence of solar radiation and other climatic factors). At the same time, the ageing of the materials reduces the

mechanical resistance of the structural components of the hives and in some cases is accompanied by the release of various substances with potentially toxic effects on the normal life activity of the colonies.

The natural processes of wood decay and the formation of cracks create an unhygienic environment and conditions for the development of fungal colonies and various microbiological agents. At the same time, the impact of certain rodents and various insects gradually compromises the integrity of the structural elements of the wooden hives.

Standard maintenance of wood beehives requires periodic treatment with various varnish-type paints and wood preservatives that could affect the condition of the colonies and the quality of bee products.

The low fire resistance of standard hives creates the preconditions for the loss of a large part of the physical stock of beekeeping farms in case of fires of natural or anthropogenic origin. At the same time, the high fire resistance of ceramic materials significantly increases the possibility to preserve the serviceability of ceramic hives in limited or larger fires.

When carrying out a complete decontamination, ceramic beehives allow the use a variety of treatments (through different impact factors). The high temperature resistance of the ceramic structural elements allows the application of thermal treatments (at higher temperature values) which is not feasible and will be destructive for standard hives made of other materials.

The presence of separate air chambers in the structural elements of the developed ceramic beehives increases their thermal and acoustic insulation performance.

Thermographic analysis of hollow ceramic plates, which are the main structural elements of a prototype beehive, was carried out using a thermal imaging infrared camera and a heat source.

Thermographic diagnostics was performed in field conditions on experimental ceramic hives with settled honey bee colonies and a settled standard wooden hive of the Dadant-Blatt system (as a control specimen).

The analysis of the obtained thermograms makes it possible to monitor the temperature distribution in different zones of the individual ceramic parts and across the whole external structure of the ceramic hive.

In the ceramic hives studied, a relatively uniform distribution of temperature values was found across most of the surface of the ceramic plates, with only local areas of contact with other structural elements (slats, lid, base profile) showing specific temperature deviations.

In the case of wood hives, it was found that the wooden walls were not evenly heated and there were distinct temperature zones. Water absorbed in the wooden walls and the formation of different areas of increased humidity create the condition for a more intense local heat transfer (compared to the dry areas) from the inner volume of the hive to the external environment. This causes a relatively more uneven distribution of temperature values in the inner space of the wood hives and affects the colony's condition and activity and the yields obtained. The presence in the wooden walls of zones of increased humidity with different localisation is specific to each hive and is determined by the type and state of the wood and the specific meteorological conditions.

Using the Guarded hot plate method, the coefficient of thermal conductivity of the main structural detail (ceramic hollow chamber plate) of a prototype beehive was determined. A laboratory thermal chamber with an installed heater and four-layer insulation was constructed. The temperature differences between the two opposite sides of the examined ceramic specimen (plate) were recorded until a constant temperature difference was established. Based on the values found, the thermal conductivity coefficient was calculated.

The studies performed prove the thermal insulation effect resulting from the presence of air chambers in the ceramic construction elements and confirm the appropriateness of the design solution.

Acoustic studies were carried out using the two chamber method to determine the air noise insulation index ($R_w=23$ dB, in

the frequency range 100-3,150 Hz) of a hollow ceramic chamber plate, which is a structural element of an experimental beehive. A dedicated laboratory setup of two equipped acoustic chambers with an experimental specimen mounted between them was constructed to carry out the study. The difference between the sound pressures recorded in the chamber with the presence of an acoustic source and those in the receiving chamber was determined.

Comparative studies and monitoring of the main indicators (over the autumn-winter period) were carried out in settled hives (with lattice and solid bottoms) of the Dadant-Blatt system, made of different materials: ceramic, wood and polystyrene. An electronic system was used to record temperature and humidity, with sensors installed in each hive and another sensor which monitors external temperature and humidity. During the testing period, the temperature (on average for the whole period and by month) in the hives was higher and the humidity lower compared to the temperature and humidity values of the external environment, regardless of the hive material and bottom construction type. The highest average temperature value during the autumn period was found in the solid-bottom ceramic hive ($29.15 \pm 6.51^\circ\text{C}$), while the minimum value was recorded in the solid-bottom polystyrene hive ($19.01 \pm 8.47^\circ\text{C}$). During the same period, the maximum value of the humidity index for the lattice-bottom hives was observed in the ceramic hive ($50.74 \pm 8.92\%$) and the minimum in the polystyrene hive ($45.91 \pm 9.62\%$). For the solid-bottom hives, the highest mean humidity was found in the polystyrene hive ($55.14 \pm 6.96\%$) and the lowest in the wood hive ($44.69 \pm 5.00\%$). During the winter period, the highest mean temperature was found in the wood hives and the lowest in the polystyrene hives, regardless of the bottom type. The greatest difference with respect to the outside temperature (mean 5.11°C) was observed in the wood hives, 5.04°C for those with a lattice bottom and 6.78°C for those with a solid bottom, respectively. The lowest mean value of the humidity index was recorded in the wood hives, regardless of the bottom type, and the maximum in the polystyrene lattice-bottom hive and the ceramic solid-bottom hive.

