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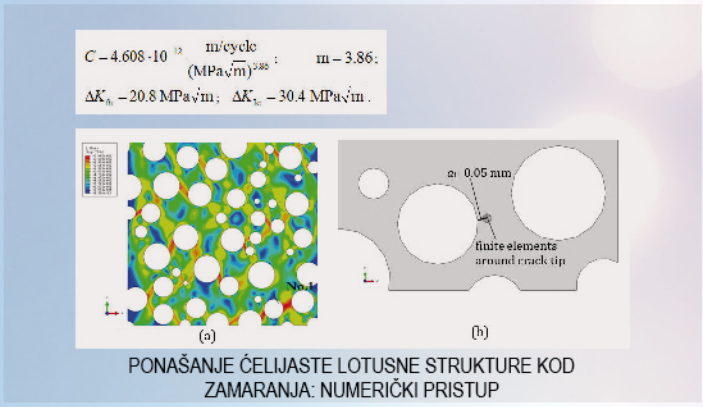

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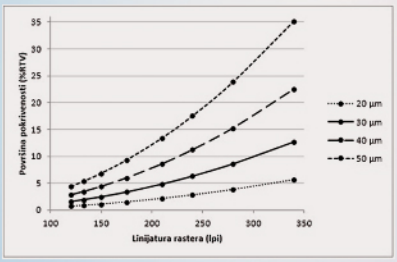
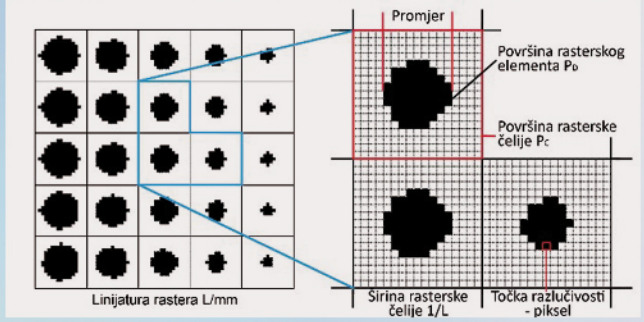
$$d = \sqrt{\frac{A_D}{25*\pi*L^2}} * 1000$$

$$A_D = (5 * d * L)^2 * \pi$$

gdje je:
A_D – postotak pokrivenosti površine
d – promjer rasterskog elementa u mm
L – linijatura rastera u l/mm





ANALITIČKI PRISTUP U ODREĐIVANJU GEOMETRIJSKOG PRIRASTA RTV KOD AM I FM RASTERSKE TEHNOLOGIJE

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UVODNA RIJEČ

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Na kraju smo još jedne kalendarske godine koja će u povijesti Sveučilišta Sjever ostati zapisana zlatnim slovima jer se nakon niza godina konačno ostvarila želja stanovnika Sjeverozapadne Hrvatske da dobiju svoje javno sveučilište koje će u potpunosti biti okrenuto potrebama i razvoju sjevera države.

29. svibnja 2015. godine Hrvatski sabor donio je na svojoj 17. sjednici Zakon o prijenosu osnivačkih prava nad Sveučilištem Sjever na Republiku Hrvatsku čime je Sveučilište Sjever i formalno postalo osmo javno sveučilište u Hrvatskoj. Time se ostvario niz novih mogućnosti za daljnji razvoj Sveučilišta, gradova koji su ga pokrenuli, ali i regije u cjelini. Sveučilište Sjever postalo je tako najmlađe javno hrvatsko sveučilište.

U ovom trenutku obrazujemo kadrove primarno u tehničkom i biomedicinskom području i izvodimo nastavu na 11 studijskih programa. Uz to, imamo izvrstan broj studenata u tzv. STEM, biomedicinskom i području informacijskih i komunikacijskih znanosti, a naši studenti po završetku studija, osim u Hrvatskoj, uspješni su i rade diljem Europe, Sjeverne Amerike i Azije, čemu u velikoj mjeri pridonosi činjenica da studenti uz teoriju dobar dio znanja stječu kroz praksu, učeći od vodećih stručnjaka u pojedinim poljima. Na tim temeljima, Sveučilište Sjever ima namjeru postati moderno europsko sveučilište koje će svoje mjesto u Hrvatskoj, ali i šire, dobiti kvalitetom znanstvenog i nastavnog rada, uspješnim povezivanjem teorije i prakse te kontinuiranim unaprjeđenjem postojećih i otvaranjem novih studijskih programa.

Tehnički glasnik, također, iza sebe ima još jednu izvrsnu godinu. Ušli smo, po posjećenosti na Portalu znanstvenih časopisa Hrvatske Hrčak, u prvih 50 časopisa iz svih znanstvenih područja (na kraju studenog 2015. bili smo na visokom 43. mjestu) i u top 10 u području tehničkih znanosti (na kraju studenog 2015. našli smo se na izvrsnom 8. mjestu). Uspjeh je to koji smo do nedavno mogli samo sanjati, ali smo ga također i očekivali, potaknuti rezultatima koje smo ostvarili u proteklih godinu, dvije. Još više no do sada, svoje stranice otvorili smo međunarodnoj znanstvenoj zajednici i ona je na to izvrsno reagirala, a usmjerenje ka internacionalizaciji našeg rada ostaje trajno usmjerenje uredništva.

Na kraju prošle godine zadali smo si zadatak da Tehnički glasnik postane relevantno mjesto ne samo novih znanstvenih spoznaja, nego i prostor koji uspješno povezuje znanost i praksu odnosno visokoškolske institucije i gospodarstvo. Spomenuti podaci pokazuju da smo u tome naumu bili uspješni!

Stoga, kao i na kraju 2014. godine, želimo još jednom zahvaliti svima koji su u ovom uspjehu sudjelovali te vas pozvati da u idućoj godini Tehnički glasnik podignemo još više i učinimo ga još boljim!

Uredništvo

SADRŽAJ
CONTENT

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IDENTIFICIRANJE RELEVANTNIH ČIMBENIKA PRIMJENE TEHNOLOGIJA ZA POTREBE DINAMIČKOG CARPOOLINGA

IDENTIFYING RELEVANT FACTORS OF APPLYING TECHNOLOGIES IN DYNAMIC CARPOOLING

Ivan Grgurević, Adam Stančić, Marko Slavulj

Izvorni znanstveni članak

Sažetak: *Razvoj i sveopća primjena brojnih suvremenih tehnologija (i usluga) znatno utječe na unaprjeđenje i dostupnost informacija u cilju povezivanja korisnika sustava zajedničkih vožnji osobnim vozilima (carpooling). Dinamički carpooling podržan informacijsko-komunikacijskim (ICTS) i lokacijsko-navigacijskim tehnologijama i uslugama (LNTS) predstavlja nadogradnju tradicionalnog i povremenog carpoolinga te suvremeni način povezivanja korisnika. U cilju kvalitetnijeg povezivanja korisnika u radu se analiziraju karakteristike ključnih programskih aplikacija koje mogu poboljšati funkcioniranje carpoolinga. Sustavnim pristupom (prema fazama istraživanja) omogućava se prepoznavanje relevantnih čimbenika primjene tehnologija za potrebe dinamičkog carpoolinga. Metodom anketiranja utvrđuju se potrebe korisnika carpoolinga unutar prometnog okruženja (prometne mreže). Cilj provedenog istraživanja je identificiranje relevantnih čimbenika primjene tehnologija za potrebe povezivanja korisnika carpoolinga i ukupnog razvoja dinamičkog carpoolinga. Doprinos članka ogleda se u utvrđivanju relevantnih čimbenika primjene tehnologija za potrebe razvoja carpoolinga kao alternativnog i održivog načina prijevoza.*

Ključne riječi: *čimbenici, dinamički carpooling / ridesharing, informacijsko-komunikacijske tehnologije i usluge (ICTS), lokacijsko-navigacijske tehnologije i usluge (LNTS), prometno okruženje*

Original scientific paper

Abstract: *Development and overall application of numerous advanced technologies (and services) affects significantly the improvement and availability of information with the aim of connecting the users of the carpooling system by passenger cars. Dynamic carpooling supported by Information-Communication (ICTS) and Location-Navigation Technologies and Services (LNTS) represents the upgrade of the traditional and casual carpooling and the modern method of connecting the users. In order to realize a better connection of users, the paper analyzes the characteristics of key software applications that can improve carpooling functioning. A systemic approach (according to research phases) allows identification of relevant factors of applying the technology for the needs of dynamic carpooling. The survey method was used to determine the needs of carpooling users within the traffic environment (traffic network). The aim of the carried out research is to identify the relevant factors of applying the technologies in order to connect the carpooling users and the total development of dynamic carpooling. The contribution of the paper is reflected in determining the relevant factors of applying the technologies for the needs of carpooling development as alternative and sustainable transportation mode.*

Key words: *factors, dynamic carpooling / ridesharing, Information-Communication Technologies and Services (ICTS), Location-Navigation Technologies and Services (LNTS), traffic environment*

1. INTRODUCTION

The dynamic or real-time carpooling / ridesharing (also known as instant ridesharing, dynamic ridesharing and ad-hoc ridesharing) is a service which enables connecting and scheduling of passengers in the function of shared rides in a very short period of time using advanced technologies. For carpooling to function well, commuters need to be able to connect with each other. Traditionally, carpooling arrangements between two or several unrelated individuals to travel to work or study were relatively inflexible. Dynamic carpooling allows additional flexibility of shared rides allowing the drivers and passengers to agree on casual shared rides in advance or within a shorter period of time, and it is based on the application and integration of various technologies. The basic characteristics of dynamic user connection are simplicity, flexibility and practicality. Telecommunications is one of the keys to effective dynamic carpooling and can shape the way travel occurs. In general, the more reliable and more efficient the underlying communications technology is, the greater is the possibilities for achieving success with dynamic carpooling [1].

The world trends of implementing various models of shared rides by passenger cars (e.g. carpooling,

carsharing, ridesharing, etc.) are oriented to the need of using innovative systems and solutions from the domain of Intelligent Transportation Systems (ITS), Innovative Transport Systems (INTS), Information and Communication Technologies and Services (ICTS) and Location and Navigation Technologies and Services (LNTS) in order to increase the use of alternative and sustainable modes of travelling [2], [3].

The intensity of traffic system development in general, as well as the intensity of the development of shared ride models require increased application of information, communication and location-navigational technologies and services. In order to achieve efficiency in performing a shared ride by passenger cars the real-time transfer of relevant and necessary information is significant. In recent years there has been a substantial number of various types and categories of papers that analyse the application of information, communication, location and navigation technologies in the function of carpooling [4], [5]. For carpooling to function adequately, the passengers should have the possibility of accessing timely information about the vehicles and rides, realizing communication and interconnections. The application of the information and communication technologies affects especially positively the connecting of the users in order to realize joint mobility [6], [7], [8].

Until recently, carpooling systems had limited usage because of the lack of efficient data processing and information-communication support. However, recent development of information, communication and location-navigation services have contributed towards the upgrade and acceptance of the carsharing system. In the last 10 years a substantial number of various types and categories of papers have been analyzing the application of information and communication technologies in the function of carpooling. In previous studies [9] the analysis was made on the application of information and communication technologies in the function of carpooling.

The analysis of the current available studies has shown a lack of studies that identify and define the relevant factors of applying the technologies that affect the performance of joint rides by passenger cars – carpooling. Current solutions in the domain of joint rides by passenger cars are partial, non-standard, and non-regulated, and the terminology is non-uniform and / or unrecognized (carpooling ≠ carsharing). The implementation of the carpooling system, as well as other subsystems of urban public transport require satisfactory infrastructural capacities that certainly include the implementation of adequate information, communication, location and navigation support.

The aim of research is to identify the relevant factors of applying the technologies facilitating the connections of carpooling users and the overall development of dynamic carpooling.

The purpose of the performed research is to improve the connections of the users of joint rides by passenger cars by using the advanced technologies and services based on them (ICTS and LNTS). Section 2 describes the procedure, that is, the used research methodology.

2. RESEARCH METHODOLOGY

Systemic approach enables recognition of key factors of applying technologies for dynamic carpooling needs. The proposed research methodology, which consists of five main operation phases is presented in Figure 1. Systemic research of relevant factors is presented by a flowchart using UML (Unified Modeling Language) notation which shows all the activities of studying the relevant factors of applying the technologies for the needs of dynamic carpooling.

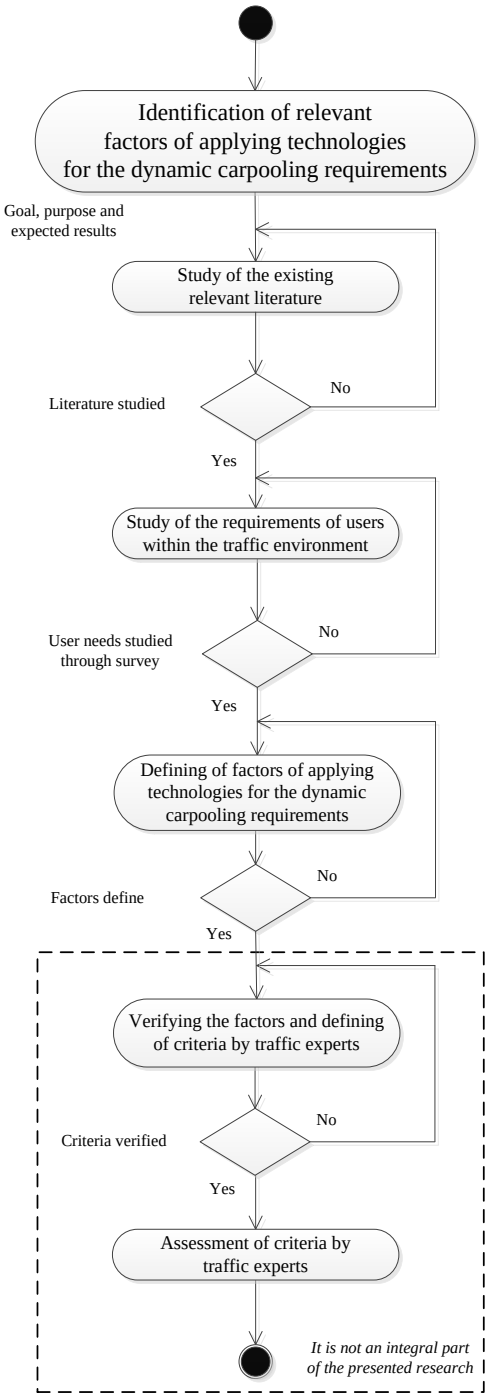

Figure 1. Research methodology of relevant factors of applying the technologies for dynamic carpooling requirements

This paper studies the first three phases (out of five). The initial activity while working on this problem included the study of the current relevant scientific literature that differs depending on the subject and objective of research, and includes the study of the characteristics of the system and the dynamic carpooling users (first phase). The study of the needs of the carpooling users within the traffic environment consists of quantitative research (second phase).

Quantitative research comprises the following knowledge obtained from the collected responses of targeted groups of users:

- Selection of relevant data from the survey;
- Segmentation of data and mapping of respondents according to the classification of workplaces, gender, age, passenger car ownership, parking, etc.;
- The weights of survey data and implementation of statistical tests; and
- Reports of quantitative results of research.

Subsection 4.2 shows the most important results of the survey of the users related to the implementation of the technology for the dynamic carpooling requirements.

The third phase of research comrises the defining of the factors of applying the technologies for the needs of realising the dynamic carpooling. Figure 1 shows the phases of systemic research of relevant factors of applyingthe technologies for the dynamic carpooling requirements.

The continuation of research (future plans) should encompass the definition of criteria for the selection of the technology for the needs of dynamic carpooling, checking of criteria based on qualitative research (traffic experts, fourth phase) and evaluation of criteria by traffic experts (fifth phase). For the evaluation of criteria the use of multi-criteria analysis is proposed. The properties of the multi-criteria analysis, such as: larger number of criteria, differences or conflicts among criteria, incomparable units of measuring criteria, selection of the best alternative (e.g. solutions, systems, implementation methods), or ranking the alternatives, can find adequate implementation in defining the factors of applying the technologies for the dynamic carpooling needs.

Further in the text the characteristics and requirements of dynamic carpooling are analyzed.

3. ANALYSIS OF THE CHARACTERISTICS AND REQUIREMENTS OF DYNAMIC CARPOOLING

In studying the carpooling system one can classify three types of problems or methods of sharing the vehicles and rides that depend on certain factors. The first suggested classification is into static (traditional carpooling as the first type of problem) and dynamic carpooling, and then the classification of the dynamic into casual (the second type of problem) and technology facilitated dynamic carpooling (the third type of problem). The core of static carpooling operation depends on interpersonal relationships and the agreement among family members, friends or employees (traditional carpooling). Casual carpooling depends on the starting location of the stop i.e. user location and at this level the relevant parameters in research [10] are identified, and the multi-criteria model is proposed in the selection of the locations in the urban environment.

The technology facilitated dynamic carpooling lies in the focus of this study. The static and dynamic classification of the carpooling system is presented in Figure 2.

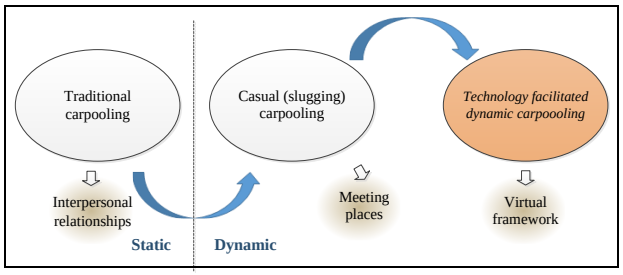

Figure 2. Static and dynamic classification of carpooling system

Dynamic carpooling facilitated by information and communication, and location and navigation technologies and services represents an upgrade of the traditional and casual carpooling and the advanced method of connecting the users.

Table 1. Characteristics of software applications in dynamic carpooling

Application	Technologies	Function / service
Web based client	Software module	Interface for controlling user accounts, editing, cancellation of trips and general communication among carpooling users.
Mobile terminal device client	Software module	Integration of wireless connection and GPS localisation. Plotting of GIS map of data of users and planned trips.
	Wireless connection	
	Localisation (GNSS, GPS / GLONASS, etc.)	
Trip matching module	Software module	Fast trip matching, filtering, scheduling and optimization of joint rides.
	Optimisation algorithms	
Database module	Database management system (DBMS)	Saving and loading data used for trip (rides) matching and user profile system.
	Database servers	
User communication module	Email servers	Communication among different carpooling users based on mobile telephony.
	Short Message Service (SMS) servers	
	Instant messengers / communication software	
API module of social network	Software web module	Connection to API (Application Programming Interface) of social network.
Payment	E-payment service provider	Transactions that refer to the realized rides, keeping the register on transport payments per user, transactions to bank accounts.
	Financial management	

Dynamic or real-time carpooling services have the tendency of relying on a similar set of technologies and share similar characteristics. The basic requirements of dynamic carpooling include the following elements of the value chain of information and communication technologies and services in the carpooling system, previously studied in [11]:

- user equipment (smartphones and other mobile terminal devices);
- applications (carpooling applications, GPS functionality);
- services (ride matching algorithms);
- network (constant network connectivity); and
- contents (traveller information, pre-trip information, data repository).

Table 1 shows the key software applications that can improve the carpooling operation. Software applications are described by applicable technologies and functions / services.

The technologies include Geographic Information System (GIS) or GLONASS (Russian: GLObal'naya NAvigatsionnaya Sputnikovaya Sistema), Global Navigation Satellite System (GNSS), Radio Frequency Identification (RfID) and various other technologies to determine the location with more or less precision, coverage, and higher or lower costs of installation and maintenance. An increasing role in using and studying carpooling belongs to GNSS systems that together with GIS information technologies and Augmented Reality (AR) enable locating the users and accessing a new segment of information. Determining the location of carpooling users can be realized also by applying other technologies, such as locating by means of base stations (GSM, UMTS, LTE) and WLAN. Apart from obtaining precise information on the location of the carpooling users in space, the RfID technology is introduced also to solve the drawbacks in sharing the transport costs among the carpooling users [3]. For the needs of carpooling various multi-agent systems have been developed that are accessible by means of mobile terminal devices [12], [13].

Dynamic carpooling uses development of mobile telephony and enables its users to organize joint drives in short periods of time from virtually any place in the world which is covered by mobile network.

4. RESEARCH DESCRIPTION AND RESULTS

4.1. Survey description

With the aim of identifying the relevant factors of applying technologies for dynamic carpooling requirements, a survey has been performed among the target group of users of advanced technologies who are familiar with the issues of carpooling (the survey area is the City of Zagreb, Republic of Croatia). The survey was carried out in April and May 2015 in three different ways: by electronic mail (32 respondents, 7.459%), by web survey (382 respondents, 89.044%) and by interview (15 respondents, 3.497%). The surveyed group comprised respondents in the age between 18 and 65, and it covered the employed citizens and full-time students. These two groups of respondents represent the active population, considered to be commuting every day in the Zagreb transport network. In order to avoid, i.e. eliminate epistemological difficulties, the survey was applied on the sample of respondents that have almost equal level of education. Thus, every respondent's answer has the same value and equally forms the statistical mass. The survey encompassed a total of 429 respondents. The number of the surveyed employees in 2015 was 223 (51.981%), and of full-time students 206 (48.019%). Statistical error for 223 employees was E = 5.51% and for 206 full-time students it was E = 5.72%. From 223 surveyed employees there were 118 male respondents (in percentage 52.914%) and 105 female respondents (47.085%). From 206 surveyed full-time students there were 98 male respondents (in percentage 47.572%) and 108 female respondents (52.427%). The target group and the number of respondents represent a representative sample for research.