Further studies were carried out in real field conditions to register the differences between the temperatures of the external environment and that in unpopulated ceramic hives (with different phase composition of the ceramic parts) and unpopulated standard wood hive (made of softwood). The measurements were carried out at different times of the day at ambient air temperatures from around 0°C to above 30°C . At low ambient temperatures, temperature differences of 0.8°C to 1°C higher than the ambient temperature were recorded in the ceramic hive, while a temperature 0.2°C higher than the ambient temperature was found in the wood hive. At daily outdoor temperatures above 28°C , a temperature difference of 2.0°C to 2.8°C (lower than the outdoor temperature) was found for the different ceramic hives, while an average temperature difference of 0.2°C was reported for the wood hive. At higher temperature values of the external environment, a temperature difference of 2.3°C to 2.6°C (lower than the external temperature) was recorded for the ceramic hive, while a temperature difference of 0.3°C was found for the wood hive.

Feedback from a number of bee product manufacturers on the experience gathered in the process of managing experimental ceramic beehives provided to individual beekeeping farms was analysed. The information obtained established a trend for increasing honey yields (up to 30 %) when using ceramic hives.

Ceramic beehives provide a long service life with negligible depreciation of the structural elements, well-balanced temperature values, appropriate humidity, a hygienic living environment and a relatively low risk of destruction of the main physical equipment of beekeeping farms in critical climatic environments and disasters.

The functional structure of the ceramic hive allows adequate control of the condition of the bee colonies and the application of modern, highly productive methods for obtaining bee products. The hive is compatible with the existing standard specialised equipment typical for beekeeping farms.

The developed experimental ceramic prototypes outperform the existing standard hives in complex indicators and provide a more

favorable microclimate for the development of bee colonies and ensure higher yields.

At the same time, the obtained experimental data allow further optimization of the performance of the structural ceramic elements when designing new beehives modifications.

3. Conclusions

The main functional characteristics of the existing systems of standard movable frame and traditional hives are discussed.

The performance characteristics of an innovative movable frame beehive consisting of thermo- and acoustic-insulating ceramic structural parts with separate air cavities are presented.

A generalized comparison of the main characteristics of the constructed ceramic beehive prototypes and the commonly used standard structural types of materials is performed.

The experimental data obtained from the laboratory and field studies confirm the constructive functionality and efficiency of the designed ceramic hive.

The high physical-chemical and thermal performance of the ceramic materials and the design characteristics of the ceramic hives guarantee their long service life, low depreciation, relatively high resistance to fire and full potential for carrying out effective decontamination by applying a variety of sanitary treatments.

The developed ceramic hive is characterized by increased climatic resistance and potential application in dynamic operating environments in regions with extreme temperature values and high cyclic temperature amplitudes.

The relatively greater mass of ceramic hives (compared to that of standard hives) provides significantly higher operational resistance to a variety of disastrous weather conditions (hurricane winds, storms, torrential rains, floods, etc.).

The developed ceramic hive provides a suitable microclimate and a balanced temperature environment for the full development of bee colonies and hygienic living conditions, resulting in a reduced risk of the spread of fungal cultures, pathogenic microbiological agents and others.

The structural characteristics of the ceramic hive meet the requirements for the application of modern economic methods for the production of high-purity bee products and allow systematic control of the different stages of the life cycle of the bee colonies.

The developed movable frame ceramic hive is a superior alternative to the predominant standard (made of other materials) types hives currently found on bee farms.

In prospect, ceramic hives can prove to be a useful major piece of material equipment for many bee farms.

A new modification of the ceramic movable frame hive with a lower mass, applicable to mobile beekeeping, is currently being developed.

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The impact of E-commerce in a distribution company

Valma Prifti¹, Dea Sinoimeri¹, Irida Markja¹

¹Department of Production and Management, Faculty of Mechanical Engineering, Polytechnic University of Tirana, Tirana 1001, Albania
E-mail: vprifti@fim.edu.al, dsinoimeri@fim.edu.al, imarkja@fim.edu.al

Abstract: This paper aims to present the role of information and communication technology in the rapid emergence of e-commerce, including its development, role and operation to date, and future prospects. When we talk about technology and its impact on society, we can talk about many different areas where information technology plays the main role. Nowadays, technology has minimized distances and not all the actions are done physically. With the development of information and communication technology, different requirements and different processes are developed, both in the public sector and in the private sector.

The main purpose of the paper is the identification and analysis of the problems that are most often faced by organizations or enterprises and consumers in the use of electronic commerce, as well as the identification of factors that influence the use of this type of commerce by the business community in Albania. It is also explained the impact of e-commerce in increasing circulation and commercial activity in local businesses, with special emphasis in the case of one of the leading distributions and sales company, Marketing & Distribution. In this paper, the factors that affect electronic commerce have been analyzed and identified in the framework of the rapid development in the field of information and communication technology. The results of this paper will be able to serve companies in the design of development policies of their businesses, starting from a newly created business, small and medium businesses to large brands, which do not yet offer electronic commerce services.

KEYWORDS: INFORMATION AND COMMUNICATION TECHNOLOGY, ELECTRONIC COMMERCE, DISTRIBUTION, BUSINESS.

1. Introduction

The internet has brought about a lot of changes in society, but one of the largest shifts of the twenty-first century has been in internet technology. There are a wide range of topics where information technology is crucial when discussing technology and its effects on society. Beginning with the basic text or email exchanges in work or daily life, we are constantly interacting with electronic forms and their utilization for completing duties and responsibilities in a variety of occupations that are located nearby or far away. These days, distances are reduced thanks to technology, and we can perform all of our tasks virtually [14], [10].

The primary goal of the research for this paper is to elucidate the theoretical concepts of electronic commerce and its various forms that are employed by Albania's business community, particularly in the Marketing & Distribution sector. It also aims to identify and analyze the most common issues that arise when consumers and organizations use electronic commerce, as well as to pinpoint the variables that affect this type of commerce's adoption in Albania. The paper aims to illustrate the areas in which internet commerce has superseded physical markets, individuals, and the requirement for resources or human resources, and the areas in which technology is gravely endangering jobs related to these sectors.

The paper aims to provide the following:

- An explanation of electronic commerce ideas;
- An understanding of the many types and forms of electronic commerce;
- An analysis of how electronic commerce operated during the pandemic of COVID-19;
- An examination of how e-commerce affected sales growth, using the company as a case study.

The research questions of this paper are:

1. What were the contributing elements to enterprises using e-commerce more frequently?
2. What are the practices of companies that see a higher percentage of their product sales through online sales?
3. To what extent does our society employ electronic commerce to advance corporate development?
4. How secure is the buying and selling of products via online shopping?

2. Methodology and research methods

The selected research methodology is grounded in quantitative techniques, such as:

- Primary information gathered via a survey,

- Secondary data acquired from scholarly and scientific publications.

The literature review approach is used to acquire information from a variety of sources, including books and scientific publications, in order to analyze and compile secondary data. Primary data, which will be gathered through empirical study with the company Marketing & Distribution current clients, will be complemented by secondary data, which is essential in identifying the problem for empirical research.

Quantitative methods are employed in the collection of primary data. This approach works well for researching problems in quantitative terms (like in our example, where we want to know how much e-commerce is used and how it affects society on a numerical level). This method makes it possible to include a sizable sample size, which improves the results' representation of the phenomena or subject of the investigation.

The study population is composed of Albanian nationals, mainly from Tirana, who have completed at least one online transaction. The sample comprises 100 clients of Marketing & Distribution, who are spread across many major cities in the nation. The sample was selected using a purposive sampling method, with the requirement that participants must have made at least one online purchase in the past two years. The surveys were created using the Google Forms platform and distributed to participants via email and social media contact.

The challenges encountered during this paper were as follows:

1. The main challenges during the realization of this research were the lack of resources, time constraints, and, at times, maintaining objectivity in the selection of methods and the interpretation of data.
2. Another challenge that can arise in research is managing the relationship with the research subjects and ensuring ethical conduct throughout the process.
3. An additional important aspect is the dedication and patience required to achieve accurate and reliable results.

3. Literature review

In today's world, information technology has evolved at a very rapid pace, advancing every day. As a result of the widespread use of computers for buying and selling various products and services by consumers and merchants on a global scale, it is important to emphasize that the computer can be considered one of the most significant inventions for humanity. The unique position of the computer, along with major technological advancements, has had

and will continue to have an exceptionally positive impact, particularly in the development of e-commerce [8], [9].

The Internet has revolutionized how people buy, sell, work, and organize business activities in more ways and at a faster rate than any other technology in business history. The spread of e-commerce worldwide has advanced significantly and is widely used in many countries. Its development is growing at an unstoppable pace, influencing the very existence of businesses as competition becomes increasingly relentless. However, e-commerce in Western Europe is still a topic of discussion regarding how to sell, how much to profit, and which platform to use.