For defining of the representative sample it was necessary to determine the frequency of using carpooling (the carpooling system does not yet exist in the city of Zagreb) by passenger cars, and the frequency was classified according to the period of usage (never, sometimes, once a week, 2-3 days a week, and 4-5 days a week). The option "sometimes", when it comes to the frequency of usage, means monthly usage of carpooling 3-4 times a week. The respondents who never use the carpooling option and the respondents who did not respond to the survey in full were eliminated from further analysis. Thus, the analysis takes into account the respondents: sometimes / monthly 3-4 days (19.438%), once a week (17.564%), 2-3 days a week (26.230%), and 4-5 days a week (22.482%). Therefore, the number of the respondents taken into account was 366. From 366 respondents, there were 191 employees with residence in the City of Zagreb (52.186%) and 175 full-time students studying in the City of Zagreb (47.814%) and who prevailingly use the carpooling services.

Further in the text the usage of information, communication, location and navigation technologies and services from the user's point of view in the function of carpooling has been analyzed.

4.2. Survey results

The survey provided the answers of the respondents about the application of certain information-communication services to the connection of the carpooling users. The application of information-communication services for the carpooling requirements is presented in Table 2. The data from Table 3 that refer to the years 2010 and 2012 are related to the carried out research [9], and the source and method of collecting data for 2015 is presented in subsection 4.1. In the mentioned survey question several answers could be given, i.e. three services mostly used by the carpooling users. The call services in order to connect the users are used by about eight out of ten respondents, seven respondents use electronic mail, and six out of ten respondents use SMS services. In 2015 the Social Networks / Media (Facebook, Twitter, My Space, LinkedIn etc.) and Instant messengers

/ communication software (WhatsApp, Viber, Skype, Line, etc.) are considered with special care as advanced methods of communication [14]. Social networks are represented by as much as 23%, i.e. Instant messengers / communication software with 17%. In the use of public Internet pages / portals, as well as carpooling applications of mobile terminal devices there was a noticeable trend of increase in the three observed years (2010, 2012 and 2015).

Table 2. Application of information and communication services in order to connect the carpooling users (a part of data dates from 2010 and 2012 [9])

Information and communication services	2010	2012	2015
Voice communication via mobile telephony	82%	87%	78%
E-mail	61%	63%	62%
SMS	74%	79%	49%
Social Networks/Media	n/a	n/a	23%
Instant messengers/communication software (WhatsApp, Viber, Skype, Line, etc.)	n/a	n/a	17%
Carpooling public websites	4%	7%	7%
Carpooling smartphone applications	1%	2%	3%
Carpooling operators (call centers)*	0%	0%	0%

** there are no carpooling operators in the city of Zagreb*

The biggest recorded fall happened in case of SMS messages (74% in 2010, 79% in 2012, and in 2015 only 49%). The reason is the development and widespread use of Instant messengers / communication software, which is realised due to its simplicity and numerous interactive possibilities (user grouping, etc.). The biggest development potential to connect the carpooling users belongs to the services based on Social Networks / Media and Instant messengers / communication software, because of numerous advantages such as simplicity and availability of usage by means of mobile terminal devices.

The significance of information and communication technologies and services in connecting carpooling users is shown in Table 3 for various research years (2010, 2012 [9] and 2015), and it is visible how vital that impact is on the future development of the carpooling model.

Table 3. Significance of ICTS in advancing connectivity of carpooling users (a part of data dates from 2010 and 2012 [9])

Significance of ICTS in advancing connectivity of carpooling users	2010	2012	2015
Of crucial importance	48.4%	50.19%	53.83%
Important and substantial contributions	42.66%	41.15%	39.62%
Contributions, but not significant	7.68%	7.64%	5.46%
Not important	1.26%	1.02%	1.09%
Total	100%	100%	100%

More than half of the respondents (197 – 53.83%) have chosen significance of ICTS as being of crucial importance (2015). More than one third of respondents (145 – 39.62%) have chosen significance of ICTS as important and substantial contribution, 20 respondents (5.46%) have chosen contributions, but not significantly, and only 4 respondents (1.09%) have chosen not important. Such results can be interpreted as the expected ones regarding the development of ICTS and its possibilities of implementation in the traffic environment.

4.3. Discussion

Applications for real-time booking of places in a passenger car have great potentials to enable the user who has the basic computer literacy to use this concept, thus reflecting the personal benefit of the user in visible savings while travelling by passenger car. The user-friendliness is insured by a simpler interface, and the applications are performed on mobile terminal devices that have access to the Internet. This type of carsharing is generally provided by the following infrastructure:

- GPS / GLONASS navigation instruments that determine the driving route and allow the accuracy of common rides;
- mobile terminal devices –smartphones in order to receive travel requests with expressed flexibility, and
- social networks that allow establishing of confidentiality and reliability between the driver and the passengers.

In order to realize a greater total number of users of joint rides by passenger cars, the application of technologies can be especially classified as shown in Table 4.

Table 4. Technological groups in the function of increasing the number of carpooling users

Technological group	Possibilities
Information and communication technologies	Mobile terminal devices (smartphones, tablets, etc.) carpooling applications
	Propagation of Internet services and potential of Future Internet (Internet carpooling portals)
	Ridematching Databases
	Social Network / Media and Social Networking Applications
Location and navigation technologies	Location Based Service (LBS)
	Availability of GNSS based location
	Hardware (RfID Cards, transmitters, receivers)

Today the innovativeness is reflected in combining the benefits of social networks to solve the carpooling issue, i.e. connection of the users and their personal safety. The lack of confidence and safety seems to be the main

problem for greater use of the system of joint rides by passenger cars, and the integrating social networks do have precisely the informing role about other users thus gaining confidence and reliability. One of the innovative characteristics of the system in the function of on-trip information is a mobile client. A mobile client consists of a software that is run on a mobile terminal device, and requires wireless Internet connection and built-in GPS / GLONASS support (containing GNSS receivers). The implementation of mobile applications allows the visibility of the contents and the ability of localizing the user, thus realizing the trip search and grouping of users (drivers and passengers). By adding such innovativeness it is possible to present a number of possibilities to overcome the current carpooling challenges.

5. IDENTIFICATION OF RELEVANT FACTORS

There are many factors that affect the system of joint rides by passenger cars, and that are closely related to attracting and accepting the users. The performed study, based on the presented research methodology in Section 2, has defined the factors that affect the usage of options of joint rides by passenger cars. Carpooling can be basically considered also by means of sociodemographic, traffic, spatial, time-related, psychological and technological factors that are presented in Figure 3.

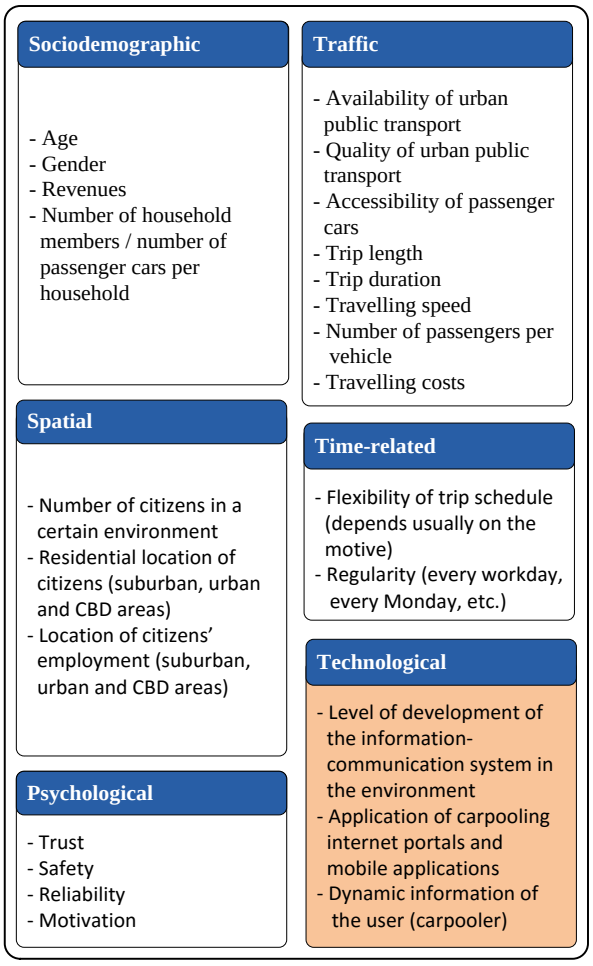

Figure 3 - Factors affecting the use of carpooling system

Studies [15], [16] confirm the mentioned factors; however, often there is an absence of psychological factors that have a significant impact on carpooling users. Psychological factors encompass the complexity of interactions among the individuals, and are characterized by psychological elements, such as confidence, safety, reliability and motivation of the user. Positive influence on the psychological factors can come from the application of various applications based on information and communication technologies (e.g. information exchange about the users via social networks, etc.).

Identified factors are interdependent and can be observed from various levels and approaches. Each of the factors consists of a number of elements and potential requirements related to the implementation of the technology in the function of dynamic carpooling. Figure 4 shows the interdependence of the recognized factors and the application of technologies.

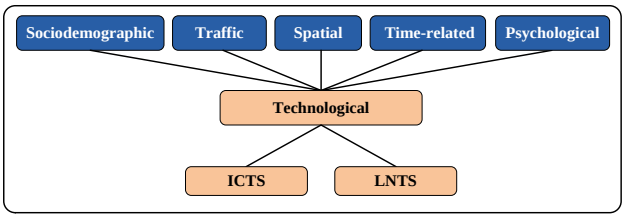

Figure 4. Interdependence of factors and technologies application

For instance, the interdependence is most simply presented through a sociodemographic element i.e. age of the user. The younger the carpooling user, the greater the benevolence of using the new and advanced technologies.

Out of identified factors that affect the performance of joint rides by passenger cars it is possible to define the selection criteria of the technology (ICTS and LNTS) for the dynamic carpooling requirements according to the target groups of users.

6. CONCLUSION

Joint ride by passenger cars (carpooling) parallel with the development of technologies (ICTS and LNTS) is becoming a more and more significant topic and subject of study on the transport demand management. Dynamic carpooling based on the strength of information, communication, location and navigation technologies and services has been a widely accepted concept to implement better transportation system.

With the aim of better connection of the users, the paper analyzes the characteristics of key software applications that can improve the carpooling operation. Based on the performed survey (in three phases) that included the analysis of the existing relevant literature and the users' needs for joint rides by passenger cars in the city of Zagreb, relevant factors of applying technologies for the dynamic carpooling requirements were recognized (sociodemographic, traffic, spatial, time-related, psychological and technological).

The survey provided answers of the respondents about the implementation of certain information and

communication services (voice communication via mobile telephony, e-mail, SMS, social networks / media etc.) and their significance was determined in case of connecting the carpooling users (in three observed years: 2010, 2012 and 2015). More than a half of the respondents (197 – 53.83%) chose the significance of ICTS as of crucial importance (2015). A potential limitation of research is the sample size. Further data should be collected in order to generalize results to a larger population.

The research results can be implemented in the procedure of introducing and operationalization of carpooling as partial measures of mobility management in the cities and in designing and production of various types of carpooling applications. The obtained research results also allow expansion of the possibilities of connecting the users of joint trips by applying the advanced information and communication technologies and the contemporary user terminal devices.

Future plans for the continuation of research include the defining of criteria (and sub-criteria) for the selection of technology for the dynamic carpooling requirements, verification of the criteria on the basis of qualitative research (traffic experts, proposed fourth research phase) and assessment of criteria by traffic experts (fifth phase). For the needs of criteria assessment, the use of multi-criteria analysis is expected.

7. ACKNOWLEDGEMENTS

This research has been carried out as part of the project "Possibilities of Applying Information and Communication Technologies and Services in the function of Carpooling Systems" (No. 251-76-01-15-13) supported by the Faculty of Transport and Traffic Sciences, University of Zagreb, Programme for Research, 2015.

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POSTUPCI RAZVRSTAVANJA OTPADA KOD POSTUPKA RECIKLIRANJA PROIZVODA

METHODS OF WASTE SEPARATION IN THE PROCESS OF RECYCLING

Tajana Vaško

Stručni članak

Sažetak: *Kod prerade otpada potrebno je otpadne proizvode, koji se sastoje od raznih vrsta materijala raznih svojstava, razdvojiti te nakon toga razvrstati kako bi se što uspješnije proveo postupak recikliranja. Opisano je ručno razvrstavanje te postupci mehaničkog razvrstavanja otpada koja se temelje na različitim svojstvima materijala kao što su razvrstavanje oblikom, magnetni postupci razvrstavanja, razvrstavanje na osnovi električne vodljivosti te razvrstavanje na osnovi gustoće. Mehanički postupci doprinose sofisticiranju razvrstavanja otpada, ali u posebnim slučajevima kod prisutnosti nečistoća, ulja i drugih zagađenja koja se ne mogu potpuno ukloniti mehaničkim postupcima, ručno razvrstavanje ima velik značaj i često ostaje glavna opcija.*

Ključne riječi: *mehaničko razvrstavanje otpada, recikliranje, ručno razvrstavanje otpada, zaštita okoliša*

Professional paper

Abstract: *In the process of waste management, there is the need to separate and sort waste products, which consist of different materials that have different properties, so that the recycling process could be carried out successfully. Here are described manual sorting procedures and mechanical classification of waste products, which are based on the various properties of materials, such as sorting by shape, magnetic separation procedures, classification based on electrical conductivity and classification based on density. As much as the mechanical procedures contributed to the sophistication of waste classification, in special cases, such as in the presence of dirt, oil and other contaminants that cannot be completely removed by mechanical methods, manual sorting remains the main option.*

Key words: *Mechanical waste separation, Recycling, Waste separation by hand, Preservation of the environment*

1. INTRODUCTION

One of the major problems in preservation of the environment, especially in developed countries, is waste that is inevitably associated with the manufacturing process of every product. Objectives pursued in waste management are to reduce waste, and increase ecologically acceptable recycling processes, with promotion and application of acceptable waste management. Additionally, it is important to emphasise the development of governmental measures for recycling.

In the process of product and material recycling, it is necessary to achieve simple disassembling, or the application of easily separable compounds. Due to the high cost of human labour in manual separation, there are numerous procedures developed for the shredding and sorting of waste by the material and fraction type. In the waste classification process, there are different material properties used, such as magnetic properties, mechanical properties, electrical conductivity, surface colour, colour of the fractured surface, emission spectral analysis, X-ray fluorescence analysis, and so on. [1]

In this article, there are described manual sorting and mechanical processes of waste separation, such as the classification by shape, magnetic sorting procedures, classification based on electrical conductivity and classification based on density.

Figure 1. International symbol of recycling [2,3]

2. MANUAL WASTE SEPARATION

One well-known, but increasingly rare method of separation of materials is the manual process. Most commonly used are visual methods that distinguish the material type by colour (Table 1.). [1]

In the case of mixed waste processing, bulky items (home appliances, furniture, etc.), and certain contaminations generated in different industries, there is often performed manual waste separation before the mechanical process. Manual classification can also be used to remove impurities from previously sorted materials. [4]

The equipment used for manual separation of materials usually involves a sorting conveyor-belt or table containing a mix of materials. Workers are positioned on one or both sides of the conveyor-belt or table. The containers for the removed parts should be easily accessible. For larger amounts of materials, there is typically a conveyor-belt used that carries the parts that need to be sorted, with previously removed harmful waste products, oily components and such. Workers, that are sorting the waste, are placed on both sides of the conveyor-belt, which holds the materials that need sorting. Working length per worker (along the belt) should be about 1.50 to 1.80 meters, and the working depth should not be bigger than 0.6 meters, so that with two workers on both sides, the width of the material flow is a maximum of 1.20 meters. The flow rate is adapted to the complexity of the materials sorted, and usually amounts to 0.15 to 0.2 meters per second. Also, it is necessary that the workers can sort parts with simple hand movements that require little power. Meanwhile, they need to have a good overview of the parts on the conveyor-belt.

Designing processes that rely on manual sorting require a good understanding of the basic principles of time and movement, composition of the waste feed, and requirements of comfort and worker safety. In the application of simple, labour-intensive designs, safety and process control cannot be neglected.

Table 1. Surface colour of metals and their alloys [1]

COLOUR	METAL / ALLOY
red, reddish	Copper
yellow to gold-yellow	Alloys Cu-Zn, Cu-Sn
bluish to dark grey bluish white at fresh break or cut, later becomes dark grey	Lead, Pb-alloys
bluish white at fresh break; later becomes bluish-grey	Zinc, Zn-alloys
pale to light grey white, light grey oxidized layer	Magnesium
white to pale grey	Aluminium, Al-alloys
almost silver-white, with faint grey shine	Nickel
almost silver-white	Tin, Sn-alloys, Cu-Ni-alloys, Cu-Ni-Zn-alloys

One of the indicators in selecting the procedure for processing waste products is the weight of parts. With increase in weight, the efficiency of mechanical (automatic) classification decreases, so in such cases it is justified to resort to manual procedures. This also applies to parts with lower mass, if the fraction is valuable (for example, due to the content of precious metals).

Figure 2. Example of a conveyor-belt for manual classification of materials [5]

3. MECHANICAL WASTE SEPARATION

Mechanical classification is relatively cheaper than the manual kind. A requirement for economical profitability of manual separation is a significant difference in the observable characteristics of the materials. Distinguished features must be apparent quickly and accurately. For example, iron is easily separated from other materials using ordinary magnets. Other metals can be sorted out by eddy current separators with slightly less accuracy. Fast separation of polymers can be achieved via density. Specifically, fluids, such as liquid and gas, can be used to separate two types of polymers. The lighter polymer with lower density than the fluid will float, while the polymer with higher density will sink. If two polymers have approximately the same density, separation is not possible.

Mechanical classification is based on three related operations:

- isolating parts or pieces for individual identification,
- identifying parts or pieces based on distinguished features and evaluating of gained measurements,
- separation of the identified parts or pieces in separate containers.

Their individual efficiency determines the overall efficiency of the individual mechanical classification process.

3.1. Separation by shape

Classification procedures based on shape and size of particles (“screening”) are used to prepare raw materials of uniform size for certain mechanical processes, and for improvement of the metal content. This is necessary, because the particle size and shape characteristics of metals are different than those of plastic and ceramics.

Screens are used for achieving efficient separation of particles through dependence on differences between particle sizes. The separation results in a division of the feedstock into at least two size fractions, one of which has the minimum particle size larger than that of the individual screen openings, and the second that has a maximum particle size smaller than the individual screen openings.

The first group is retained on or within the screen, because the particles are too big to pass through the openings. The second group passes through the screen openings and contains particles with sizes under average. Screens may also be used to separate materials into three or more size classes. In such cases, several screen surfaces of different size openings are fitted in series in the frame of the screening equipment. [4]

Predominantly, three types of screens are used by the solid waste industry for sizing particular fractions of processed and unprocessed mixed waste and previously sorted materials. These three types are the vibratory flat bed screen, the disc screen, and the trommel screen. Of the three, the trommel has proven to be quite effective and efficient for processing mixed waste and other mixtures where large, flat particles (e.g., paper) and aggregated-type particles (e.g., crushed glass) must be separated and represents the most commonly used type of screen used for separation by the shape and size of particles.

This device has a high resistance against clogging, which is important according to the diversity of the shapes and sizes of particles that the waste consists of. The vibratory flat bed screen is also largely used, especially in facilities for non-ferrous material recycling, but with the frequent problem of wire clogging.

In the case of size classification of formerly separated materials, vibratory flat bed and trommel screens are used in a number of facilities. The size classification of waste feedstocks that contain components with similar particle size distributions or that contain materials that can capture smaller particles and, therefore, hinder their flow through the openings of thee screen surface requires tumbling in order to be efficient.

Figure 3. End view of a trommel screen [4]

The trommel is a downwardly inclined, rotary cylindrical screen; its screening surface can be either a wire mesh or perforated plate. It can be used to process raw mixed waste prior size reduction, as well as to process shredded mixed waste. The characteristic tumbling movement, caused by the rotating screen, results in efficient separation. [4]

3.2. Magnetic separation

Magnetic separation or classification is a process used to segregate magnetic (i.e., ferrous) metal from a mixture of different types of materials, e.g., mixed waste or commingled metal, glass, and plastic containers. The process is technically simple and relatively low cost. Magnets used in the separators can be either permanent or electromagnetic. Magnetic separators are available in three configurations: magnetic head pulley, drum, and magnetic belt. The magnetic head pulley-conveyor consists of a magnetic pulley that serves as the head pulley of a conveyor.

In this kind of operation, the material to be sorted passes over the magnetic pulley, and the magnetic particles are pulled way around the rotating pulley while the non-magnetic particles follow a separate unrestrained path. Figure 4. shows a magnetic belt that consists of a stationary magnetic assembly that is mounted between the head and tail pulleys. Their function is to attract the magnetic particles and carry them away against the belt surface while the non-magnetic particles fall under the influence of gravity.

In the case of the drum magnet, the electromagnetic assembly is usually mounted inside the rotating drum where the assembly remains stationary.