A more comprehensive definition of e-commerce is: "The use of electronic communications and digital information processing technology in business transactions to create, transform, and redefine relationships for value creation between organizations, and between organizations and individuals." The main types of e-commerce are: business-to-business (B2B), business-to-consumer (B2C), business-to-government (B2G), consumer-to-consumer (C2C), and mobile commerce (m-commerce). E-commerce refers to the process of buying, selling, transferring, or exchanging products, services, and/or information via computer networks, including the internet. E-commerce is part of the internet economy, involving any form of business transaction executed electronically between companies, individuals, or organizations [20], [17].

E-commerce provides significant support to businesses in terms of development by helping to enhance service quality, which is a key focus for many businesses. It also reduces costs related to reaching customers, increases sales levels, and improves various primary elements that connect businesses and consumers, with e-commerce being at the core. The acceptance rate of e-commerce is also influenced by the sector in which the business operates. Its adoption is higher among businesses in industries such as manufacturing, transportation, trade, services, and others [3], [12], [19].

There are two important indicators that must be considered when developing e-commerce:

1. Consumer protection
2. Data privacy

Digital payment systems are the backbone of e-commerce transactions, allowing for secure and efficient transfer of funds between buyers and sellers through various online channels

4. Case study (M&D)

For nearly three decades, Marketing & Distribution (M&D) has been a leading logistics and distribution company in Albania, representing both national and international brands with high-quality products. As a trusted distributor for key global partners, M&D offers top-tier services in logistics, distribution, product handling, and storage. The company's skilled staff is its primary asset, and it is highly regarded by its clients for being a reliable and constructive partner. M&D provides integrated logistics services, including customs procedures, public and bonded warehousing, packaging, labeling, and nationwide distribution.

M&D was among the first distribution companies in Albania to implement e-commerce. Many of its processes, including product catalogs, financial transactions, and purchasing services, are conducted online through the company's websites, such as markdist.com and b2bkancelari.com. Customers can order products online and pay using credit/debit cards, PayPal, bank transfers, mobile payments, or cash on delivery. Recently, mobile payment options have also been introduced.

With the growing use of the internet, the percentage of M&D's products distributed through e-commerce is rapidly increasing.

Products are posted on the company's official websites, as well as on its Instagram and Facebook pages. However, most e-commerce transactions are still tied to the purchase and delivery of physical products [5].

B2B Office is one of the most important departments of the M&D company, offering a wide range of office supplies and featuring a highly developed e-commerce system.

You can start your online shopping experience by visiting <https://b2bkancelari.com/account/login> on your electronic device.

1.To make a purchase, you first need to create a Personal Account. The account creation process is simple—just provide your email address, and you'll be able to set up your account easily.

Fig. 1. B2B Office Website

- 2.Select the items you wish to purchase by clicking "Add to Cart."
- 3.In the Cart, you can increase the quantity by selecting different items.
- 4.If, after selecting, you wish to remove one or more items from the purchase, you can delete them by selecting "View Your Cart" and then clicking "Remove" next to the selected product.
- 5.You can return to the homepage and continue adding more items to your cart. Click on the Cart icon on the right side of the page, and a quick preview window will appear with information on the quantity and price of the item.
- 6.Proceed to the shipping section, where you will enter the recipient's address and choose the shipping method.
- 7.Choose a payment method: Cash or Bank Card (Visa or MasterCard).
- 8.If you choose Cash, you will pay upon receiving the order.
- 9.If you choose the Bank Card, you will need to enter your card details in the required fields.
- 10.Once the payment is completed, you will receive a confirmation email with an invoice, and your order will be processed for stock verification.

At the moment, payments can only be made in the LEK currency. Once our network expands to other regions, you will have the option to pay in local currencies. When paying by bank card, funds are typically withdrawn when your order is ready for shipping, although your bank or card issuer may reserve the amount immediately.

Deliveries are made from **Monday to Saturday**, with a 24-hour delivery window for Tirana and Durrës, and up to 72 hours for other cities.

1. For orders over **10,000 LEK**, delivery is free.
2. For orders under **10,000 LEK**, the delivery cost is **250 LEK** for Tirana and Durrës, and **350 LEK** for other cities.

If you've made a payment and want to change the delivery address, you can either contact customer service or inform the driver when they call to notify you of the delivery.

5. Analysis of results

5.1 Descriptive analysis of results

The analysis of results is the core component of the research, and therefore, will be given special attention. The data obtained from the survey, which was administered using the Google Forms survey management software, will reflect the demands and needs of e-commerce users or online shoppers.

The survey was sent via email and WhatsApp to 100 loyal clients of the company, who have made at least two online purchases through the company's official website since 2020.

Table 1. General data from the survey

Category	Response	Percentage
Gender		
	Male	28.1%
	Female	71.9%
Age		
	15-25 years	56.3%
	26-35 years	37.5%
	36-45 years	6.2%
Residence		
	Tirana	53.1%
	Other cities	46.9%
Legal status		
	LLC	51.9%
	Individual	28%
	Clients without NIPT	12.6%
	Institutions	7.4%
Preferred shop method		
	Physical	62%
	Online	38%

The research questions outlined in the Introduction of this paper are:

1. What were the contributing elements to enterprises using e-commerce more frequently?

The first research question is confirmed by the responses provided to question 6, regarding the impact of COVID-19 on the growth of online commerce.

According to the data presented in the table, approximately **93.8%** of respondents believe that the COVID-19 situation was the driving factor behind the increase in online commerce.

2. What are the practices of companies that see a higher percentage of their product sales through online sales?

The second research question is confirmed by the responses to question 9, which relates to the most sold products at Marketing & Distribution.

According to the data presented in the table, approximately **50.5%** of respondents indicated that personal hygiene products are the most commonly sold items through online commerce.

3. To what extent does our society employ electronic commerce to advance corporate development?

The third research question is confirmed by the responses to question 8, which asked how frequently respondents purchased online within a month after the outbreak of COVID-19.

The data shows a significant increase in respondents who purchased online at least once a month, once a week, or 2-3 times a week from Marketing & Distribution. This suggests that the company transitioned to online sales effectively during and after the lockdown period. This shift, imposed by the pandemic, has been utilized very positively by Marketing & Distribution to boost its economic development, increase revenue, and improve product sales.

4. How secure is the buying and selling of products via online shopping?

The fourth research question is confirmed by the responses to question 11, regarding the safety of online purchases.

According to the data presented in the table, approximately **59.4%**, who have purchased online, believe that this electronic form of trading is safe.

Table 2. Specific data from the survey

Question	Response	Percentage
6. Do you believe that the COVID-19 situation spurred the growth of online commerce?		
	Yes	93.8%
	No	6.2%
7. How often did you purchase online within a month before the outbreak of COVID-19?		
	Once a month	50.6%
	Once a week	15.6%
	2-3 Times a week	15%
	Never	18.8%
8. How often did you purchase online within a month after the outbreak of COVID-19?		

	Once a month	46.4%
	Once a week	18.6%
	2-3 Times a week	16.2%
	Never	18.8%
9. Which category of products do you purchase most often online from Marketing & Distribution?		
	Personal hygiene products	50.5%
	Alcoholic beverages	25.8%
	Office supplies	15.5%
	Lavazza coffee	8.2%
10. Factors that influence the decision to purchase products?		
	Quality	42.5%
	Price	27.5%
	Delivery time	19.7%
	Company reputation	10.3%
11. Are online purchases safe?		
	Yes	59.4%
	No	25%
	No opinion	15.6%
12. How satisfied are you with the products sold online by Marketing & Distribution?		
	Very satisfied	38.4%
	Moderately satisfied	35.3%
	Slightly satisfied	21%
	Not satisfied at all	5.3%

5.2 Reliability analysis of data

Reliability analysis is one of the key elements in data collection to determine whether the measurement tool used in the research is

reliable. The **Reliability Statistics** table summarizes the results of the reliability analysis. The reliability coefficient, **Cronbach's alpha**, that we used to measure whether e-commerce is an important factor influencing economic development is **0.818** or **81.8%**.

Cronbach's alpha is a widely-used statistic that measures the internal consistency of a set of scale or test items. It is used to estimate the reliability of a psychometric test and is particularly important when analyzing survey data [15], [7], [6]. Cronbach's alpha is a measure of internal consistency, that is, how closely related a set of items are as a group. It is considered to be a measure of the reliability of a test or scale. According to Cronbach's alpha reliability scale, if $0.80 < \alpha < 1.00$, the measurement tool is considered to have a high level of reliability. In our case, the reliability coefficient is **highly reliable**, as $0.80 < 0.818 < 1.00$.

6. Conclusions

In this paper following the pandemic, businesses that transitioned to this form of commerce, or those that added it alongside their physical operations, have experienced increased turnover and sales. These businesses are now several steps ahead of those that did not adapt to the trends and imposed circumstances. This is believed to be due to technological advancements, the rapid growth of the internet, the integration of marketing and sales strategies by companies, and the shift in generations who have direct access to electronic markets or the digital economy. Orders are now placed through smartphones, laptops, or personal computers, saving time and eliminating spatial limitations. The pandemic played a significant role in the economic growth of Marketing & Distribution, positively influencing product sales through online platforms, particularly via the company's official website and the B2B Office department's page. Ultimately, companies can build ongoing relationships with customers, enabling them to continuously provide their latest offers.