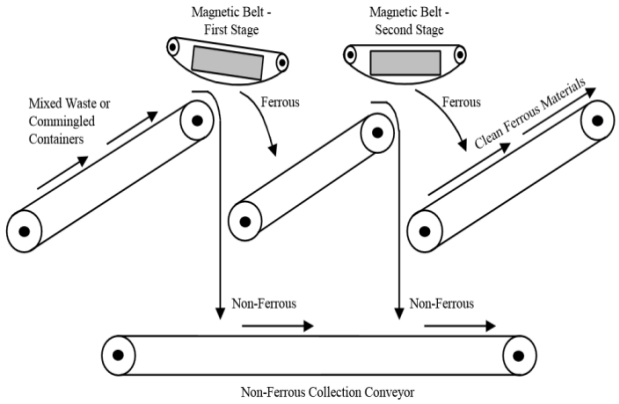

Figure 4. Device with multiple stages of magnetic separators (schematic) [4]

Figure 5. Magnetic belt for separation [4]

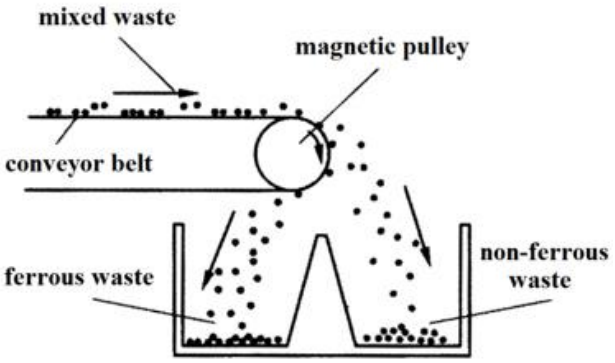

Figure 6. Example of magnetic separation – separating ferrous waste with a magnetic pulley [1]

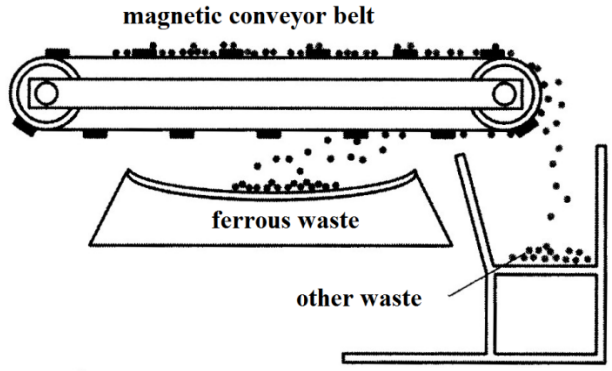

Figure 7. Example of magnetic separation – separating ferrous particles with a magnetic conveyor belt [1]

According to [6], magnetic separation procedures can be divided into:

- Ferromagnetic techniques – shredded waste travels with the conveyor belt over a magnetic pulley with a strong magnetic field. The ferromagnetic materials are drawn by the magnet to the conveyor belt, and the non-magnetic particles fall due to gravity.
- High gradient magnetic separation – can be used to separate paramagnetic materials from non-magnetic materials by directing the waste flow through a strong magnetic field with high gradients.

3.3. Separation based on electric conductivity

Electric conductivity-based separation separates materials of different electric conductivity or resistance. There are three typical types of techniques: eddy current separation, corona electrostatic separation, and triboelectric separation. This type of separation was initially developed to recover non-ferrous metals from shredded automobile scrap or for treatment of municipal solid waste. [7]

Currently, eddy current separators (Figure 8.) are almost exclusively used for waste reclamation, where they are particularly suited for handling the relatively coarse sized feeds. The separation criteria in this process are electric conductivity and density. Principles of this kind of separation are repulsive forces exerted in the electrically conductive particles due to the interaction between the alternative magnetic field and the eddy currents induced by the magnetic field (Lorentz force).

When a conductive material fraction is in an alternate magnetic field, an induction of eddy currents occurs in it. Conductive particles rotate away from the electric current while the non-conductive particles don't. It is used for separating non-ferrous metals away from ferrous, or only for separating non-ferrous metals. With this procedure, particles larger than 5 millimetres can be processed.

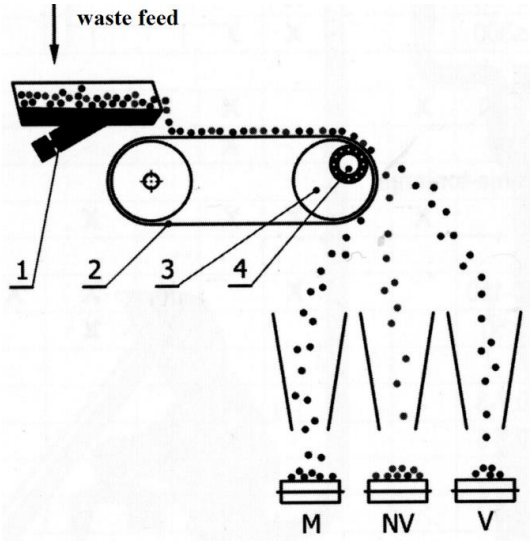

Figure 8. Separating particles with eddy currents by the company Steinert (M – magnetic particles, NV – non-conductive particles, V – conductive particles, 1 – vibrator, 2 – conveyor belt, 3 – pulley, 4 – polarizer) [1]

The rotor-type electrostatic separator, using corona charging, (Figure 9.) is used to divide raw materials into conductive and non-conductive fractions. Extreme differences in electric conductivity or specific electric resistance between metals and non-metals supply an excellent condition for the efficient application of this kind of separators in waste recycling.

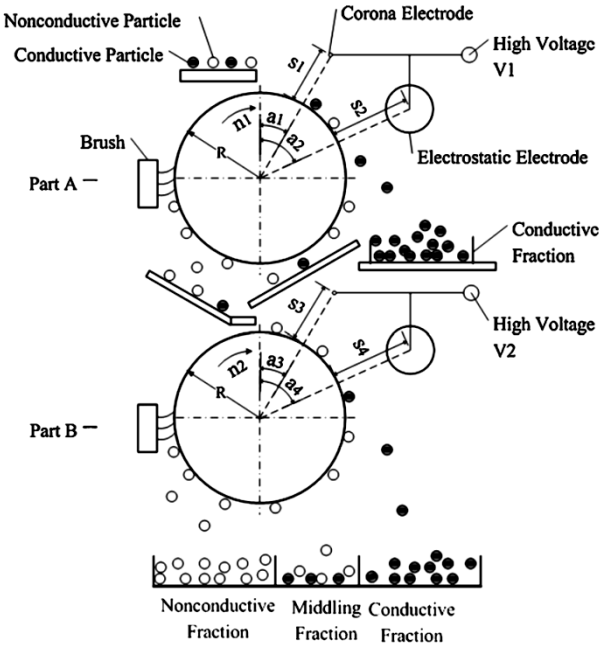

Figure 9. Schematic representation of the two-roll type corona-electrostatic separator [8]

Electrostatic separation has been utilized for the recovery of copper or aluminium from chopped electric wires and cables, or the recovery of copper and precious metals from printed circuit board scrap. Particle sizes that can be separated by this process are 0.1 to 5 millimetres, that is, 10 millimetres for laminar particles. Fragmented particles get electrostatically charged and guided through boards with different charge. Conductive materials are detracted from the electrode, because of the same charge as on the board. Nonconductive particles are drawn to the board surface.

Triboelectric separation (Figure 10.) makes it possible to sort plastics depending on the difference in their electric properties. There are many advantages of triboelectric electrostatic separation, such as independence of particle shape, low energy consumption, and high throughput. It is used to separate plastic particles with the size of 5 millimetres, exceptionally 10 millimetres.

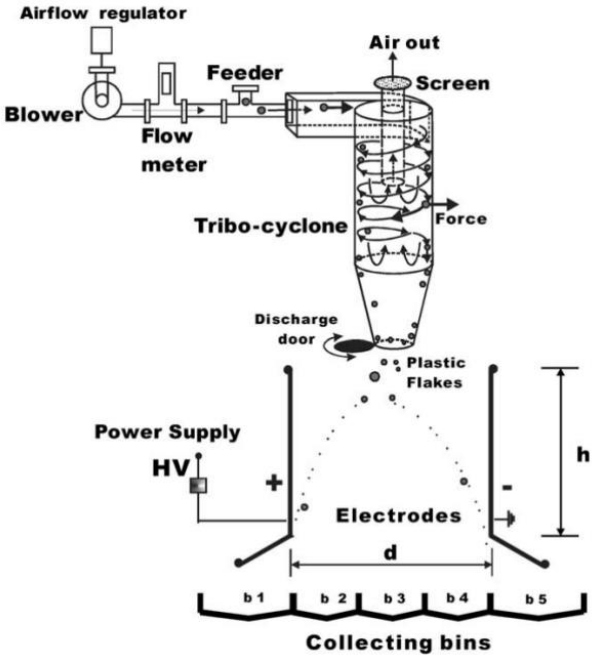

Figure 10. Schematic design of the triboelectric separator [9]

3.4. Separation based on density

Several different methods are employed to separate heavier materials from lighter ones. The difference in density of the components is the basis of separation. This method separates materials of different specific gravity by their relative movement in response to the force of gravity and one or more other forces, the latter often being the resistance to motion offered by a fluid, such as water or air. The motion of a particle in a fluid is dependent not only on the particle's density, but also on its size and shape, large particles being affected more than smaller ones. In practice, close size control of feeds in gravity processes is required in order to reduce the size effect and make the relative motion of the particle specificly gravity dependent. [7]

Air classification is a process of separating categories of materials by the differences in their aerodynamic characteristics. The aerodynamic characteristic of a particular material is primarily a function of the size, geometry, and density of the particles. The process consists of the interaction of a moving stream of air, shredded waste material, and the gravitational force within a confined volume. In the interaction, the drag force and the gravitational force are exerted in different directions upon the particles. The result is that waste particles that have a large drag-to-weight ratio are suspended in the air stream, whereas components that have a small ratio tend to settle out of the air stream. Paper and plastic materials are usually found in the light fraction, whereas metals and glass are components of the heavy fraction. Air classifiers, also called wind sifters, appear in a number of designs, such as vertical, horizontal and zigzag tubes (Figures 11.-14.).

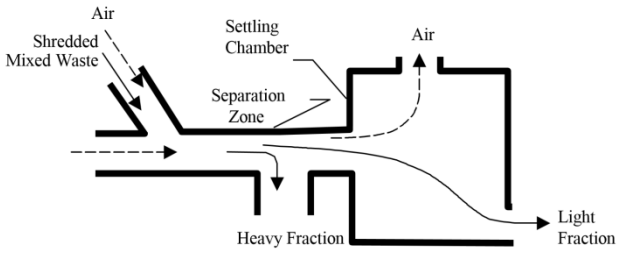

Figure 11. Horizontal air classifier [4]

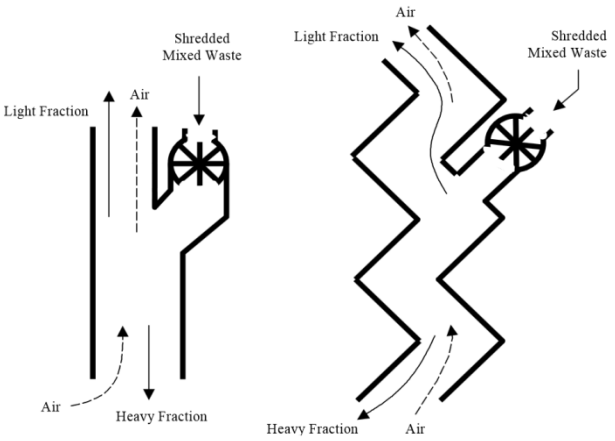

Figure 12. Vertical straight and vertical zigzag air classifiers [4]

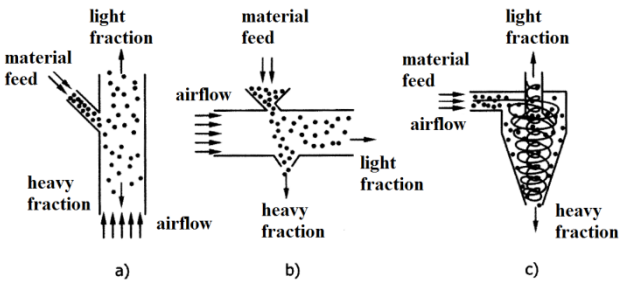

Figure 13. Air classifiers (a: counter current method, b: cross current method, c: centrifugal method) [1]

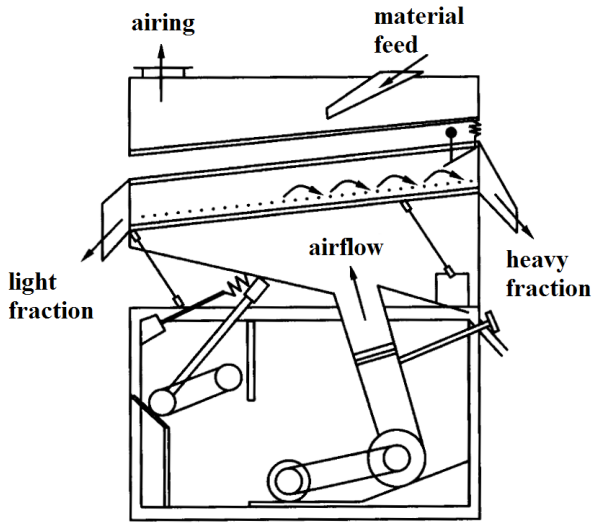

Figure 14. Table for air classification [1]

The gas-cyclone separates solid particles from a gas by means of centrifugal forces that appear due to differences in density and dimensions of the particles. They are mainly used to extract dust from air (Figure 15.).

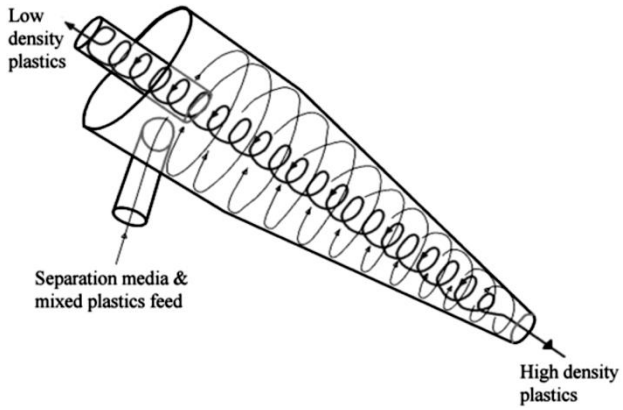

Figure 15. Conocylindrical cyclone [10]

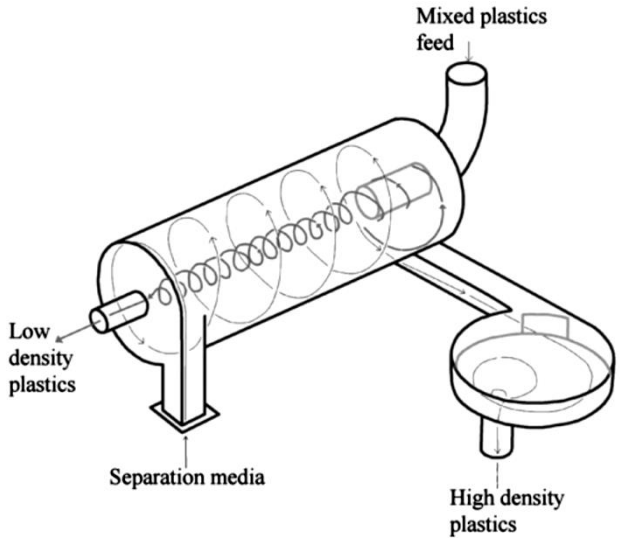

Figure 16. Cylindrical cyclone [10]

The float-sink technique is used to separate solid particles by means of differences in density. The particles are immersed in a liquid having a density value between the densities of the two components that need to be separated. Heavier particles sink to the bottom, while lighter particles float on the surface.

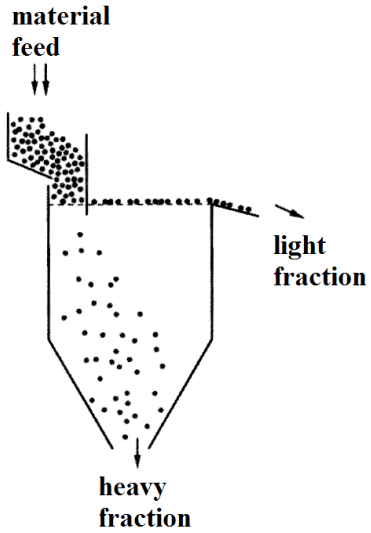

Figure 17. Float-sink technique in liquids [1]

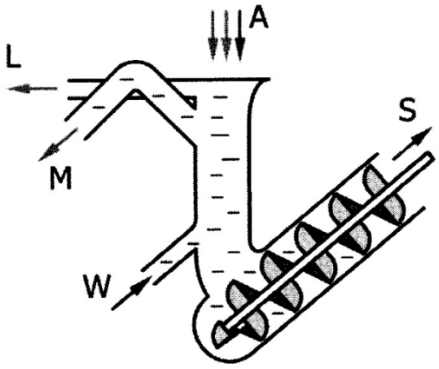

Figure 18. Schematic display of separation in fluid current - counter current method: A – material feed, L – light fraction, M – medium fraction, S – heavy fraction, W - water [1]

The hydrocyclone is used to separate solid particles from a fluid stream based on differences of particle density and dimensions, affected by centrifugal forces generated by the whirly motion of the fluid that passes through a circular tube. It is also used to separate contamination from a liquid.

4. CONCLUSION

The advantage of manual separation is that the recovered material is more pure than that recovered from mechanical separation, and therefore has a higher value. The disadvantage is the high cost due to the worker labour expenses. As the mechanical separation techniques are improved, the disadvantages of manual recycling will become overwhelming for materials used in small quantities or low weight materials. [11]

Magnetic separators, particularly those of low intensity in the form of a pulley, are commonly used for the separation of ferromagnetic materials from non-ferrous or other non-magnetic waste. The classification based on electrical properties separates materials of

different electrical conductivity or different electrical resistance. The most important methods are: eddy current separation, electrostatic separation and triboelectric separation. In order to separate heavier materials from lighter ones, methods are used based on the difference in densities of components. This type of classification includes: gas- and hydro-cyclone, float-sink technique and air classification.

Processing of municipal waste or previously sorted waste to recovered materials includes a number of processes depending on the level of the previous separation, as well as the type of material that needs to be processed. The principles of each process are influenced by the physical and chemical characteristics of certain materials or types of material for which they are intended.

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UNAPRIJEĐENA SIMULACIJA NIVOA VODE ZA PROTOTIPNU AUTOMATIZIRANU CRPNU STANICU

ADVANCED SIMULATION OF WATER LEVEL FOR PROTOTYPE AUTOMATED PUMPING STATION

Kruno Kokot, Igor Petrović, Zoran Vrhovski

Stručni rad

Sažetak: *U ovom članku opisan je proces analize i unaprjeđenja prototipnog modela crpne stanice koji se koristi za izradu, provjeru i unaprjeđenje programskog koda, te vizualizacije sustava (SCADA sustav). Originalno rješenje je bilo iznimno dobro za analizu rada upravljačkog sustava, no mehaničke komponente modela nisu dovoljno dobro obrađene. U obrađenim unaprjeđenjima prvenstveno se osvrtalo na mehaničke odnose dotoka i odtoka vode, te promjene u nivou vode, što je u originalnom rješenju riješeno ručno. Novo rješenje mehatronički je naprednije i bolje jer obuhvaća realniju sliku dinamičkog stanja crpne stanice. Uz to, novo rješenje automatizirano provodi simulaciju nivoa vode direktno iz istog PLC uređaja koji provodi regulaciju rada pumpi, pa je s te strane sustav dobro integriran.*

Ključne riječi: *Automatizacija, crpna stanica, PLC, SCADA, TIA Portal*

Professional paper

Abstract: *In this paper the process of analysis and improvement of a prototype model of a pumping station is described, which is used to build, validate and improve the programming and visualization of the system (SCADA system). The original solution was extremely good for the analysis of the control system, but mechanical components of the model were not sufficiently processed. In described improvements the main issue was mechanical relations of incoming and outgoing water flow, and result differences in water level, which were provided manually in the original solution. The new solution is more advanced and better from the point of view of Mechatronics, since it can give a more real image of a dynamical state in the pumping station. Furthermore, the new solution conducts automated simulation of water level directly from the same PLC device which controls the operation of the pumps, so from that point of view the system is well integrated.*
Key words: *Automation, pumping station, PLC, SCADA, TIA Portal*

1 INTRODUCTION

The existing prototype automated pumping station, with details described in [1], is a faithful replica of a real pumping station drive concerning the integration of digital automation. The automation was implemented using a Siemens Simatic S7-1200 PLC device, with characteristics available in [2], and the visualisation was implemented using a WinCC application in the TIA Portal V11 SP1, with characteristics available in [3]. The communication between the PLC device and a SCADA application is achieved using a Profinet communication protocol described in [4]. The prototype automated pumping station was used to test the operation of real pumping stations and to improve the solution programme of a pump control.

The paper presents the analysis of the drawbacks of the mechanical part of the station, according to [5] and gives solution to the identified problems, according to [6]. Improvements were found for every identified problem, as well as a repeated evaluation of the new solution, according to [7]. The new system must give a more realistic display of the way a real pumping station works.

In order to create a new solution, the existing PLC device was used, as well as the communication channel and the upgraded SCADA application.

2 ANALYSIS OF THE EXISTING PROTOTYPE MODEL OF A PUMPING STATION

The existing prototype model of a pumping station consists of components which can be found in a real pumping station. The result of water level movement is simulated manually. A water level measurement in real pumping stations is replaced by three limit switches which show the state of water level as “higher” or “lower” than their level. The levels of the belonging KPs are marked as “low”, “medium” and “high”. Two DC engines in the model replace real pumps. The model is controlled by the PLC S7-1200 with the SCADA support. Figure 1 shows the existing prototype model of a pumping station. The existing model components which are important for the paper are the mechanical parts for water level simulation:
1 a panel for manual water level simulation

2 limit switches for water level simulation

The limit switches are connected as digital inputs and they can show four different states:
1 a level lower than “low“
2 a level higher than “low“ and lower than “medium“
3 a level higher than “medium“ and lower than “high“
4 a level higher than “high“

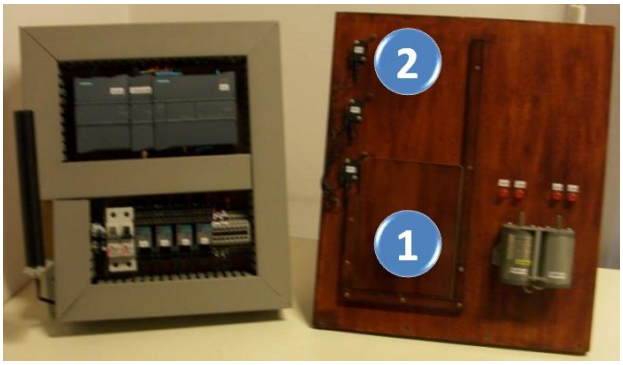

Figure 1 The exisiting prototype model of an automated pumping station

In real pumping stations the incoming water level, which the regulation is based on, is performed using an analogue signal. The pump operation is based on a regulation according to default levels which are entered by an operator. Digital inputs are performed using level switches and they also serve as a security system which takes the main regulating function if, for some reason, a level sensor falls out of the system, i.e., makes an error. Standard procedure for industrial equipment is using voltage analogue signals 0-10 V, i.e., current analogue signals 4-20 mA. Such uniformly chosen signals enable compatibility of all the equipment used in the operation. Standard procedure for input / output digital signals in industrial application is normally 24VDC, while internal intermediate circuits of a PLC device (galavanically separated from input / output connectors, inaccessible to a user) are performed on a 5VDC level.

The pump regulation is based on a “main/auxiliary“ regime, where the pumps exchange their main and auxiliary statuses in each iteration. The controller is performed in such a way that it holds water level within a certain range which is determined by an operator. In the case of the existing model the flexibility of the system is very small considering the fact that there is a difference between only four band levels instead of an exact amount of water level.

It has been established that the main drawback of the existing prototype automated pumping station is the way the water level is simulated in the station. Namely, the existing solution performs a simulation based on recognition of discrete water levels. This kind of simulation is good enough concerning the simulation of working conditions of the control system, but it is not good enough in showing the real relationship between mechanical phenomena and the actions determined by actuators, in this case water pumps. The water level is changed manually according to the rise or fall of water level with discrete levels which are precisely defined by limit switches. They also serve as a replacement for real level switches. It is necessary to create such a way of water level simulation which will continuously change the existing discrete water levels from 0 to 100 %. In this paper we devised a way which still demands a manual simulation of water level.

Two DC engines, which represent the operation of two pumps, make the power section of the existing model. In order to be able to show the possibility of using the PLC, both DC engines were reversed. A solution programme was used to solve the inhibition of energisation of both rotation directions of DC engines.

3 IMPROVEMENT OF THE PROTOTYPE MODEL OF A PUMPING STATION

The components for water level simulation were taken as finished circuits from a scanner and a printer and they were connected to a rheostat. Figure 2 shows the system for water level simulation and it consists of the following components, which are marked with a number:
1 a rounded board made of acrylic glass
2 limit switches
3 a drive motor and a spur wheel with a slider
4 a rheostat

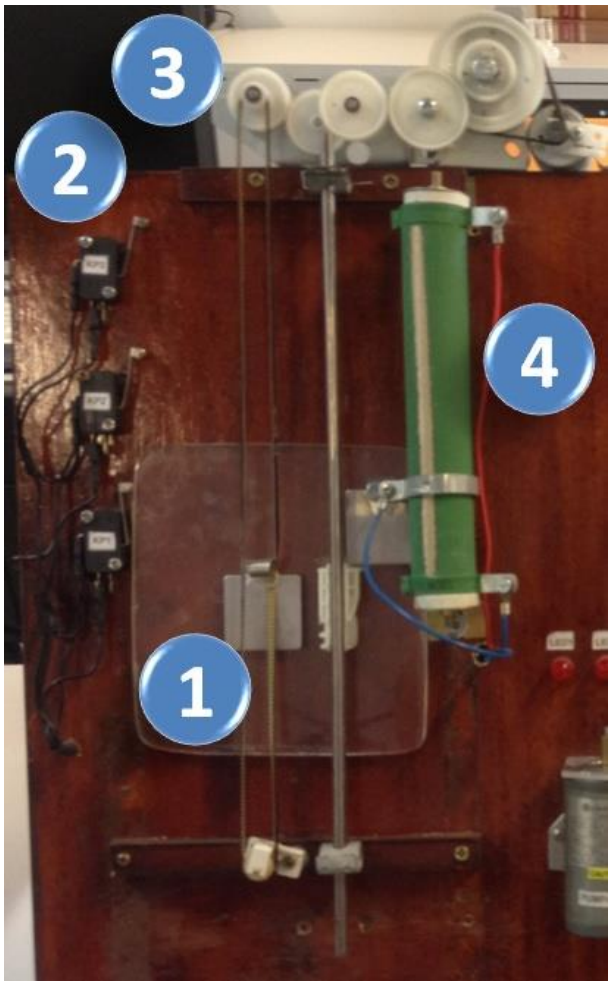

Figure 2 The improved prototype model of a pumping station

The drive part for the movement of the water level simulation system is a DC engine and the feedback is achieved using a sensor which is designed as a rheostat

and it shows water level in the shaft. Considering the fact that these are the main components of the designed system, it is necessary to know well their characteristics. These data are necessary for the pairing of the system with a control panel. The drive motor data are given for the nominal voltage value of 12 VDC and they amount to 8170 r/min and 0,89 A with developed power of 6,74 W. The rheostat data are adjusted to the signalling mode which the system is expected to work in. A linear rheostat was chosen with total resistance of 1 kΩ with ± 5 % tolerance and rated power of 100 W.

The existing wiring of the prototype model of a pumping station was upgraded with new cables and conductors. The characteristics of the wiring (group appliances, colour, sectional views) from the existing condition were preserved and used for the newly installed equipment. The cables and conductors were fixedly connected to the control panel and disconnection can be completely done on the mechanical part of the prototype model of a pumping station, as it is shown in Figure 3. The final version of the mechanical part of the prototype model of a pumping station is shown in Figure 4.

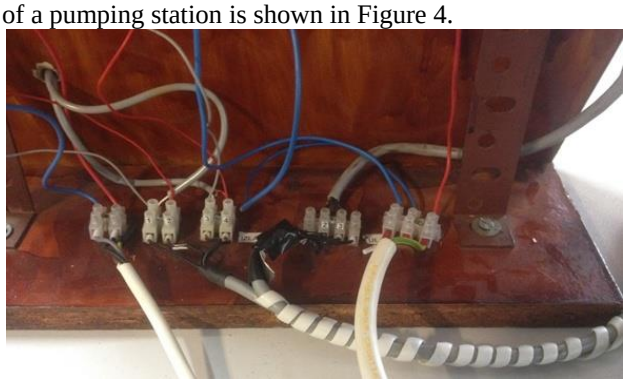

Figure 3 Wiring of the prototype model of a pumping station

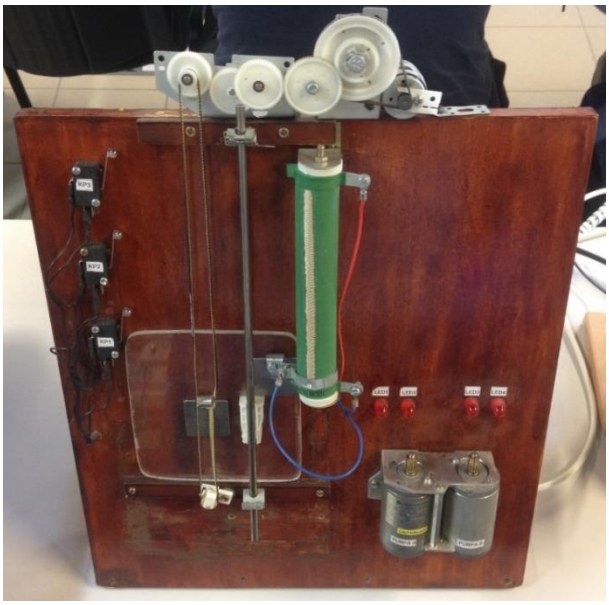

Figure 4 The final version of the prototype model of a pumping station

The power section of the DC motor supply requires reconstruction so that another reversible DC motor can be capacitated. For that reason the pump operation is rearranged in such a way that they work in one direction only, which is actually correct, and the other two relays are used for two directions of the DC drive motor for water level simulation. Minimal changes in wiring resulted in full functionality of the power section of the prototype model of a pumping station.

4 RESULTS OF THE IMPROVED PUMPING STATION MODEL IN OPERATION

The existing solution, in response to manual water level simulation using limit switches, defined four discrete levels, which were described in previous chapters. The values of water level were defined as: 5% for a level lower than "low", 15% for a level higher than "low" and lower than "medium", 55% for a level higher than "medium" and lower than "high" and 95% for a level higher than "high". Uniform lifting of the water level simulation panel in the existing solution resulted in the response to the SCADA, as it is shown in Figure 5. It is evident that the state changes at the moment when the state of the limit switches changes. It is a significant change and in one case it is 10% and in the other two cases even 40%. This kind of feedback resolution is not satisfactory.

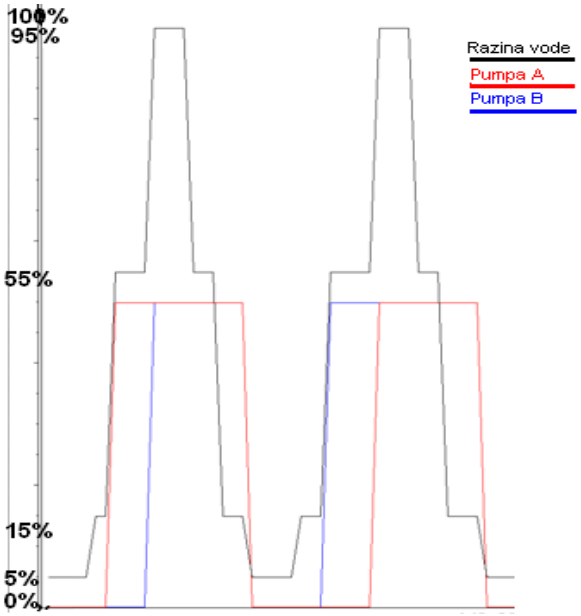

Figure 5 A graphical representation of the operation of two cycles of the existing state - high level [1]

The programme which was made for the redesigned model included a regulation of water level using pumps, a visualisation and a control of water level simulation in the pumping station. A visualisation screen which serves for the pump control and the water level simulation is shown in Figure 6 during the testing run. It is evident that the improvement had a good result and that is a continuous water level simulation. In this case the water level above the limit switch is "medium" and below the limit switch is "high", but this time the amount is not assumed to be 55%, as it is in the old solution, but in this case its actual value is measured and for the shown example it is 77%. A system operation has been recorded for the same typical scenarios as in [1]. In the first scenario there is an

incoming water flow and it is assumed that one pump is enough to pump out water. After that, a scenario is recorded in which there is an incoming water flow, but a single pump operation is not enough to reduce the water flow. Then two pumps operate together, which creates an outgoing water flow high enough to reduce the water level. Responses in Figure 7 show primarily that the water flow changes continuously, which were demanded. The testing of the scenario shows that the regulation of functionality did not change according to the old solution which faithfully described a real controller which is used in pumping stations.

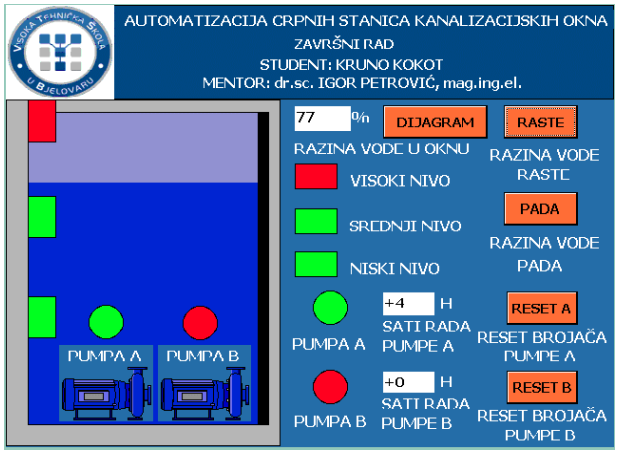

Figure 6 A SCADA screen for water level regulation

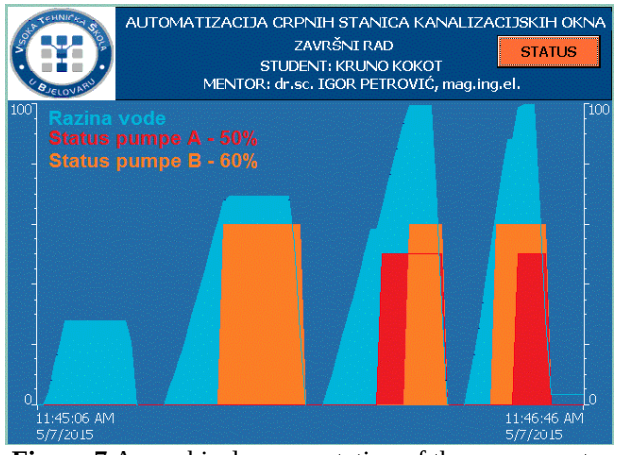

Figure 7 A graphical representation of the responses to operation scenarios of the pumping station

5 CONCLUSION

A discrete water level simulation in the pumping station, which was shown in the original prototype model of a pumping station, was good enough from the point of view of performance and testing the control programme operation and communication with SCADA.

In this paper more attention was paid to the analysis of drawbacks of the mechanical part of the prototype model and improvements were suggested and implemented. The quality of simulation of water level measurement was improved. Incorporation of new active and passive components enabled an automated rise and fall of the simulated water level and at the same time a continuous feedback to the PLC was achieved.

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PONAŠANJE ĆELIJASTE LOTUSNE STRUKTURE KOD ZAMARANJA: NUMERIČKI PRISTUP

FATIGUE BEHAVIOUR OF LOTUS-TYPE POROUS STRUCTURE: NUMERICAL APPROACH

Matjaž Šraml, Janez Kramberger, Sašo Dervarič, Srečko Glodež

Izvorni znanstveni rad

Sažetak: *Cilj ovog članka analizirati je zamornu čvrstoću ćelijaste lotusne strukture crvićastog lijevanog željeza kao osnovnog materijala. Broj ciklusa naprezanja potrebnih za širenje pukotine od inicijalne do kritične dužine pukotine određeno je numerički pomoću modela konačnih elemenata, u okviru Abaqus computation FEM koda. Kriterij maksimalnog vlačnog naprezanja razmatra se kad se analizira putanja pukotine unutar ćelijaste strukture. Izvršenje računalne analize pokazuju kako su koncentracije naprezanja oko individualnih ćelija veće kada vanjsko opterećenje djeluje u transverzalnom smjeru u odnosu na distribuciju ćelija. Članak je produljenje rada, prezentiranog na posljednjoj MATRIB konferenciji u 2014. godini [1]*

Ključne riječi: *numerička analiza, porozne strukture, zamorna čvrstoća*

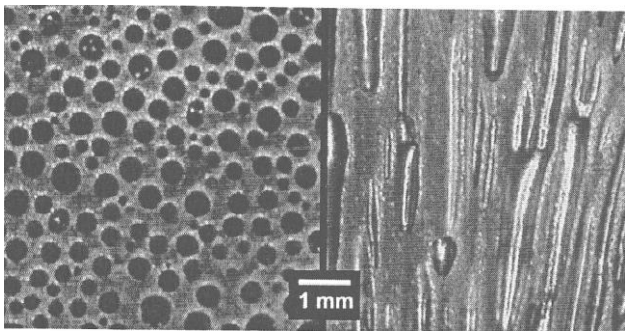
Original scientific paper

Abstract: *The objective of this paper is to analyse fatigue strength behaviour of lotus-type structure with nodular cast iron as a base material. The number of stress cycles required for crack propagation from initial to the critical crack length is numerically determined using finite element (FE) models, in the frame of Abaqus computation FEM code. The maximum tensile stress (MTS) criterion is considered when analyzing the crack path inside the porous structure. The performed computational analyses show that stress concentrations around individual pores are higher when external loading is acting in transversal direction in respect to the pore distribution. The actual paper is prolongation of the work, presented at the last MATRIB conference in 2014 [1]*

Key words: *Lotus-type porous structures, fatigue strength, numerical analysis.*

1. INTRODUCTION

Lotus-type is a new type of porous material which comprises unidirectional pores. This makes the lotus-type materials very useful for application in lightweight structures, medicine, automotive engineering, sports equipment, etc. [2]. The porosity of lotus metals is usually lower than 70 %, which is lower if compare to some conventional porous metals where porosity is often higher than 70 % [3]. Moreover, pores of lotus-type metals are cylindrical, where the length of pores is usually large if compare to pore diameter (Fig. 1). Since the stress field around the pores depends on the loading direction, the relative high level of anisotropy is typical for lotus-type materials. While uniform stress distribution appears in the case when loading is acting along longitudinal direction of pores, the relative high stress concentration around the pores is characteristic for the perpendicular loading direction.



(a) (b)

Figure 1. Cross section of lotus-type porous iron in transversal (a) and longitudinal (b) direction [2].

When porous material is used as a structural element, the fatigue behaviour of such porous structure should be known. Some investigations regarding fatigue behaviour of aluminium porous structures have been reported in [4-6].

However, these results can not be used for lotus-type porous materials due to different pore shapes and their orientations. Seki et al [3, 7, 8] have been studied the fatigue behaviour of cooper and magnesium lotus-type porous structures where the effect of porosity, anisotropic pore structure, and pore size distribution have been taken into account. Their experimental research has shown that for the fatigue loading parallel to the longitudinal axis of pores the stress field in the matrix is homogeneous and slip bands appear all over the specimen surface. This is not the case for transverse loading, where stress field is inhomogeneous and slip bands are formed only around pores because of high stress concentration in this region. Lately, some research works on metal foams have already been done at the University of Maribor [9-11]. However, these materials have not been fully characterized yet, particularly in the way of fatigue life behaviour.

In the present paper, the fatigue process of lotus-type material is divided into the crack initiation and crack propagation phase, where the total service life of treated structural element equals:

$$N = N_{\mathrm{i}} + N_{\mathrm{p}}, \tag{1}$$

where N_{i} is the number of loading cycles required for the fatigue crack initiation and N_{p} is the number of loading cycles required for the crack propagation from initial to the critical crack length when final fracture can be expected to occur.

When determining the crack initiation phase N_{i}, the strain life approach with consideration of simplified universal slope method [19] has been used

$$\varepsilon_{\mathrm{a}} = 0.623 \cdot \left(\frac{R_{\mathrm{m}}}{E}\right)^{0.832} \cdot (2N_{\mathrm{i}})^{-0.09} + 0.0196 \cdot (\varepsilon_{\mathrm{f}})^{0.155} \cdot \left(\frac{R_{\mathrm{m}}}{E}\right)^{-0.53} \cdot (2N_{\mathrm{i}})^{-0.56} \tag{2}$$

where ε_{a} is the total strain amplitude, R_{m} is the ultimate tensile strength, E is the modulus of elasticity and ε_{f} is the true fracture strain. It is evident from Eq. (2) that the two exponents are fixed for all metals and that only monotonic material properties R_{m}, E and ε_{f} control the fatigue behavior.

The crack propagation phase in this paper is described using Paris equation

$$\frac{\mathrm{d}a}{\mathrm{d}N} = C \cdot \Delta K^{m} \tag{3}$$

where $\mathrm{d}a/\mathrm{d}N$ is the crack growth rate, ΔK is the stress intensity factor range ($\Delta K = K_{\max} - K_{\min}$), and C and m are the material parameters which are determined experimentally according to the load ration $R = K_{\min}/K_{\max}$ (the value R=0.1 has been considered in this study). The number of loading cycles N_{p} required for the crack propagation from initial crack length a_{i} to the critical crack length a_{c} can then be determined with integration of Eq. (3):

$$\int_0^N \mathrm{d}N = \frac{1}{C} \int_{a_{\mathrm{i}}}^{a_{\mathrm{c}}} \frac{\mathrm{d}a}{\Delta K(a)} \tag{4}$$

2. COMPUTATIONAL MODEL

In publications [2, 11] the regular models with aligned or for some angle aligned pores have been used when determining the strength behavior of lotus-type porous material. In these studies, the used computational models are built of multiple representative volume elements (RVEs) which are presented by a square block with central cylindrical hole of diameter d. The porosity of such structure is then regulated with change of pore diameters by keeping the size of the RVEs as a constant value [2]. In our study, the irregular pores distribution of lotus-type material is considered where only pore distribution in transversal direction is assumed. A special image recognition code was developed, which was used to convert the chosen lotus-type material cross section image into the CAD model which is then used to create the appropriate numerical model. The transverse computational model by square cross section of treated porous structure with length of 3.3 mm and randomly distributed pores with minimum and maximum diameters $d_{\min}$ = 0.084 mm and $d_{\max}$ = 0.47 mm, is introduced, respectively (Fig. 2). For such pores distribution, the porosity is equal to 36 %. The boundary conditions are presented as displacement value of 0.01 mm at the top edge and fixed restraints in the bottom edge of used computational model (Fig. 2).

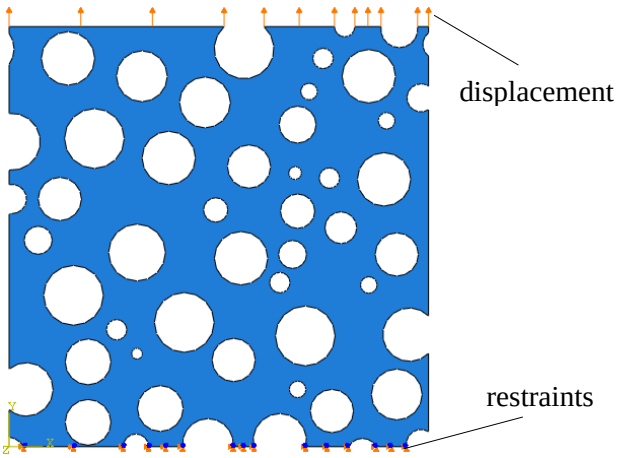


Figure 2. 2D computational model for pores distribution in transversal direction.

In performed computational analyses the lotus-type structure is made of nodular cast iron EN-GJS-400-18-LT as a base material, with monotonic material properties presented in Table 1. The true stress-strain behavior of material (Fig. 3), which is needed for determining the crack initiation phase N_{i}, is assumed.