The concluding analysis of this research reveals that the majority of respondents are relatively satisfied with the quality of online products offered by local companies, as well as with the customer service and care provided. What these companies need to do is to continue working harder, first to maintain, and then to increase customer satisfaction, while improving their offerings in line with global developments and innovations in this sector.

7. Acknowledgment

This research was carried out with the cooperation and financial support of AKKSHI (National Agency for Scientific Research and Innovation) within the National Project "Digitalization of industrial and service companies in Albania" in Polytechnic University of Tirana.

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Photogrammetry applications for digitizing cultural heritage artifacts. Case studies: digitalization of different artifacts in Albania

Erald Piperi^{1,*}, Ilo Bodi² and Ornela Durmishaj³
 Polytechnic University of Tirana, Albania¹
 Polytechnic University of Tirana, Albania²

Executive Director at Archaeological Parks of Apollonia and Byllis, Albania³

epiperi@fim.edu.al

Abstract: Ultimately, digitizing cultural heritage is not just about preservation; it is about enriching the cultural narrative, making it inclusive, and ensuring that knowledge and appreciation of our shared history are passed down to future generations. Digitization involves advanced techniques such as 3D scanning, high-resolution photography, and digital modeling. These technologies help create accurate and detailed representations of cultural assets, ensuring that the digital versions retain the original's integrity and details. Ensuring high reliability for small-sized objects is a crucial challenge in digitizing cultural heritage sites, especially when dealing with objects that lack movement, transporting, low ambient light conditions, reflective material, etc. By incorporating three-dimensional models into the research and dissemination process, cultural heritage institutions can make their work more appealing and accessible to a wider audience, fostering greater appreciation and understanding of our shared cultural heritage.

Keywords: ARCHEOLOGY, PHOTOGRAMMETRY, 3D PRINTING, CULTURAL HERITAGE

1. Introduction

Digitizing cultural heritage enriches the cultural narrative, making it inclusive and ensuring that future generations will appreciate our shared history. Through technological advancements and a focus on precision and accessibility, we can preserve, study, and celebrate cultural heritage innovatively and impactfully. Technological innovations are fundamental to this endeavor, refined over the years to create increasingly precise and accurate digital models that preserve metric and technical data useful for subsequent analysis and experimentation. From literature research there exist different scanning technologies for converting real objects to high-resolution 3D files such as photogrammetry, active scanning system, structured light scanners, etc [1]. Choosing the right technological solutions depends on many factors as desired level of detail (LOD) acquisition, elaboration time, object size and surface reflectiveness, versatility of the scanning system, cost, etc. By leveraging digital technologies, heritage sites, and museums develop new narrative forms for cultural content and concepts, enhancing visitor engagement and education [2].

Each of these methodologies has its strengths and is chosen based on the specific requirements of the object being digitized. Photogrammetry known as passive system [3] , with its ability to create detailed and textured 3D models, is particularly valuable for capturing the shape and color information of cultural heritage objects. Instead, the 3D active scanning systems based on structured light, include a wide range of system setups starting from low-cost to high-user system [4], [5], [6] are known for their accuracy, precision, and high level of geometry detail during scans. All the systems are capable of scanning from micro-med-long range object size by different modifications of the system itself. There are a lot of cases where these systems are used in the cultural heritage by exploiting in deep detail the pros and cons of each system [7] , [8], [9], [10], [11]. Advancements in heritage surveying tools and methodologies have significantly improved the capacity to document cultural heritage. Numerous studies have recently emerged, focusing on modern survey experiences, the tools and techniques employed, and strategies to mitigate errors in these processes. The application of these innovations has seen a remarkable increase, streamlining and enhancing the accuracy of heritage registration [12].

The goal of this contribution is to present the knowledge and experience gathered through the 3D-IMP-ACT project. This major research endeavor illustrates the practical use and key insights obtained from its approaches and outcomes. The 3D-IMP-ACT [13] research project exemplifies the integration of technological

advancements in cultural heritage preservation, making it more inclusive and accessible while ensuring the accurate representation and study of historical artifacts. This project started in 2018 and employed the latest technology in the fields of 3D and virtual reality, to promote the touristic attractiveness of the region, by enhancing cooperation between universities and public bodies in dealing with the preservation, management, and promotion of cultural assets.

2. Methodology

The article offers a practical approach shaped by a thorough analysis of the latest advancements and details possible workflows grounded in the author's experience in the field of 3D scanning technologies in difficult areas such as inside environments (museums) and field archeological sites.