Table 1. Monotonic material properties of nodular cast iron EN-GJS-400-18-LT [12]

Yield strength	Ultimate tensile strength	True fracture strain	Modulus of elasticity	Poisson's ratio
R_e [MPa]	R_m [MPa]	ε_f [–]	E [MPa]	ν [–]
256	417	0.235	$1.82 \cdot 10^5$	0.33

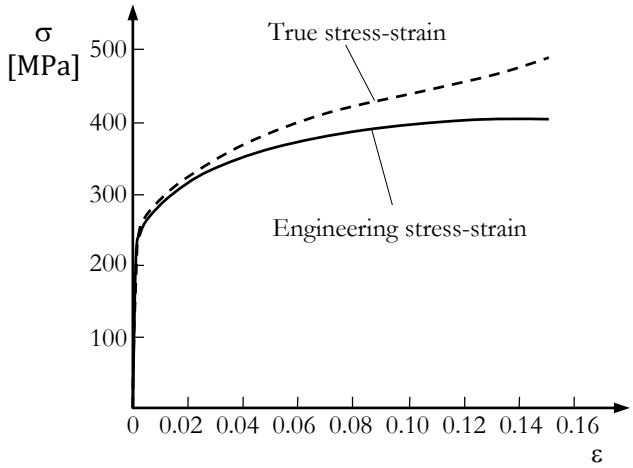


Figure 3. True stress-strain curve of base material [12].

3. NUMERICAL ANALYSIS

Computational models were discretized with quadratic finite elements with linear interpolation. Previous verification of required finite element size has also been done in respect to the results convergence with relative error 0.05. Figure 4 shows the 2D FE-mesh for treated porouos structure.

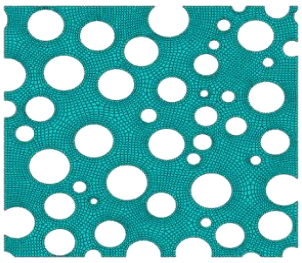
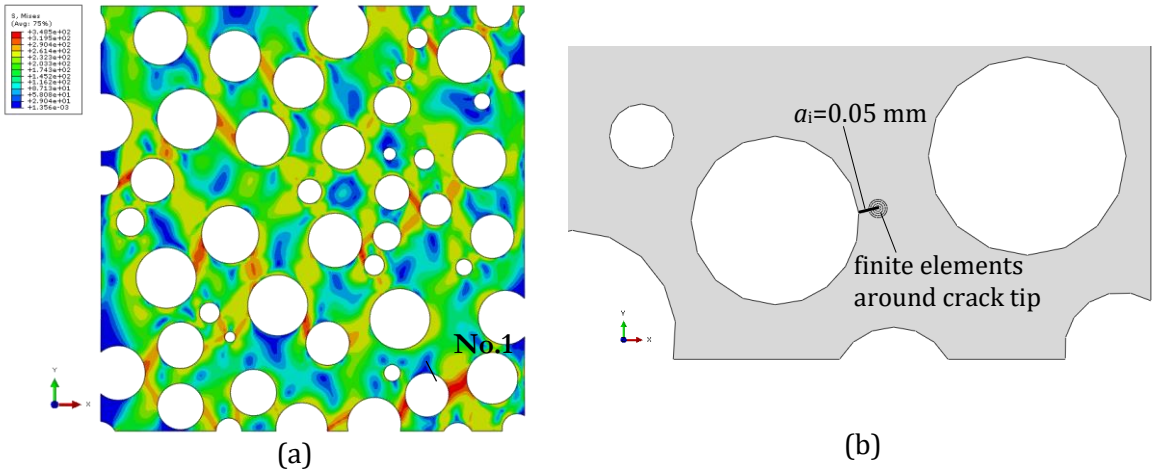


Figure 4. 2D FE-mesh

3.1. Crack initiation phase

When studying the crack initiation phase, the stress filed around individual pores and location of the maximum stress concentration should be determined first. The maximum von Mises equivalent stress $\sigma_M = 350$ MPa with the appropriate total strain $\varepsilon = 0.022$ are recognized in a cross section No. 1 (Fig. 5 (a)). Considering the pulsating loading ($\varepsilon_a = \varepsilon/2 = 0.011$) and material properties as presented in Table 1, the number of loading cycles N_i required for the fatigue crack initiation is then calculated according to Eq. (2). In the next step, the initial crack $a_i = 0{,}05$ mm is added into the critical cross section No. 1 (Fig. 5 (b)) and the numerical procedure is continued with the crack propagation phase. When the fatigue crack reaches the critical length, the complete fracture of cross section No. 1 occurs which mean that two neighboring pores are connected with a seam and the complete procedure is repeated regarding to the other critical cross section.



(a) (b)

Figure 5. Crack initiation phase: (a) maximum stress concentration in a cross section No. 1 and (b) initial crack in a cross section No. 1.

3.2. Crack propagation phase

The crack initiation period of each critical cross section is finished with the formation of initial crack of length a_i after the appropriate number of stress cycles N_i. The crack propagation period is then analyzed using Paris equation (3), where the following material parameters have been considered [12]:

$$C = 4.608 \cdot 10^{-12} \frac{\text{m/cycle}}{(\text{MPa}\sqrt{\text{m}})^{3.86}}; \qquad \text{m} = 3.86;$$

$$\Delta K_{th} = 20.8\ \text{MPa}\sqrt{\text{m}}; \quad \Delta K_{Ic} = 30.4\ \text{MPa}\sqrt{\text{m}}.$$

Than, the stress intensity factor is determined using Abaqus FEM software, where the equivalent stress intensity range ΔK_{eq} as a combined value of mixed mode conditions ΔK_I and ΔK_{II} has been considered. To analyse the fatigue crack growth under mixed mode conditions the value ΔK in Eq. (3) has to be replaced with the value ΔK_{eq}. The crack propagation angle is in each calculating step determined using maximum tensile stress (MTS) criterion. The analysis of crack propagation has been stopped when the equivalent stress intensity factor range ΔK_{eq} exceeded the critical value ΔK_{Ic} or when the crack reached the vicinity of neighboring pore. At that moment it was assumed that two neighboring pores are connected with a seam and the computational procedure was continued with the crack initiation period in other critical cross section. Figure 6 shows the numerical procedure of crack propagation in a cross section No. 1.

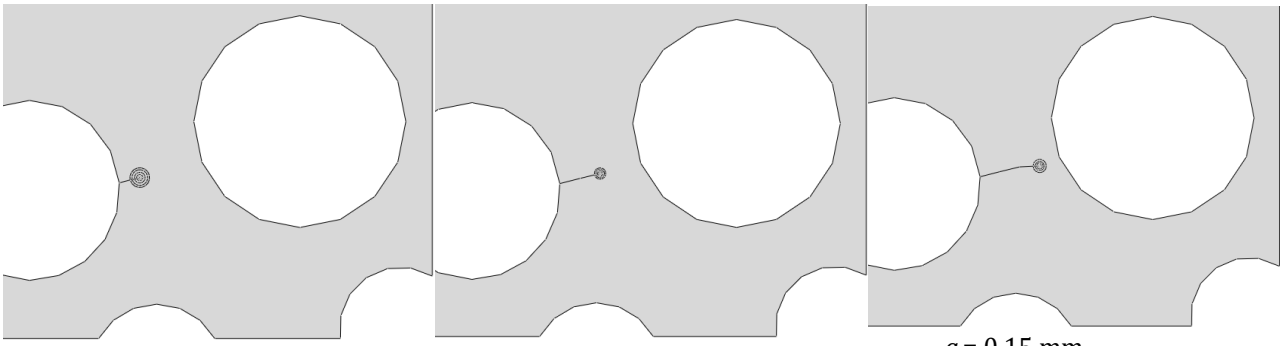


Figure 6. Schematic procedure of crack propagation period in a cross section No. 1.

4. DISCUSSION OF THE RESULTS

Figure 7 shows the numbering of critical cross sections where both, crack initiation and crack propagation period have been studied. The maximum stress concentration appeared, firstly, in cross section No. 1 where initial failure occurred after certain number of stress cycles (N_i = 472 cycles for formation of initial crack of length a_i = 0.05 mm and N_p = 212 cycles for this initial crack to propagate until critical length a_c = 0.15 mm). Thereafter, the complete computational procedure is repeated in a cross section No. 2, where the maximum stress concentration occurred in the next calculating step. Here, the seam between neighboring pores in a cross section No. 1 is considered during the numerical analyses. As shown in Figure 7, seven subsequent cross sections have been analyzed in respect to the crack initiation and crack propagation period in treated lotus-type porous structure with pore distribution in transversal loading direction. The final computational results are presented in Tables 2 and 3. The appropriate total number of stress cycles according to Eq. (1) can then be assumed as a total fatigue life of treated structure.

Table 2. Computational results for the crack initiation phase

Cross section No.	Von Mises equivalent stress	Total strain amplitude	Crack initiation phase	Initial crack length
	σ_M [MPa]	ε_a	N_i [cycles]	a_i [mm]
1	350	0.0110	472	0.05
2	378	0.0229	110	0.03
3	344	0.0136	307	0.03
4	336	0.0121	387	0.03
5	327	0.0108	489	0.03
6	326	0.0200	495	0.03
7	304	0.0090	731	0.03

Table 3. Computational results for the crack propagation phase

Cross section No.	Initial crack length	Critical crack length	Function	Crack propagation phase
	a_i [mm]	a_c [mm]	ΔK_{eq} = f(a)	N_p [cycles]
1	0.05	0.15	4E+08a^2+35734a+13.171	212
2	0.03	0.09	1E+09a^2+40056a+14.989	113
3	0.03	0.09	1E+09a^2+115195a+6.629	350
4	0.03	0.19	-4E+08a^2+139479a+6.189	1109
5	0.03	0.13	3E+08a^2+113530a+12.203	162
6	0.03	0.13	-5E+08a^2+119507a+10.049	519
7	0.03	0.11	-5E+07a^2+17932a+11.267	1099

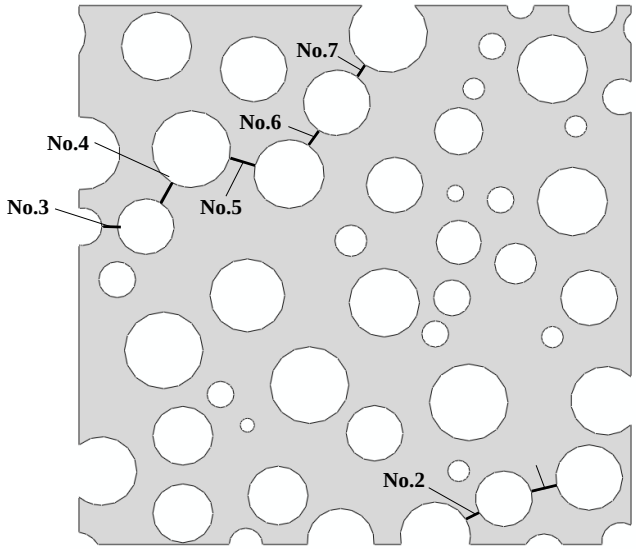


Figure 7. Numbering of critical cross sections.

4. CONCLUSION

The computational fatigue strength investigation in respect to the crack initiation and crack propagation in dynamic loaded lotus-type porous structure made of nodular cast iron is discussed in this paper. The crack initiation period, Ni, has been determined using strain life approach with consideration of simplified universal slope method to determine the number of stress cycles, Ni, required for formation of initial cracks. The crack propagation period, Np, has been determined using Paris equation, where the relationship between the stress intensity factor and crack length has been determined using Abaqus FEM software. Here, the MTS criterion has been considered when analyzing the crack path inside the lotus-type porous structure. The crack initiation and crack propagation period have been studied in seven subsequent critical cross sections between different pores as shown in Figure 7. The total fatigue life, N, of the lotus-type porous structure under given boundary conditions has then been determined as a sum of Ni and Np for all considered cross sections.

Computational results for the pores distribution in the transversal direction have shown that the number of stress cycles for the crack initiation in the individual cross sections varied between 307 and 731, while the number of stress cycles for the crack propagation until final breakage of individual cross section varied between 113 and 1109, which correspond to the regime of low cycle fatigue. Computational results have also shown that quite uniform stress distribution appears in the case when loading is acting along longitudinal direction of pores. Therefore, the appropriate longer fatigue life could be expected in that case.

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3D OBLIKOVANJE I PRORAČUN KUĆIŠTA VIJČANE PUMPE

3D DESIGN AND CALCULATION OF A SCREW PUMP HOUSING

Božidar Hršak, Ante Čikić, Tajana Vaško, Igor Čusek

Stručni članak

Sažetak: *Prikazano je 3D oblikovanje i proračun kućišta trovretene vijčane pumpe na temelju postojeće 2D radioničke dokumentacije u lijevanoj izvedbi. Izrađen je kontrolni proračun debljine stjenke kućišta trovretene vijčane pumpe za materijale SL–25, NL–42, AlSiMg i ispitni tlak 1,5 MPa (15 bara). Svi 3D modeli pozicija, sklop i ″generirana″ 2D radionička dokumentacija izrađeni su u programskom alatu SolidWorks naprednim tehnikama 3D oblikovanja. U programskom modulu Solidworks Simulation provedene su analize naprezanja kućišta trovretene vijčane pumpe Finite Element Analysis – FEA za materijale: SL–25 , NL–42 i AlSiMg koje su potvrdile točnost provedenog kontrolnog proračuna, te analiza toka strujanja fluida u 3 modelu sklopa trovretene vijčane pumpe. Pomoću 3D pisača MakerBot Replicator 2X primjenom FDM tehnologije taložnog očvršćivanja materijala izrađen je umanjeni 3D model sklopa trovretene vijčane pumpe. Istaknuta je praktična primjenjivost unapređenja i razvoja vijčanih pumpi.*

Ključne riječi: *Analiza naprezanja kućišta, analiza toka strujanja fluida, kućište trovretene vijčane pumpe, proračun debljine stjenke kućišta, 2D radionička dokumentacija, 3D oblikovanje*

Professional paper

Abstract: *Shown is the 3D design and calculation of a three-spindle screw pump housing based on existing 2D workshop documentation of a cast version of the housing construction. A control calculation of the thickness of the wall of the housing of the three-spindle screw pump has been made for materials SL–25, NL–42, AlSiMg and test pressure of 1,5 MPa (15 bars). Each 3D model of positions, assemblies and generated 2D workshop documentation are made in the software tool SolidWorks with advanced techniques of 3D modelling. In the software module SolidWorks Simulation stress analysis of the housing of a three-spindle screw pump was performed, that is, Finite Element Analysis – FEA for materials SL–25 , NL–42 and AlSiMg, that confirmed the accuracy of the calculations made, and the analysis of the fluid flow of the 3D model of the assembly of the three-spindle screw pump. With help of the 3D printer MakerBot Replicator 2X with application of FDM technology of sedimentary hardening of materials, a miniature 3D model of the assembly of the three-spindle screw pump was created. The practical application of the improvement and development of screw pumps is emphasized.*

Key words: *Stress analysis of housing, Fluid flow analysis, Housing of a three-spindle screw pump, Calculation of wall thickness of housing, 2D workshop documentation, 3D modelling*

1. INTRODUCTION

The application of screw-like machine elements for medium flow is dating from the third century B.C. and is attributed to the Greek philosopher Archimedes. Screw pumps of simple construction with a screw positioned inside a pipe were used for pumping water out of canals with the purpose of watering. Today, screw pumps with one, two or three spindles are produced and only have one driving shaft, while the synchronous rotational speed in two-spindle pumps is achieved with a pair of the same gear wheels, whereas in three-spindle pumps with the pressure of the working medium. Inside one-spindle screw pumps, alteration of the volume of the working space is established with periodical changes of the space between the inner wall of the housing and the rotor, while the rotor is spinning [1].

One-spindle screw pump (Figure 1.) has only one rotating element, and is mostly used in pharmacy, food and chemical industry.

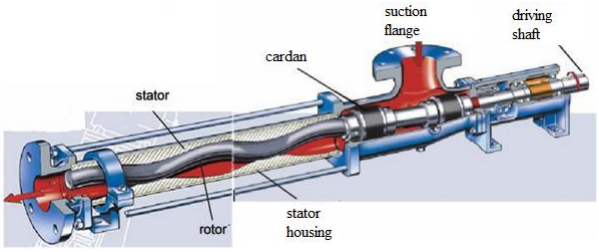

Figure 1. One-spindle screw pump [2]

Two-spindle screw pumps are divided into one-flow and two-flow pumps. This pump drives the medium away in one axial direction, just as the one-spindle screw pump.

On Figure 2. the one-flow two-spindle screw pump is shown.

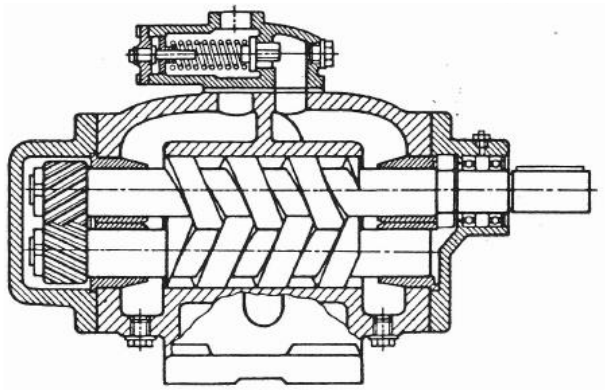

Figure 2. One-flow two-spindle screw pump [1]

The two-flow two-spindle screw pump (Figure 3.) separates the medium in the suction box into two parts that are lead off to the outer parts of the pump screws. With the spinning of the screws, the part of the medium that was lead off to the left side, is driven from the left to the centre of the pump, where it is brought together with the part that was driven to the right at the suction box, and is lead out of the screw pump through the flange.

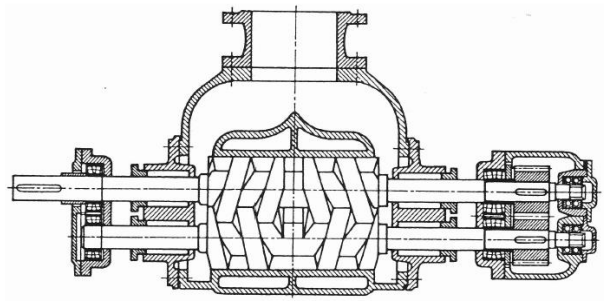

Figure 3. Two-flow two-spindle screw pump [1]

With the goal of optimisation of the existing product, the control calculation of the wall thickness of the housing is shown for the test pressure 1,5 MPa (15 bars) and housing materials SL–25, NL–42, and AlSiMg, and 3D modelling of parts and assembly of a three-spindle screw pump based on existing 2D documentation of a cast version of the housing construction. Applying reverse engineering, in the software tool *SolidWorks*, a 3D model of the assembly of the three-spindle screw pump is created, with all the positions, and with the *Exploded View* feature, the exploded 3D model of the three-spindle screw pump is displayed. In the software module *SolidWorks Simulation*, stress analysis (*Finite Element Analysis – FEA*) and safety factor analysis (*Factor Of Safety - FOS*) are performed for the housing of the pump at the test pressure 1,5 MPa (15 bars) and materials: SL–25, NL–42 and AlSiMg, and the analysis of the fluid flow of the 3D model of the assembly of the three-spindle screw pump.

2. THREE-SPINDLE SCREW PUMP

The three-spindle screw pump contains three spindles, of which one is the guide spindle, and the other two are guided. The guide and guided spindles are positioned inside the liner in which they rotate and form transporting chambers. With the rotation of the spindles, the helixes close the transporting chambers, take hold of the medium in the suction box, and continuously „drag“ the medium along the spindle axis and push it into the pressure chamber of the housing of the pump. The helixes of the spindles are two-stroked and their surface is designed so that it ensures fine sealing between the guide and guided spindles, and between the spindles and liner. The guide spindle transfers the load and is mostly driven by electro- or pneumatic motor, while the guided spindles hinder the back flow of the liquid from the pressure chamber into the suction chamber and are used for sealing inside the pump [3].

Figure 4. displays the schematic view of the spindles inside the liner of the three-spindle screw pump.

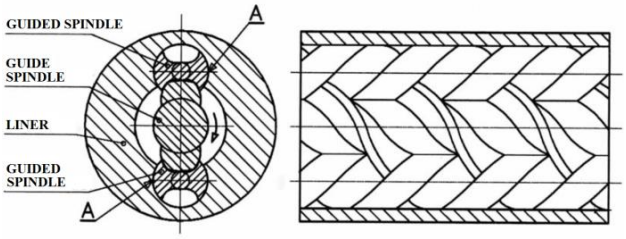

Figure 4. Schematic view of the spindles inside the liner of the three-spindle screw pump [3]

Three-spindle screw pumps are designed in an „H“ construction with the input and output on the same axes, or „S“ construction with the input and output on parallel axes [4]. Also, they can be constructed horizontally (Figure 5.) or vertically (Figure 6.).

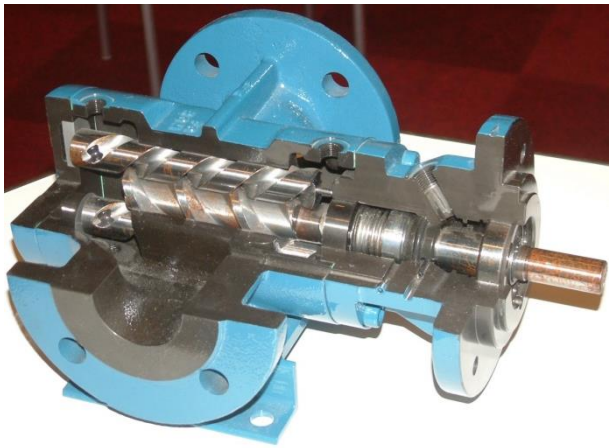

Figure 5. Cross-section of a horizontal construction of the three-spindle screw pump [5]

Figure 6. Vertical construction of the three-spindle screw pump [6]

Three-spindle screw pumps are used as transfer or fuel dosing pumps, oil pumps, oil pumps in main or auxiliary motors, oil and fuel separators, and as hydraulic system pumps for pressures up to 8 MPa [3]. Media in the pumps are gasoline and heavy fuel oils, lubricants and hydraulic oils, and other self-lubricating and nonaggressive fluids.