This study used photogrammetry as one of the best methods for indoor scan of the artefacts especially when they are impossible to remove or to touch them. This technique also can scan from medium to large size artifacts. In all the typologies of the artifacts digitized inside the museum space, the first process of photo acquisition was done without "flash" and in RAW format, and then the next step was the digital manipulation of each photo (chromatic aberration, distortion, etc.) for increasing photo quality. After this digital manipulation, all the images are elaborated in Agisoft Metashape software [14]. The hardware setup consists of using DSRL cameras with different lenses (Table 1, Table 2), mounted in a professional tripod and with a remote camera control.

Table 1. Camera characteristics and lens used setup (a)

DSRL camera NIKON D850	Sensor type/resolutions	Full frame BSI CMOS/ 45.7 Megapixel
	Sensor size (mm)	APS-C (22.3 x 14.9 mm)
	Pixel size (µm)	4.35
	Weight (g)	1005
	RAW file	CR2
	Frame rate (fps)	7
Lens used	Nikon AF-S FX NIKKOR 28-300mm f/3.5-5.6G	
Trigger camera	Manual remote switch/software	

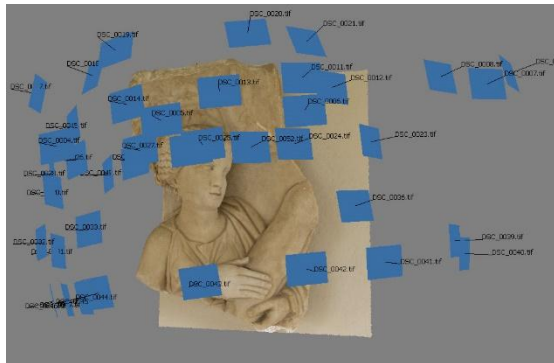
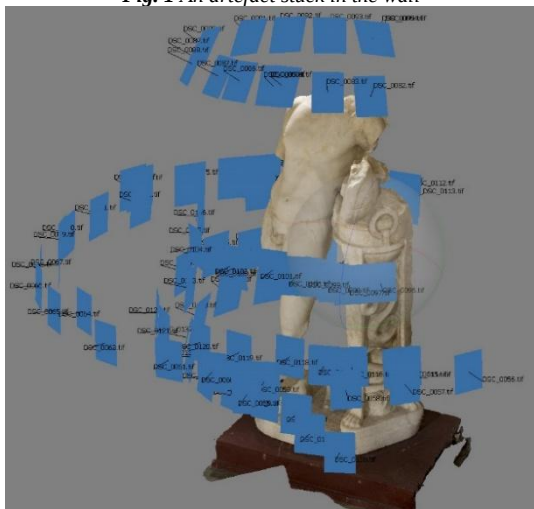
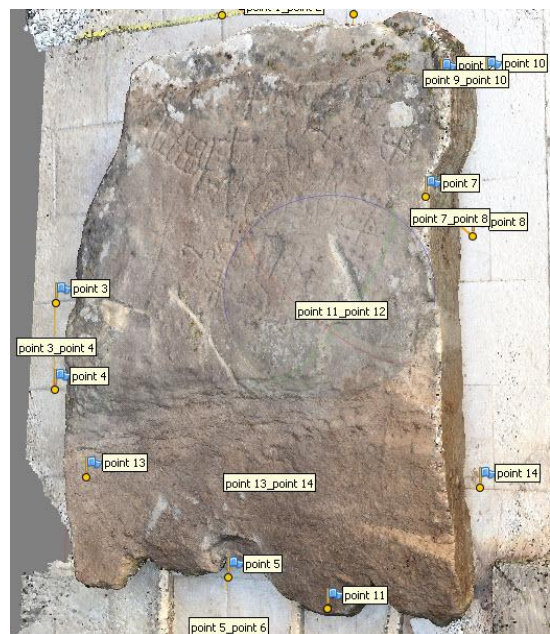
Table 2. Camera characteristics and lens used setup (b)

DSRL camera CANON 1200D	Sensor type/resolutions	CMOS APS-C /18.0 Megapixel
	Sensor size (mm)	APS-C (22.3 x 14.9 mm)
	Pixel size (µm)	4.3
	Weight (g)	480
	RAW file	CR2
	Frame rate (fps)	5
Lens used	Canon EF-S 18-55mm f/3.5-5.6 IS II kit	
Trigger camera	Manual remote switch/software	

The photogrammetry workflow is an easy self-learning curve and can achieve great results with low-budget hardware. Nowadays a big database of literature and guidelines explaining the state of the art of the photogrammetry technique [15], where every person in the institution of cultural heritage (specialist, technician, etc) can become a professional digitizer or a 3D creator in a short time.

3. Related works

Following some simple setup for the inside photogrammetric process, related to camera-lens-object-ambient interaction the user should take precautions steps for maximizing geometry and texture details. In spaces like museum pavilions the objects are exposed in different and difficult positions like (i) stuck in the walls (Fig. 1), (ii) very close to the facade (Fig. 2), (iii) inside of glass blocks (Fig. 3), (iii) on the floor (Fig. 5), (iv) small and large object size (Fig. 4) and all the cases represent problems in texture material and light conditions.

**Fig. 1** An artefact stuck in the wall**Fig. 2** The artifact is very close to the facade, causing problems with the back 3D scan**Fig. 3** Artifacts inside glass block**Fig. 4** Large object**Fig. 5** Artifact exposed on the floor

The first results were the digital file creation in the form of a 3D file of the artifact and then performing different 3D analyses for investigation such as dimensions, volume, and possible intervention strategies for reconstructions. Regarding the second scenario, archaeological sites also performed by using the photogrammetry technique (Fig. 6). In this case, a clear strategy for the pictures overlaps process needs to be understood and performed by succeeding with the minimum number of pictures taken and weather conditions should be taken into consideration.

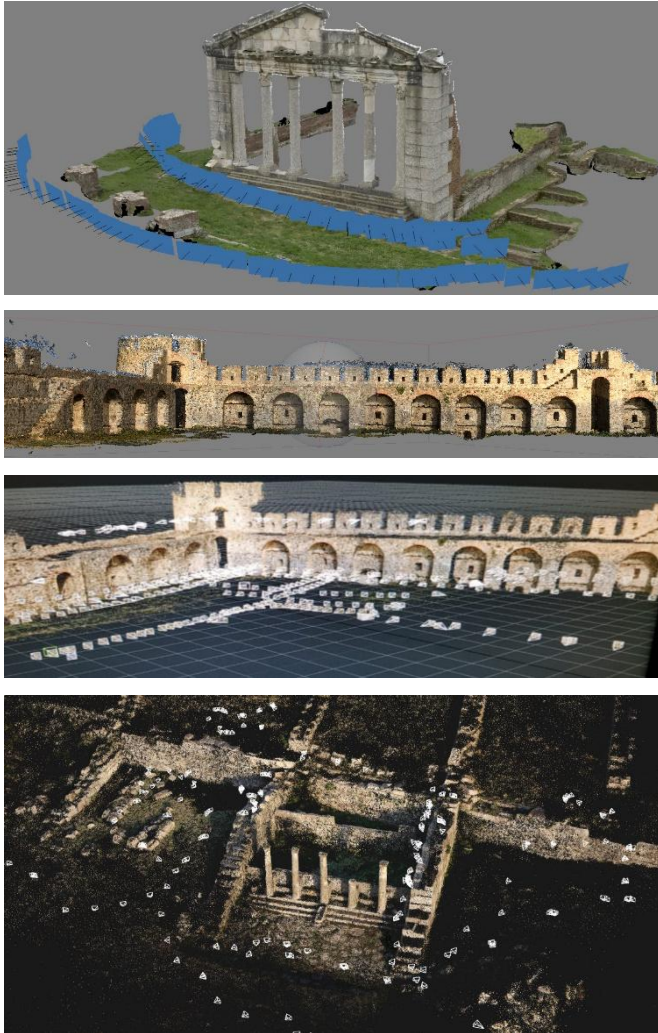


Fig. 6 Outdoor photogrammetry scanning

4. Results

Advanced non-contact 3D scanning methods, such as photogrammetry, laser scanning, and structured light, have greatly benefited the cultural heritage sector. These technologies enable precise and detailed 3D documentation of historical artifacts, architecture, and archaeological sites. By capturing accurate digital replicas, they help preserve and restore cultural heritage while minimizing the risk of damage from physical handling. Additionally, these 3D models make it easier to share artifacts with researchers, educators, and the public, enhancing access and learning opportunities. This digital preservation also ensures that even if the physical artifacts are lost or damaged, their accurate representations remain available for future study and appreciation. While there are countless ways to benefit from advanced 3D scanning technologies, this work focused on three key outputs: accurate documentation, 3D scanning for creating digital replicas, and enhancing access and education (Fig. 7). These technologies ensure precise recording of artifacts, allowing for detailed study and preservation. Digital replicas make it possible to share and explore cultural heritage in new ways, broadening access for researchers,

educators, and the public, and fostering greater understanding and appreciation of historical artifacts.



Fig. 7 Different outputs obtained from 3D scanning and 3D printing

5. Acknowledgments

The authors would like to express their sincere gratitude to all the partners and individuals involved, for providing them with the opportunity to be a part of the 3D-IMP-ACT project financed by IPA Interreg II funds. This involvement made it possible to undertake and complete this research work. We are especially thankful to the project coordinator Prof. Luigi. M. Galantucci for his guidance, support, and encouragement throughout the project. Additionally, we appreciate the valuable feedback and resources provided by the Albanian Institution which significantly contributed to the implementation of the project.

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