The flow rate of three-spindle screw pumps totals 50 to 560 litres per minute, while the working temperature goes from 20 to 180 °C with the working pressure of 10 bars [4].

Table 1. displays common characteristics of one-, two-, and three-spindle screw pumps.

Table 1. Common characteristics of one-, two- and three-spindle screw pumps [7]

Pump type	Desirable application	Common characteristics
One-spindle screw pump	Fluids that contain solids	Self-priming Good suction capacity Not sensitive to viscosity Weak pulsation Almost noiseless functioning Safe handling Low susceptibility to dirt
Two-spindle screw pump	Fluids with or without lubricating characteristics, Fluids that contain air or gas	
Three-spindle screw pump	Media with lubricating characteristics, high pressure and noiseless functioning	

3. CONTROL CALCULATION OF THE WALL-THICKNESS OF THE HOUSING OF THE THREE-SPINDLE SCREW PUMP

Based on the existing 2D workshop documentation for a cast construction, a control calculation of the wall-thickness of the housing of the three-spindle screw pump is performed for the test pressure of 1,5 MPa (15 bars) and housing materials: SL–25 , NL–42 and AlSiMg.

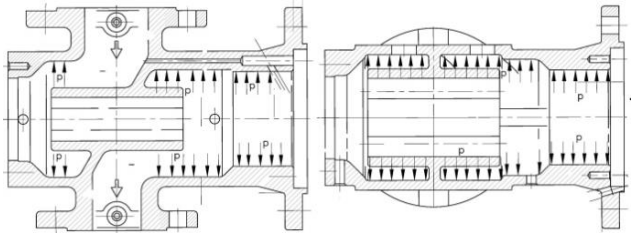

Figure 7. Housing of the three-spindle screw pump

Test pressure 1,5 MPa (15 bars) and housing material of the three-spindle screw pump SL – 25 [8]:

$$\delta_o = \frac{p \cdot d}{200 \cdot \sigma_{dop}} \quad \text{mm,} \tag{1}$$

$$C = 6 \cdot \left(1 - \frac{p \cdot d}{27500}\right) \quad \text{mm,} \tag{2}$$

$$\delta = \delta_o + C \quad \text{mm,} \tag{3}$$

whereat:

δ_o - theoretical thickness of the housing wall, = 1,50 mm,

δ - real thickness of the housing wall, = 7,11 mm,

p - test pressure, = 15 kp/cm^2,

d - nominal diameter, = 120 mm,

σ_{dop} - allowable stress, = 6 kp/mm^2 SL-25 [9]

C - addition due to inaccuracies in production, = 5,61 mm.

Acquired wall thickness of the pipe of the housing of the tree-spindle screw pump δ = 7 mm.

Test pressure 1,5 MPa (15 bars) and housing material of the three-spindle screw pump NL – 42 [8]:

Relations (1), (2) and (3) are used, whereat:

δ_o - theoretical thickness of the housing wall, = 0,97 mm,

δ - real thickness of the housing wall, = 6,58 mm,

p - test pressure, = 15 kp/cm^2,

d - nominal diameter, = 120 mm,

σ_{dop} - allowable stress, = 9,3 kp/mm^2 NL-42 [9]

C - addition due to inaccuracies in production, = 5,61 mm.

Acquired wall thickness of the pipe of the housing of the tree-spindle screw pump δ = 6,5 mm.

Test pressure 1,5 MPa (15 bars) and housing material of the three-spindle screw pump AlSiMg [8], according to relations (1), (2) and (3), whereat:

δ_o - theoretical thickness of the housing wall, = 3 mm,
δ - real thickness of the housing wall, = 8,61 mm,
p - test pressure, = 15 kp/cm^2,
d - nominal diameter, = 120 mm,
σ_{dop} - allowable stress, = 3 kp/mm^2 AlSiMg [9]
C - addition due to inaccuracies in production, = 5,61 mm.

Acquired wall thickness of the pipe of the housing of the tree-spindle screw pump δ = 8,5 mm.

4. CONSTRUCTION OF THE 3D MODEL OF PARTS AND ASSEMBLY OF THE THREE-SPINDLE SCREW PUMP

Based on the existing 2D workshop documentation of the cast version of the housing of the three-spindle screw pump the sketch of the mounting flange with the diameter ∅230 mm is created, and material is added with the *Extruded Boss/Base* feature (Figure 8.).

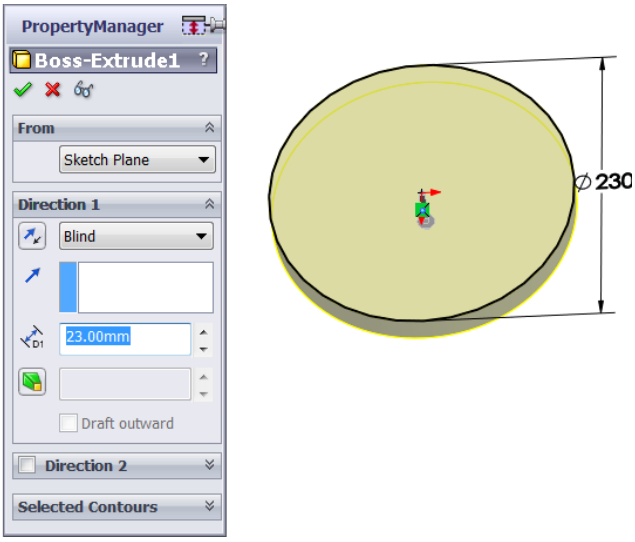

Figure 8. 3D modelling of the mounting flange with adding material through the *Extruded Boss/Base* feature

With help of the feature for advanced 3D modelling and the feature for final rendering, the housing of the three-spindle screw pump was created (Feature 9.).

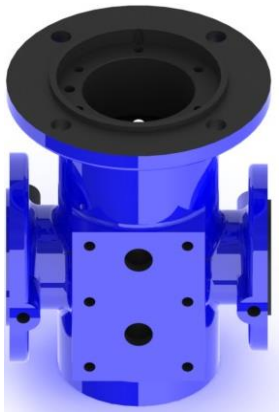

Figure 9. Rendered (photorealistic) depiction of the 3D model of the three-spindle screw pump

The process of 3D modelling of the guide spindle of the three-spindle screw pump starts with creating the sketch and adding material with the *Extruded Boss/Base* feature (Figure 10.).

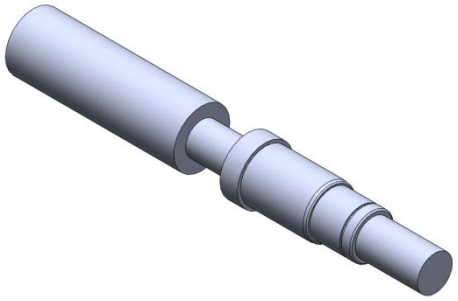

Figure 10. Initial 3D model of the guide spindle of the three-spindle screw pump with the feature *Extruded Boss/Base*

With help of the feature for advanced 3D modelling and the feature for final rendering (*Final Render*) a rendered (photorealistic) 3D model of guide spindle (Figure 11.) and guided spindle (Figure 12.) are created.

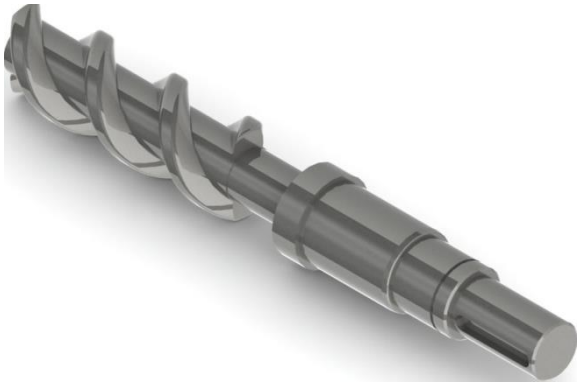

Figure 11. Rendered (photorealistic) display of the 3D model of the guide spindle of the three-spindle screw pump

Figure 12. Rendered (photorealistic) display of the 3D model of the guided spindle (left helix) of the three-spindle screw pump

In a similar way, the other parts that the assembly of the three-spindle screw pump contains are designed (ring, bearing, housing lid, separator, distance ring, carrier, seal). After modelling of all the needed parts, the assembling is performed (Figure 13. and 14.).

Figure 13. Photorealistic display of the 3D model of the assembly of the three-spindle screw pump

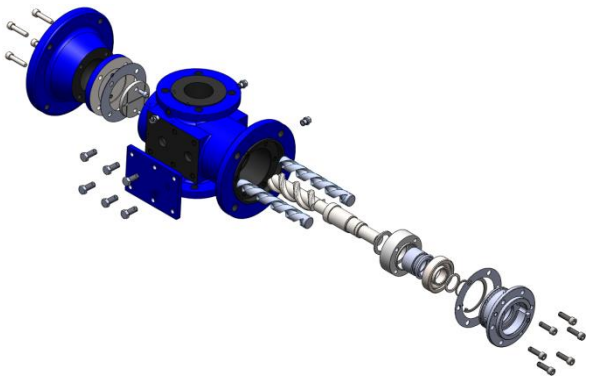

Figure 14. *Exploded View* of the 3D model of the assembly of the three-spindle screw pump

5. 3D PRINTING OF THE ASSEMBLY MODEL OF THE RETURN FLAP VALVE WITH LEVER AND WEIGHT

3D printing of the model of the three-spindle screw pump (Figure 15.) is achieved with the FDM technology of sedimentary hardening of materials with the 3D printer *MakerBot Replicator 2X*.

Figure 15. Finished (miniature) 3D model of the assembly of the three-spindle screw pump created by the 3D printer *MakerBot Replicator 2X*

6. STRESS ANALYSIS (FINITE ELEMENT ANALYSIS – FEA) OF THE HOUSING OF THE THREE-SPINDLE SCREW PUMP

The stress analysis (*Finite Element Analysis - FEA*) of the housing of the three-spindle screw pump is performed in the program module *SolidWorks Simulation* based on the control calculation of the wall thickness of the housing for the test pressure 1,5 MPa (15 bars) and materials SL–25, NL–42 and AlSiMg.

On Figures 16. and 17. are results of the stress analysis (*Finite Element Analysis - FEA*) and safety factor calculation (*Factor Of Safety - FOS*) displayed for the housing of the three-spindle screw pump for the test pressure 1,5 MPa (15 bars), wall thickness of the housing $\delta = 7$ mm and material SL – 25.

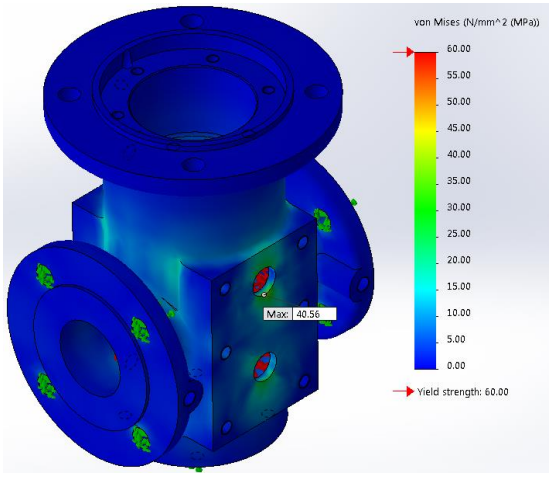

Figure 16. Results of the stress analysis of the housing of the three-spindle screw pump with the test pressure 1,5 MPa (15 bars), wall thickness $\delta = 7$ mm and material SL – 25

Results of the performed analysis for the material SL – 25 confirm that the nominal stress of the housing of the three-spindle screw pump (Figure 16.) is considerably lower than the allowed stress for the material SL–25 that is mentioned in chapter 3., which amounts to $\sigma_{dop} = 60\,N/mm^2$, so that it is established that the initial control calculation of the wall thickness of the housing of the three-spindle screw pump is accurate, which is visually and numerically displayed on Figure 16.

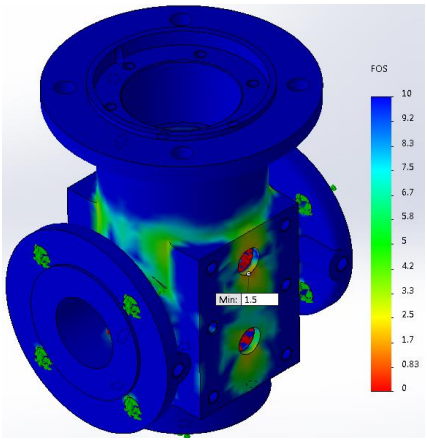

Figure 17. Factor of safety of the three-spindle screw pump with the test pressure 1,5 MPa (15 bars), wall thickness $\delta = 7$ mm and material SL – 25

Additionally, the analysis of the safety factor of the three-spindle screw pump (*Factor of Safety – FOS*) for the given test pressure 1,5 MPa is performed. The gained results show that the minimal safety factor (*Factor Of Safety – FOS*) amounts to 1,5; and for the other parts is significantly larger which is visually and numerically displayed on Figure 17., so that it can be concluded that the housing can endure even higher working pressure than the test pressure.

Figures 18. and 19. display the results of the stress analysis (*Finite Element Analysis - FEA*) and safety factor analysis (*Factor Of Safety - FOS*) of the housing of the three-spindle screw pump for the test pressure 1,5 MPa (15 bars), wall thickness $\delta = 6,5$ mm and material NL – 42.

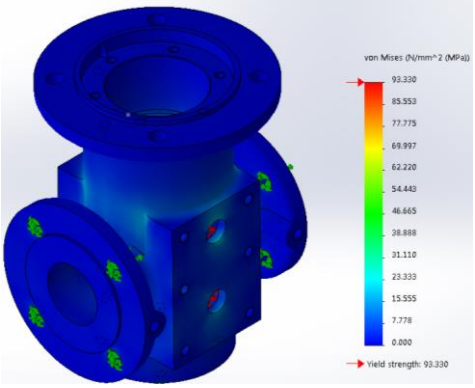

Figure 18. Results of the stress analysis of the housing of the three-spindle screw pump with the test pressure 1,5 MPa (15 bars), wall thickness $\delta = 6,5$ mm and material NL – 42

Results of the performed analysis for the material NL – 42 also confirm that the nominal stress of the housing of the three-spindle screw pump (Figure 18.) is considerably lower than the allowed stress for the material NL – 42 that is mentioned in chapter 3., which amounts to $\sigma_{dop} = 93N/mm^2$, so that it is established that the initial control calculation of the wall thickness of the housing of the three-spindle screw pump is accurate, which is visually and numerically displayed on Figure 18.

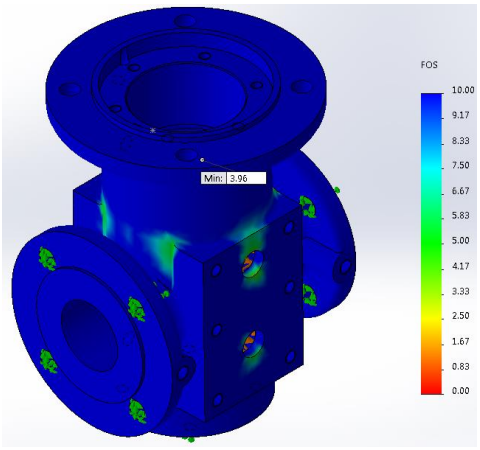

Figure 19. Factor of safety of the three-spindle screw pump with the test pressure 1,5 MPa (15 bars), wall thickness $\delta = 6,5$ mm and material NL – 42

The gained results show that the minimal safety factor (*Factor Of Safety – FOS*) of the heaviest loaded parts of the housing amounts to 3,96 ; and for the other parts is significantly larger which is visually and numerically displayed on Figure 19., so that it can be concluded that the housing can endure an even higher working pressure than the test pressure.

On Figures 20. and 21. are results of the stress analysis (*Finite Element Analysis - FEA*) and safety factor calculation (*Factor Of Safety - FOS*) displayed for the housing of the three-spindle screw pump for the test pressure 1,5 MPa (15 bars), wall thickness of the housing $\delta = 8,5$ mm and material AlSiMg.

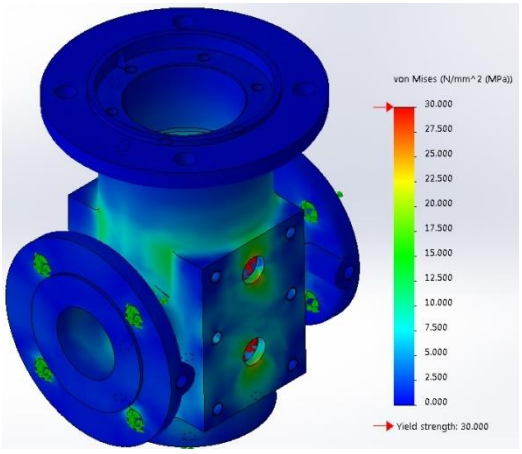

Figure 20. Results of the stress analysis of the housing of the three-spindle screw pump with the test pressure 1,5 MPa (15 bars), wall thickness $\delta = 8,5$ mm and material AlSiMg

Results of the performed analysis for the material AlSiMg confirm that the nominal stress of the housing of the three-spindle screw pump (Figure 20.) is considerably lower than the allowed stress for the material AlSiMg that is mentioned in chapter 3., which amounts to $\sigma_{dop} = 30\,\mathrm{N/mm^2}$, so that it is established that the initial control calculation of the wall thickness of the housing of the three-spindle screw pump is accurate, which is visually and numerically displayed on Figure 20.

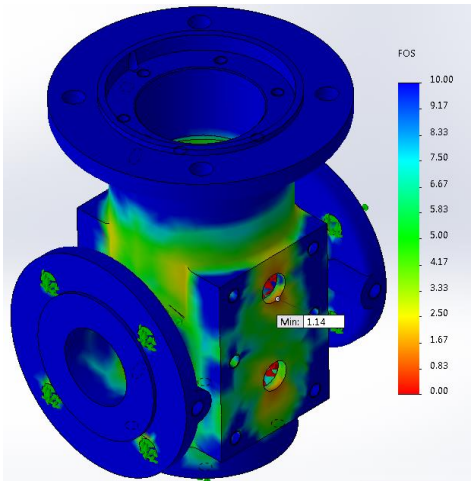

Figure 21. Factor of safety of the three-spindle screw pump with the test pressure 1,5 MPa (15 bars), wall thickness $\delta = 8,5$ mm and material Al.Si.Mg NL – 42

The gained results show that the minimal safety factor (*Factor Of Safety – FOS*) of the heaviest loaded parts of the housing amounts to 1,14 ; and for the other parts is significantly larger which is visually and numerically displayed on Figure 21., so that it can be concluded that the housing can endure even higher working pressure than the test pressure.

8. FLUID FLOW ANALYSIS (FLOW SIMULATION)

The analysis of the fluid flow in the 3D model of the assembly of the three-spindle screw pump is performed in the program module *SolidWorks Flow Simulation*. Whereat, the flanges of the housing of the three-spindle screw pump are closed with *Lids* that are used to define the input and output parameters with the *Boundary Conditions* feature. On the input flange, a volume flow rate of 0,000935 m^3/s is given, and on the output flange the atmospheric pressure of 0,1 MPa is set. After defining of all needed parameters, the analysis of the fluid flow is performed. On Figures 22. and 23. the fluid flow is shown with graphical depictions of the fluid flow rate through the 3D model of the pump assembly.

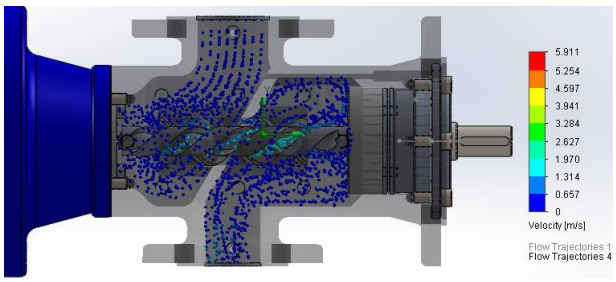

Figure 22. Two-dimensional display of the fluid flow and speed rate through the 3D model of the assembly of the three-spindle screw pump

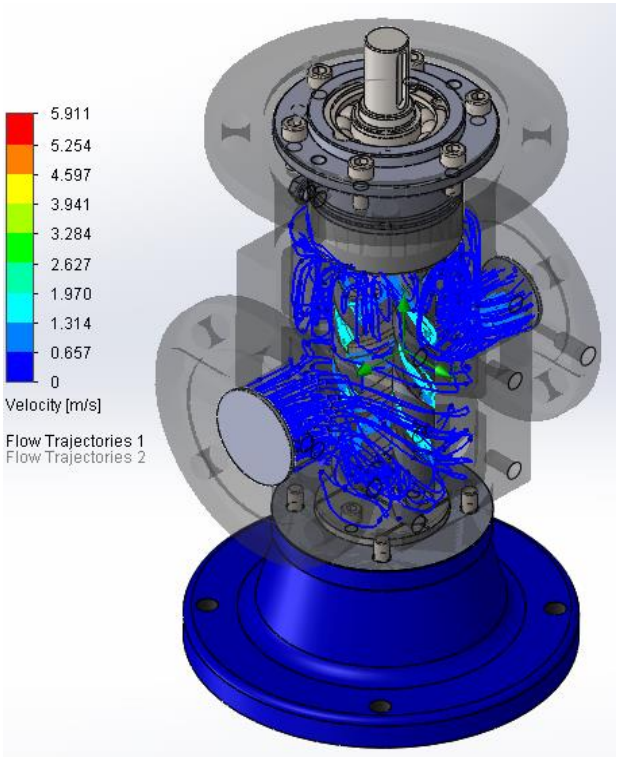

Figure 23. Three-dimensional display of the fluid flow and speed rate through the 3D model of the assembly of the three-spindle screw pump

9. CONCLUSION

Based on the existing 2D workshop documentation of the cast version, the control calculation of the wall thickness of the housing of the three-spindle screw pump is shown for the test pressure 1,5 MPa (15 bars) and materials SL–25, NL–42 and AlSiMg.

Using reverse engineering, a „flexible“ 3D model of the assembly of the three-spindle screw pump with all parts, just as the complete 2D workshop documentation of the assembly and parts is created. In the program module *SolidWorks Simulation* are performed: stress analysis (*Finite Element Analysis – FEA*) and safety factor analysis (*Factor Of Safety – FOS*) for the housing of the three-spindle screw pump for the test pressure 1,5 MPa (15 bars) and materials SL–25, NL–42 and AlSiMg that confirmed the accuracy of the performed control calculation, as well

as the analysis of the fluid flow in the 3D model of the assembly of the housing of the three-spindle screw pump. With advanced program tools and the program module *SolidWorks Simulation* it was concluded that the 3D model of the housing of the three-spindle screw pump can reliably endure the test pressure, and therefore assure the safe „transport" of the medium in the pipe systems.

Applying the FDM technology of sedimentary hardening of materials with the 3D printer *MakerBot Replicator 2X* the printing of the miniature 3D model of the assembly of the three-spindle screw pump was performed. This is the preposition for the practical implementation of the improvement and development of machine elements of screw pumps.

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DISTRIBUIRANI OBRAMBENI MEHANIZMI ZA CLONE NAPADE TEMELJENI NA ALGORITMU ZA ISTRAŽIVANJE GRAVITACIJE (GSA) U WSN

DISTRIBUTED DEFENSE MECHANISM FOR CLONE ATTACKS BASED ON GRAVITATIONAL SEARCH ALGORITHM (GSA) IN WSN

P. Uma Maheswari, P. Ganesh Kumar

Izvorni znanstveni članak

Sažetak: *Bežične senzorske mreže (WSN) često su raspoređene u neprijateljskom okruženju i ranjive su na napade zbog prirode senzora koji su tehnološki ograničeni. Clone napad u WSN jedan je od glavnih problema gdje se poruke prisluškuju, zarobljeni čvor se klonira te napadač proizvede višestruke čvorove istog identiteta. Kako bi nadvladali te probleme, ovaj rad predlaže distribuirani obrambeni mehanizam za clone napade temeljen na algoritmu za istraživanje gravitacije (GSA) u WSN. Kako bi se sumnjivi čvorovi efikasno detektirali, čvorovi u kanalu mogu se podijeliti u čvorove svjedoke i tražene čvorove. Čvorovi svjedoci odgovorni su za otkrivanje sumnjivih čvorova, dok traženi čvorovi trebaju za potrebe procesa detekcije navesti svoj identitet. Za izbor čvorova svjedoka, koristi se GSA kako bi se izabrala grupa čvorova koji su najprikladniji. Nakon izbora čvorova svjedoka, otkivanje clone napada vrši se promatranjem ponašanja susjednih čvorova. Otkrivanjem clone napada aktivira se proces opoziva kako bi se opozvao clone napad u čvorovima svjedocima. Prema rezultatima dobivenim iz simulacije može se zaključiti kako predloženi algoritam pruža bolju zaštitu od clone napada smanjivanjem odbacivanja paketa i povećavanjem omjera isporuke paketa.*

Ključne riječi: *GSA, DDM, WSN, clone napadi, otkrivanje, zakon gravitacije, zakon gibanja*

Original scientific paper

Abstract: *Wireless Sensor Networks (WSN) are often deployed in hostile environment and are vulnerable to attacks because of the resource constrained nature of the sensors. Clone attack in WSN is one of the major issues where the messages are eavesdropped, the captured node is cloned, and multiple nodes with same identity are produced by attacker. In order to overcome these issues, in this paper, a Distributed Defense Mechanism for Clone Attacks based on Gravitational Search Algorithm (GSA) in WSN is proposed. For efficiently detecting the suspect nodes, the nodes in the channel can be divided into witness node and the claimer node. The witness nodes are responsible for the suspect nodes detection, whereas the claimer nodes should provide their identities for the detection process. For the witness nodes selection, we utilize the GSA to pick out the best witness nodes set. After selecting the witness nodes, clone attack detection is performed by observing the behavior of the neighbor nodes. On detecting the clone attack, revocation procedure is triggered to revoke the clone attack in the witness nodes. By simulation results, it can be concluded that the proposed algorithm provides better protection to clone attacks by reducing the packet drop and increasing the packet delivery ratio.*

Keywords: *GSA, DDM, WSN, Clone attacks, Detection, law of gravity, law of motion*

1 INTRODUCTION

Wireless Sensor Networks (WSNs) is a network formed by a large number of distributed autonomous nodes with sensors, embedded processor, and low-power radio to enable wireless communication with each other and also with the base station [1]. Sensors are resource-constrained tiny devices with limited memory storage capacities, low computation capacities, and reduced energy supply, which can neither be charged nor be replaced [2, 3]. Sensor nodes can sense the environmental changes, that is, physical, mechanical or chemical changes, and transfer it to base station for user analysis. Signal can be processed, computed, and aggregated before forwarding data to base station in order to reduce both communication and energy costs. WSN can be used for collecting and monitoring data. It can be used in military applications, environmental applications, smart homes, health monitoring, and so forth [2, 4, 5]. Yet, sensor nodes are prone to various attacks because of limited computing resource and feeble wireless communication. Attacks in routing protocol make the network unstable. Limited processing power and resources may impose difficulty in utilizing defense mechanisms of wired networks in wireless networks [4].

Data security is devastated by threats, vulnerabilities, and attacks, which are the three crossly related entities that intend to bypass the security control of the system. In

addition, there are active and passive attacks [1]. As sensors are unshielded devices, WSNs are prone to various types of novel attacks such as compromising attacks, intrusion attacks, deny-of-service (DoS) attacks, and nodes replication attacks [6, 7]. Several existing attacks in WSNs are physical attacks, sybil attacks, clone attacks, sinkhole attacks, and replication attacks [1, 3, 4, 6].

Clone attack is also called as replication attack in which the exchanged messages can be eavesdropped, and nodes can be captured by an attacker, thereby obtaining all information stored in devices. Then, the captured nodes can be cloned, and multiple nodes are generated by the attackers with same identity. The clones could be then deployed in network area to launch a variety of malicious activities [6, 7].

A self-healing efficient protocol, which is randomized and distributed, is presented for detecting node replication attacks [7]. Here, a random value is distributed among all the nodes using a centralized or distributed mechanism. A digital signature is then added by each node, and its claim ID and geographical location are broadcasted. The claim is not sent directly to the specific node instead transmitted to the node that is closest to the location. Moreover, the signature check will be carried out only in destination, but not in forwarding nodes. Here, the witness has to be captured faster within a window period so as to prevent clones in detecting the witness of clones.

However, this scheme focuses more on exhausting battery of nodes and verifies the received signature and the message freshness, but it failed to detect the attacks. Moreover, the witness selection procedure is not accurate and consumes more time. Most

of the existing mechanisms that detect clone attacks are not efficient and also, they did not provide any approaches to mitigate the attack.

In this paper, we propose a Distributed Defense Mechanism for Clone Attacks in WSN based on GSA where the witness nodes are used to detect the clone attacks. The witness nodes periodically broadcasts request messages with a time stamp to the claimer nodes. GSA is used to select the witness nodes in the network. Clone attack detection is performed by observing the behavior of the neighbor nodes. Then, revocation procedure is triggered by flooding the network with two incoherent response messages received by the witness node. This cancels the clone attacks in the witness nodes. This algorithm provides better protection to clone attacks with reducing packet drop and increased packet delivery ratio.

The paper is organized as follows. Section 2 presents the literature review of existing works on clone attacks in WSN. Section 3 presents the proposed methodology of distributed defense mechanism for clone attacks. The simulation results and analysis are presented in section 4 and the conclusion is given in section 5.

2 LITERATURE REVIEW

Mauro Conti et al [7] have proposed a new self-healing, Randomized, Efficient, and Distributed (RED) protocol for the detection of node replication attacks. This protocol is highly efficient in communication, memory, and computation; and is much more effective than competing solutions in the literature; also resistant to the new kind of attacks. RED is more resilient in its detection capabilities. However RED is more influenced by path lengths, since a malicious node can stop the protocol wherever it appears in the paths.

Mebi Sernaz and Anand Pavithran [8] have proposed risk aware mitigation scheme for the isolation of clone nodes and black hole nodes. It provides better response with adaptive isolation and the response cost calculation when IDS inform it with an alert confidence value. By combining Time Domain Detection and Space Domain Detection (TDD and SDD) with risk aware mitigation, a good detection and response mechanism can be developed for the detection of clone nodes in MANET.

H. Wen et al [9] have proposed a novel scheme to detect the node clone attack in WSN by channel identification characteristic in which the clone nodes are distinguished by the channel responses between nodes. The proposed scheme aims at achieving fast detection and minimizing the data transmission cost by taking advantage of temporal and spatial uniqueness in physical layer channel responses. The proposed approaches feature nearly-perfect resilience to node clone attack with low communication and computation costs, low memory requirements and high detection probability. However the detection rate falls with increase in the velocity.

Zhongming Zheng et al [10] have proposed a location-aware energy-efficient ring based clone detection protocol with clone detection protocol, which guarantees successful clone attack detection and has little negative impact on the network lifetime. Moreover, their proposed protocol can significantly improve the network lifetime, compared with the existing approach. The proposed protocol can approach 100% clone detection probability with trustful witnesses. However the energy consumption is high.

Richard Brooks et al [13] have proposed an algorithm to detect the presence of clones in the sensor network. Keys on the cloned nodes are detected by looking at how often they are utilized to authenticate the nodes in the network. The system can recover from a cloning attack by terminating connections with the help of cloned keys. Results show that this method can accurately detect the presence of clones in the system and support their removal. Moreover, the extent of false positives and false negatives in the clone detection process is qualified. However, the key encryption technique requires more computation and resource consumption.

Zhijun Li, and Guang Gong [14] have propose two node clone detection protocols with different tradeoffs on network conditions and performance. The first protocol depends on a distributed hash table (DHT) that is used to construct a fully decentralized, key-based caching and checking system. This protocol is capable of catching the cloned nodes effectively. As DHT-based protocol increases the communication cost, the second distributed detection protocol is proposed that provides good communication performance for dense sensor networks, by a probabilistic directed forwarding technique with random initial direction and border determination. These protocols can obtain better efficiency on communication overhead and satisfactory detection probability along with minimal storage consumption.

Yingpei Zeng et al [15] have proposed two new NDFD protocols, RAndom WaLk (RAWL) and Table-assisted RAndom WaLk (TRAWL) based on random walk. The random walk strategy performs weel as it distributes a core step, the witness selection, to every passed node of random walks. Hence, the adversary cannot easily determine the critical witness nodes. The number of walk steps needed for ensuring detection is theoretically analyzed. These protocols have the lowest overheads in witness selection, whereas the communication overheads of these protocols are higher but are affordable due to their security benefits.

Conti et al. [16] have proposes two distributed, efficient, and cooperative protocols to detect replicas. They are history information-exchange protocol (HIP) and HIP's optimized version (HOP). Both HIP and HOP influence local communications and node mobility. It differs for the amount of computation required. By considering two different mobility models, the behavior of these protocols are studied against the introduced types of attacker. Results show that the solutions provide high detection rate while experiencing limited overhead.

Soumya Sara Koshy and Sajitha et al [17] have proposed a zone-based node replica detection in WSN using trust in which the network is divided into a number of zones and the zone leaders are chosen before the node deployment. Hence, the zone is dynamically formed. Trust values are estimated for each node and replica nodes are detected by the zone leader based on these trust values. Before the zone formation, the trust values are checked and updated. Result shows that this technique can improve the packet delivery ratio and reduce the end to end delay.

Mayur R. Khandekar and U. K. Raut [18] have surveyed the node replication attack algorithms in WSN. Several replication attack detection algorithm are analyzed and these algorithms are classified into two schemes, namely, centralized and distributed schemes. Generally, distributed detection scheme is preferred over the centralized detection scheme, even if both the schemes have some disadvantages. The recent research has mainly focused on the communication costs and energy efficiency of the algorithm.

Wibhada Naruephiphat et al. [19] have proposed an area-based clustering detection (ABCD) method for WSN to achieve high successful detecting replica rate with less communication overhead than the line-selected multicast approach. Even though ABCD requires more memory capacity to store location claims in the central node, it can easily support more number of nodes in a network. When the number of sensor nodes in the network increases, ABCD can reduce the number of message stored in a node and preserve the network lifetime.

Lei Jin et al. [20] have proposed a detection framework to discover the suspicious identities and to validate them. For this, two approaches based on attribute similarity and similarity of friend networks are utilized. The first approach considers the scenario in which mutual friends in friend networks are taken into account, whereas the second approach captures the scenario in which similar friend identities are involved. The suspicious identities are finally validated. Results demonstrate the flexibility and effectiveness of these approaches.

Wazir Zada Khan et al. [21] have considered a node replication attack or clone node attack in which an adversary can create its own clone nodes and misinform the network to acknowledge them as legitimate nodes. The existing attack detection techniques are broadly categorized into distributed and centralized classes. The algorithms in both classes are capable of detecting and preventing clone attacks with some noteworthy shortcomings. This study analyzes the challenges and issues in clone detection schemes that need to be resolved to become more applicable to real-life situations.

Moirangthem Marjit Singh et al [22] have reviewed the existing node replication attack detection techniques for static WSNs. These techniques can be classified into two categories, namely, location aware protocol and location independent protocol. In location aware protocols, the nodes should know their geographic location. Hence, it requires GPS or relies on the base station to compute their location coordinates. In location independent protocol, the knowledge of the nodes' location is not required to detect node replication. The performance of these techniques depends on the density of the networks.

3 PROPOSED METHODOLOGY

3.1. Overview

In this paper, we propose a Distributed Defense Mechanism for Clone Attacks in WSN based on Gravitational search algorithm where the nodes are divided into two groups, namely, witness nodes and claimer nodes [9]. The witness nodes periodically broadcasts request messages with a time stamp to the claimer nodes. On receiving the messages, these claimer nodes send the response message with in a time interval to the witness node. The response message contains the node ID and the pilot. With this, the suspected nodes are detected, and they are stored in the suspected list. In order to confirm the clone attacks, the suspect list is broadcasted to the claimer nodes. Hence, after receiving the broadcasted message, the claimer nodes send the response message which contains node ID, sequence, and time stamp. If the two nodes have the same ID and different random sequence, then the nodes are considered to be attacked.

For selection of witness nodes in the network, GSA can be used that tends to find the global optimum faster than other algorithms with higher convergence rate. Gravitational constant adjusts the accuracy of the search, thereby decreasing with time. As GSA is a memory-less algorithm, it works efficiently like the other algorithms with memory. This shows the good convergence rate of the GSA [11]. After the detection of the clone attack, revocation procedure [7] can be used. Here, the revocation is triggered by flooding the network with two incoherent response messages received by the witness node. This cancels the clone attacks in the witness nodes.

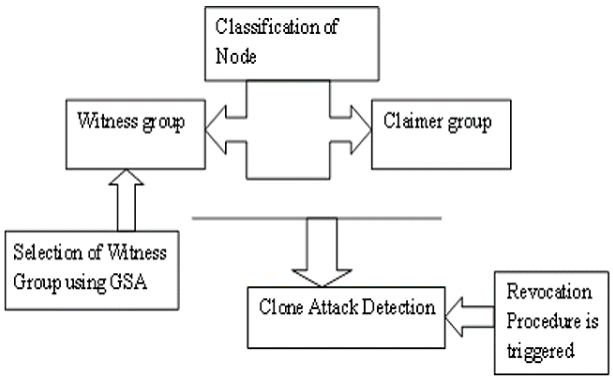

Figure 1. Block Diagram

3.2. Classification of Nodes

For effective identification scheme, all nodes are divided into two main groups: witness group and claimer group in which the nodes are represented as n_j^w and n_j^c, respectively. The nodes in the network channel periodically play these two roles.

Here, the witness node periodically transmits request messages M_w to claimer node with time stamp S_w. As a result, all neighboring claimer nodes, present within the signal range of the witness nodes, receive the previous request messages M_w. In return, the claimer node transmits the return response messages M_c to the witness nodes within time interval $\Delta d + \Delta\varepsilon$, where Δd represents response delay and $\Delta\varepsilon$ must be less than the network channel coherence time $\Delta\Gamma$.

The response message M_c can be represented in the following format:

$$M_c : \{Node\,ID, Pilot\} \tag{1}$$

Once witness node receives the messages M_c, then they extract the channel measure $\hat{\underset{-}{B}}_{t_j}(n_j^c \to n_l^w)$, here j = 1, 2,……., H_c, $l = 1,2,.....,H_w$, where H_c and H_w represents the number of nodes present in claimer group and witness group, respectively.

After that, they perform comparison, we normalize the likelihood ratio test (LRT) statistic as $\Theta_{j,k}^l$, which is given below.

$j \neq k \neq l$, j = 1, 2,……., G_c, $l = 1,2,.....,G_w$.

$$\Theta_{j,k}^l = \frac{N_{co} \left\| \tilde{\underset{-}{B}}_{d_1}(ol_j \to n_l) - \tilde{\underset{-}{B}}_{d_2}(ol_k \to n_l) \right\|^2}{\left\| \tilde{\underset{-}{B}}_{d_1}(ol_k \to n_l) \right\|^2} \begin{cases} < B_1 \\ > B_0 \end{cases} \gamma \tag{2}$$

where $\hat{\underset{-}{B}}_{d}$ denotes the channel response with measurement errors.

N_{co} represents the normalization factor and assume the threshold $\gamma \in [0,1]$.

3.3. Selection of Witness Node

In order to detect the clone attack, selection of the best and authenticated witness node is a major challenge. In the proposed scheme, the selection of the witness node is performed using Gravitational Search Algorithm (GSA), which is described in the following section.

3.3.1. Gravitational Search Algorithm (GSA)

This section describes about GSA optimization algorithm which is based on the law of gravity. Gravitational search algorithm (GSA) is a new optimization algorithm that depends on the law of gravity given by Newton: "Every particle in the universe attracts every other particle with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them." In GSA, agents are considered as objects, and their performance is estimated by their masses. All these objects attract each other by the gravitational force, and this force results in global movement of all objects towards the object which comprises heavier masses. Thus, masses assist using a direct form of communication based on gravitational force.

In GSA, each agent mainly has the following four specifications: position, inertial mass, active gravitational mass, and passive gravitational mass. The position of the mass gives the solution of the problem, and its gravitational and inertial massed are found with the help of fitness function. Or, in other words, each mass represent a solution and the algorithm is directed by properly regulating the gravitational and inertia masses. By elapse of time, it is assumed that masses be attracted by the heaviest mass and this mass is the optimal solution. The GSA need to be considered as an isolated system of masses.

In the proposed algorithm, heavy masses corresponds to good solution as it moves more slowly than lighter ones, assuring development step of the algorithm. Moreover, it mainly obeys Newtonian laws of gravitation and motion which is described as below:

Law of Gravity

Each particle attracts every other particle with a gravitational force, where gravitational force is directly proportional to product of their masses and inversely proportional to the distance between them. In GSA,

distance is considered as D instead of D^2 to get better experimental result.

Law of Motion

The new current velocity of any mass is equivalent to the sum of the fraction of its previous velocity and variation in the velocity. Variation in the velocity called as acceleration of any mass can be defined by force acted on the system divided by mass of inertia.

Consider a system with P agents (masses). The position of the *i*th agent can be defined as below:

$$Y_i = (y_i^1, \ldots\ldots, y_i^e, \ldots\ldots, y_i^n \text{ , for i = 1,2,…,P} \quad (3)$$

where, y_i^e represents the position of the *i*th agent in *e*th dimension.

At a particular time 's', force acting on mass i from mass k is given as below:

$$F_{ik}^e(s) = G(t)\frac{N_{pi}(s) \times N_{ak}(s)}{D_{ik}(s) + \eta}(y_k^e(s) - y_k^e(s)) \quad (4)$$

where N_{ak} denotes the active gravitational mass related to agent k. N_{pi} represents the passive gravitational constant at time s. η represents small constant. D_{ik} (s) is the Euclidian distance between two agents (masses) i and k:

$$D_{ik}(s) = \| Y_i(s), Y_k(s) \|_2 \quad (5)$$

In order to give a stochastic characteristic to the GSA, it is assumed that the total that acts on agent i in a dimension e to be an arbitrarily weighted sum of eth component of the forces applied from other agents:

$$F_i^e(t) = \sum_{k=1, k\neq i}^{P} rand_k F_{ik}^e(s) \quad (6)$$

where $rand_k$ is a arbitrarily number in the interval [0,1]. Hence, according to the law of motion, the acceleration of the agent i at a particular instant time t, and in direction dth, $a_i^e(t)$ can be given as below:

$$a_i^e(t) = \frac{F_i^e(t)}{N_{ii}(t)} \quad (7)$$

where N_{ii} represents the inertial mass of the ith agent.

In addition, the next velocity of an agent is measured as a fraction of its current velocity additional to its acceleration:

Hence, its position and velocity can be computed as below:

$$v_i^e(s+1) = rand_i \times v_i^e(s) + a_i^e(s) \quad (8)$$

$$y_i^e(s+1) = y_i^e(s) + v_i^e(s+1) \quad (9)$$

where $rand_i$ denotes uniform random variable in the interval [0, 1]. This random variable is used to give a randomized characteristic to the search.

The gravitational constant, G, is initialized at the starting and is decreased with time to control the search accuracy. Otherwise, G is a function of the initial value G_0 and time (s):

$$G(s) = G(G_0, s) \quad (10)$$

Gravitational and inertia masses are simply computed by the fitness evaluation. A heavier mass represents more efficient agent, which means better agents have higher attraction level and walk more slowly. By assuming the equality of gravitational and inertia mass, the values of masses are computed using map of fitness. Hence, the gravitational and inertial mass is updated using the following equation:

$$N_{ai} = N_{pi} = N_{ii} = N_i \text{, i = 1, 2 ,…,P} \quad (11)$$

$$n_i(s) = \frac{fit_i(s) - worst(s)}{best(s) - worst(s)} \quad (12)$$

$$N_i(s) = \frac{n_i(s)}{\sum_{k=1}^{P} n_k(s)} \quad (13)$$

Where $fit_i(s)$ denotes the fitness value of the agent i at time s, and

$$best(s) = \begin{cases} \min\limits_{k\in\{1,\ldots\ldots P\}} fit_k(s) & \text{minimization problem} \\ \max\limits_{k\in\{1,\ldots\ldots P\}} fit_k(s) & \text{maximization problem} \end{cases} \quad (14)$$

$$worst(s) = \begin{cases} \max\limits_{k\in\{1,\ldots\ldots P\}} fit_k(s) & \text{minimization problem} \\ \min\limits_{k\in\{1,\ldots\ldots P\}} fit_k(s) & \text{maximization problem} \end{cases} \quad (15)$$

In order to perform a good comprise between exploration and exploitation, it is important to reduce the number of agents with elapse of time in equation (7). Here, only a set of agents with bigger mass apply their force to other. However, the policy needs to be used carefully as it may reduce the exploration power and enhance the exploitation abilities. In order to avoid the trapping in a local optimal, the algorithm use exploration at the commencement. By elapse of iteration, exploitation must fade in and exploration must fade out. To enhance the performance of GSA by controlling exploitation and exploration only the J_{best} agents attracts the others.

J_{best} is mainly a function of time, with initial value J_0 at the commencement and decreases with time . At the beginning, all agents apply the force; as time moves, J_{best} is decreased linearly and at the end, there will only one agent applying force to the others. Hence, equation (6) can be modified as:

$$F_i^d(s) = \sum_{k \in J_{best}, k \neq i} rand_k F_{ik}^d(s) \quad (18)$$

where J_{best} represents set of first J agents with the best fitness value and biggest mass. The different steps of the proposed algorithm can be described as below:

1. Search space identification
2. Randomized initialization
3. Fitness computation of agents
4. Update G(s), best(s), worst(s), and $N_i(s)$ for i = 1, 2… P
5. Computation of total force in different direction
6. Computation of acceleration and velocity
7. Update agents' exact position
8. Repeat Step 3 to 7 till stop criteria is reached
9. End

Hence, the agent with the best fitness value is selected as a witness node to detect the suspect node for clone attack.

3.4. Clone Attack Detection

Once, the witness node is selected, clone attack detection starts by observing the behavior of the neighbor node. Here, we have considered three scenarios for malicious node detection, as shown in Fig. 2.

Scenario 1: As in figure 2(a), two or more malicious node surrounds a witness node. Node oa_2 represents the captured node, and ol_2 represents the cloned node from oa_2 . The witness node here is, n_2^w . Lines shows the nodes surround n_2^w .

In case, $|d_j - d_k| \leq \Delta\varepsilon$ and $\Theta_{j,k}^l < \gamma$ for nodes oa_2 and ol_2 , n_2 can then conclude that nodes oa_2 and ol_2 are suspects nodes. Hence, these suspects' nodes are saved into $susplist_{n_2^w}$. After that, n_2^w transmits $susplist_{n_2^w}$ to the network and ejects the clone node.

Scenario 2: As shown in figure 2(b), two or more malicious node belong to different witness nodes and here the witness nodes share part of their neighboring nodes.

Scenario 3: As shown in figure 2(c), two or more malicious nodes belong to the distinct witness nodes and the witness nodes are far from each other and hence they do not share any of their neighbor nodes. In both second and third situations, witness node is unable to find the suspect nodes based on performance comparison according to equation (2). Hence, each and every witness nodes transmits a list of its neighbor node to other witness nodes.

Once, a witness node n_l^w receives the list of their neighbor nodes from other witness nodes, it verifies all the list and save the witness ID that consist of at least one same notes ID with it into same node ID list $snIDlist_{n_l^w}$. Moreover, random sequence is transmitted to find the suspect nodes. Hence, all witness nodes present in $snIDlist_{n_l^w}$ transmits randomly selected sequences $sq_{n_l^w}$ to their neighboring node and requests all their neighbor nodes to reply back the received sequences along with their ID. The transmitted random sequences are different in different witness nodes. The response of the neighbor node can be

$$M_s : \{NodeID, sq_{n_l^w}\} \quad (19)$$

After that, every witness node transmits $report_{n_l^w}$ that consist of neighboring nodes' M_s to other witness nodes. Then, the witness nodes verifies the $report_{n_l^w}$ .In case, two nodes with same ID holds distinct random sequence, it indicate clone node attack occurred.

Consider, figure 2(a) where node n_2 denotes the witness node and the other seven nodes are the neighbor nodes, in which nodes oa_2 and ol_2 comprised of same ID. First, node n_2 transmits request message M_w . Once neighbor node received M_w , they reply back by transmitting response message to n_2, in which responses of node oa_2 and ol_2 are $M_o^{oa_2} = \{oa_2, pilot\}$ and $M_o^{ol_1} = \{ol_1, pilot\}$ within response time interval respectively. The node n_2 obtains channel response $\hat{\underline{B}}_{d_2}(oa_2 \rightarrow n_2)$ and $\hat{\underline{B}}_{d_2}(ol_2 \rightarrow n_2)$ from the pilot and computes the $\Theta_{oa_2, ol_2}^{n_2}$.

In case, $\Theta_{oa_2, ol_2}^{n_2}$ is larger than threshold γ , node n_2 can easily determine that oa_2 and ol_2 are suspects nodes. After that, oa_2 and ol_2 are saved into $susplist_{n_2^w}$. The node n_2 then transmits the $susplist_{n_2^w}$ and removes oa_2 and ol_2 .

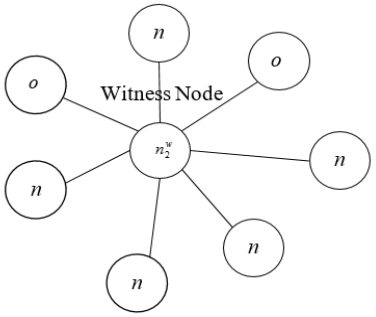

Figure 2(a). Scenario 1: Detection of Malicious Node

Now, we can consider the scenario in Figure.2b. Here, it is assumed that the witness nodes are randomly selected as n_7 and n_{10}. Their neighbor nodes (illustrated with lines and dashed lines in figure 2(b)) are listed here in Table 1. It is now easier to know that the clone nodes ol_2 and ol_4 belong to different witness node and the witness node is unable to find them in the situation as shown in Figure.2b. Hence, the detection scheme needs to depend on transmitting random sequence in order to find the suspect nodes. In this scenario, witness nodes n_7 and n_{10} transmits the randomly selected sequences sq_7 and sq_{10} to their neighbor nodes, respectively and request their neighbor nodes to reply back the received sequences along with their ID:

$$M_s : NodeID, sq_{n_l^w}$$

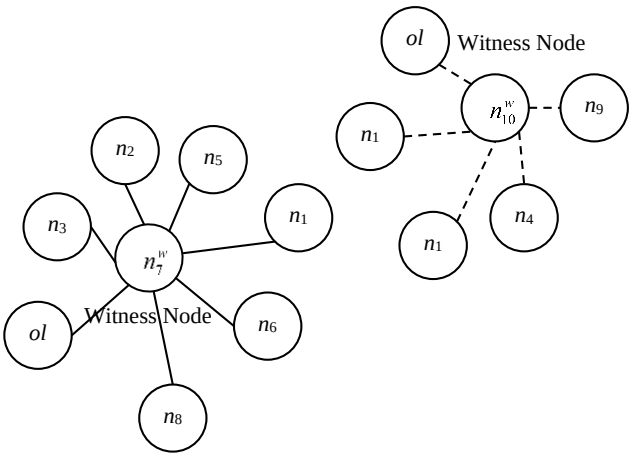

Figure 2(c). Scenario 3 for detection of Malicious Node

Table 1 Received Sequences and IDs of Neighbor Nodes

n_7	Received Sequences and IDs of Neighbor Nodes					
	ol_2	n_2	n_5	n_3	n_6	n_{11}
identity	ID_{oa_2}	ID_{n_2}	ID_{n_5}	ID_{n_3}	ID_{n_6}	ID_{n_8}
Received Sequences	sq_{n_7}	sq_{n_7}	sq_{n_7}	sq_{n_7}	sq_{n_7}	sq_{n_7}, $sq_{n_{10}}$
n_{10}	ol_4	n_1	n_{11}		n_{13}	n_{14}
identity	ID_{oa_2}	ID_{n_1}	$ID_{n_{11}}$	ID_{n_5}	$ID_{n_{14}}$	-
Received Sequences	$sq_{n_{10}}$	$sq_{n_{10}}$	sq_{n_7}, sq_{n10}	sq_{n10}	sq_{n10}	-

After that witness nodes n_7 and n_{10} transmits $report_{n_7}$ and $report_{n_{10}}$. On receiving the $report_{n_7}$ and $report_{n_{10}}$, witness node verifies the $report_{n_7}$ and $report_{n_{10}}$. Nodes ol_2 and ol_4 are generated from the captured node oa_2, hence their identity is the identity of node oa_2. The witness node nodes n_7 and n_{10} notices that node ol_2 and ol_4 have same identity but random sequences. Hence, it is concluded that clone attack occurred. Moreover, it is important to note that the node n_5 and node n_{11} are not only the neighbor of node n_7 but the neighbor of node n_{10}, hence they can easily receive both sq_{n_7} and $sq_{n_{10}}$.

Hence, in this scenario, random sequence will fail to detect the clone node, in case there is a node which is the neighbor node of two or more witness node at the same time. To avoid the shortcomings of random sequence scheme, the witness node transmits the random sequence along with the timestamp S_w that cannot be modified by any node other than the sender witness node. Hence, the response of the neighbor node becomes:

$$M_s : \{NodeID, sq_{n_l^w}, S_w\} \quad (20)$$

If a node transmits the received sequence transferred from other nodes, timestamp S_w becomes $S_w + 1$.

3.4.1. Revocation Procedure

Once, the clone attack is detected, revocation scheme is triggered. It is performed by flooding the network with the two incoherent claims received by the witness node n_w. Here, every claim message of a node is signed with private key of the same node based on the response message received from the claimer node. This cancels the clone attack occurred in the witness node.

3.5. The Overall Algorithm

1. *Divide the nodes in to claimer node* $(n_j^c, j = 1,2,....P_c)$ *and witness node* $(n_j^w, j = 1,2,....P_w)$
2. *Witness node broadcast* $M_w : \{S_w = \Delta d + \Delta\varepsilon\}$
3. *Claimer node transmits the response message* $M_c : \{Node\,ID, Pilot\}$
4. *Extract channel response* $\hat{B}_{-t_j}(n_j^c \to n_l^w)$ *from pilot*
5. *Compute* $\Theta_{j,k}^l$
6. *If* $|d_j - d_k| \le \Delta\varepsilon$ *and* $\Theta_{j,k}^l < \gamma$ *for nodes* oa_2 *and* ol_2, n_2 *can then conclude that nodes* oa_2 *and* ol_2 *are suspects nodes*

7. *suspects' nodes are saved into* $susplist_{n_l^w}$ *.go to step 4.*
8. *Broadcasts* $susplist_{n_l^w}$ *to other nodes.*
9. *Broadcasts randomly chosen sequences*
10. *Response to the received sequences* $M_s : \{NodeID, sq_{n_k^w}, S_w\}$.
11. *If two node with same ID holds distinct random sequence,*
12. *Then clone node attack occurred*
13. *Trigger the revocation procedure*
14. *Flood the network with incoherent claims received by witness node.*
15. *// Selection of witness Node//*
16. *Apply GSA*
17. *// GSA Algorithm//*
18. *Generate initial population*
19. *Compute the fitness of each agent*
20. *Update the G, best and worst of population*
21. *Compute mass, and acceleration of each agent*
22. *Update each time velocity and position*
23. *If meeting the end of criteria*
24. *Then return best solution*
25. *Else go to step 19*

4. SIMULATION RESULTS

4.1 Simulation Parameters

We use NS2 [12] to simulate our proposed Distributed Defense Mechanism for Clone Attacks based on Gravitational Search Algorithm (GSA). We use the IEEE 802.11 for wireless MAC layer protocol. It has the functionality to notify the network layer about link breakage. In our simulation, the number of attackers is varied as 1,2,3,4 and 5. The area size is 50 meter x 50 meter square region for 50 seconds simulation time. The simulated traffic is Constant Bit Rate (CBR).

Our simulation settings and parameters are summarized in Table 2.

Table 2. Simulation parameters

No. of Nodes	50,100,150 and 200
Area	500 X 500
MAC	802.11
Simulation Time	50 sec
Traffic Source	CBR
Rate	50Kb
Propagation	TwoRayGround
Antenna	OmniAntenna
Packet Size	512
No. of Attackers	1,2,3,4 and 5

4.2 Performance Metrics

We evaluate performance of the new protocol mainly according to the following parameters. The proposed DDMGSA is compared with the Distributed Detection of Clone Attacks (DDCA) [7] and ERCD: An Energy-efficient Clone Detection Protocol [10].

Average Packet Delivery Ratio: It is the ratio of the number of packets received successfully and the total number of packets transmitted.

Average end-to-end delay: The end-to-end-delay is averaged over all surviving data packets from the sources to the destinations.

Energy Consumption: It is the amount of energy consumed by the nodes to transfer the data to the receiver.

Packet Drop: It is the number of packets dropped during the data transmission.

Communication Overhead: It is measured as the ratio of number of controls packets exchanged to the total number of packets exchanged.**sults & Analysis**

A. Varying the Attackers

Among 100 nodes, the number of attackers is increased from 1 to 5 and the performance is evaluated for the above metrics.

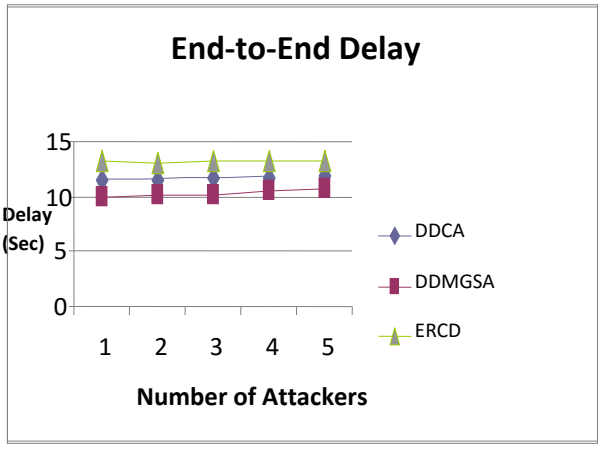

Figure 3. Attackers Vs Delay

Figure 3 shows the results of delay by varying the attackers from 1 to 5 for all the 3 techniques. When comparing the performance of the techniques, we infer that DDMGSA has the least delay among the 3 techniques followed by DBCA and ERCD. DDMGSA outperforms DBCA by 12% and ERCD by 22%.

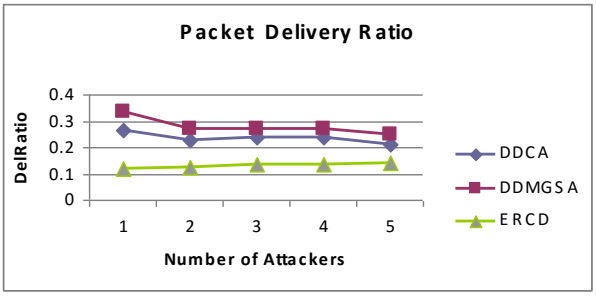

Figure 4. Attackers Vs Delivery Ratio

Figure 4 shows the results of delivery ratio by varying the attackers from 1 to 5 for all the 3 techniques. When

comparing the performance of the techniques, we infer that DDMGSA has the highest delivery ratio among the 3 techniques followed by DBCA and ERCD. DDMGSA outperforms DBCA by 15% and ERCD by 53%.

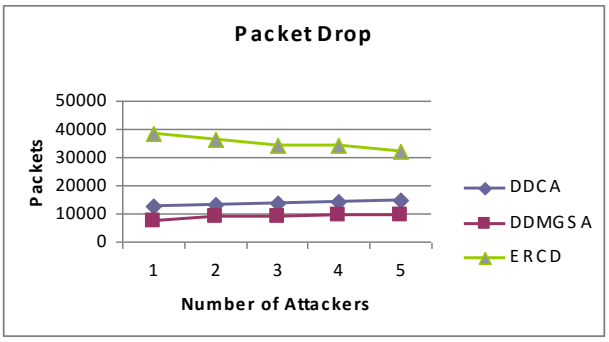

Figure 5. Attackers Vs Drop

Figures 5 shows the results of packet drop by varying the attackers from 1 to 5 for all the 3 techniques. When comparing the performance of the techniques, we infer that DDMGSA has the least packet drop among the 3 techniques followed by DBCA and ERCD. DDMGSA outperforms DBCA by 30% and ERCS by 75%.

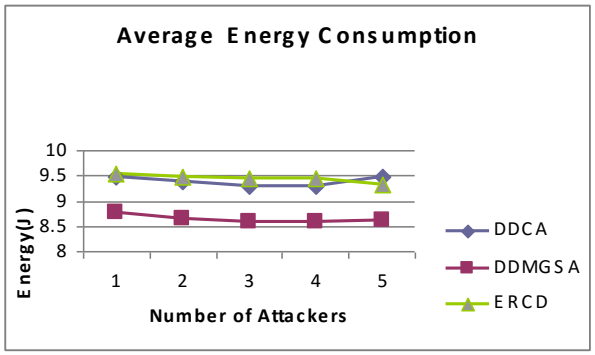

Figure 6. Attackers Vs Energy Consumption

Figure 6 shows the results of energy consumption by varying the attackers from 1 to 5 for all the 3 techniques. When comparing the performance of the techniques, we infer that DDMGSA has the least energy consumption among the 3 techniques followed by DBCA and ERCD. DDMGSA outperforms DBCA by 8% and ERCD by 9%.

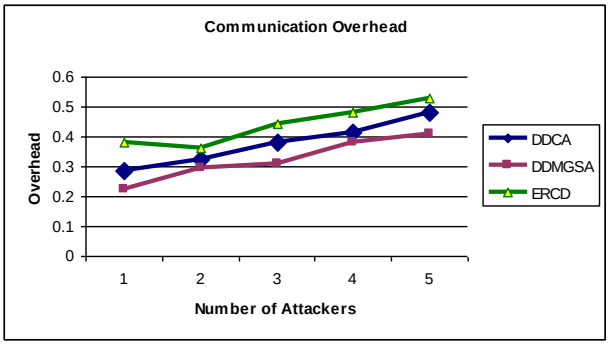

Figure 7. Attackers Vs Communication Overhead

Figure 7 shows the results of communication overhead by varying the attackers from 1 to 5 for all the 3 techniques. When comparing the performance of the techniques, we infer that DDMGSA has the least overhead among the 3 techniques followed by DBCA and ERCD. DDMGSA outperforms DBCA by 14% and ERCD by 26%.

B. Varying the Nodes

Keeping the number of attackers as 2**,** the number of nodes is increased from 50 to 200 and the performance is evaluated for the metrics.

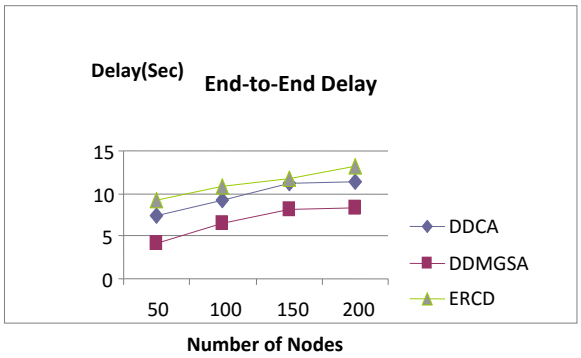

Figure 8. Nodes Vs Delay

Figure 8 shows the results of delay by varying the nodes from 50 to 100 for all the 3 techniques. When comparing the performance of the techniques, we infer that DDMGSA has the least delay among the 3 techniques followed by DBCA and ERCD. DDMGSA outperforms DBCA by 31% and ERCD by 40%.

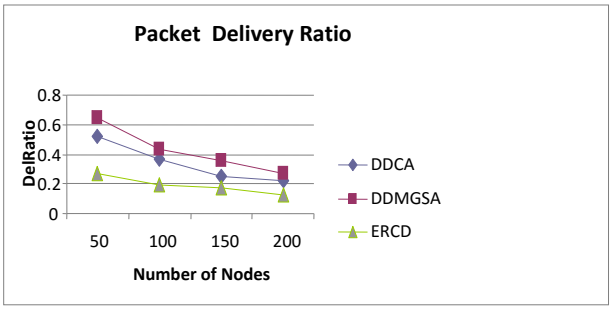

Figure 9. Nodes Vs Delivery Ratio

Figure 9 shows the results of delivery ratio by varying the nodes from 50 to 200 for all the 3 techniques. When comparing the performance of the techniques, we infer that DDMGSA has the highest delivery ratio among the 3 techniques followed by DBCA and ERCD. DDMGSA outperforms DBCA by 19% and ERCD by 55%.

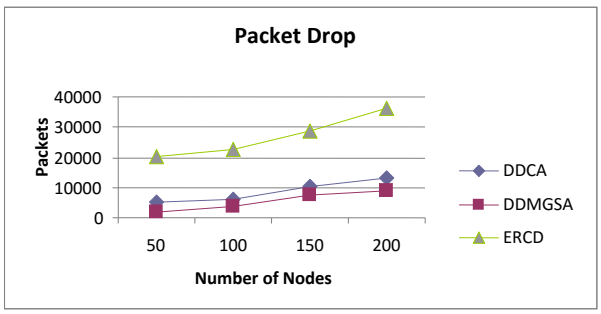

Figure 10. Nodes Vs Drop

Figure 10 shows the results of packet drop by varying the nodes from 50 to 100 for all the 3 techniques. When comparing the performance of the techniques, we infer that DDMGSA has the least packet drop among the 3 techniques followed by DBCA and ERCD. DDMGSA outperforms DBCA by 39% and ERCS by 80%.

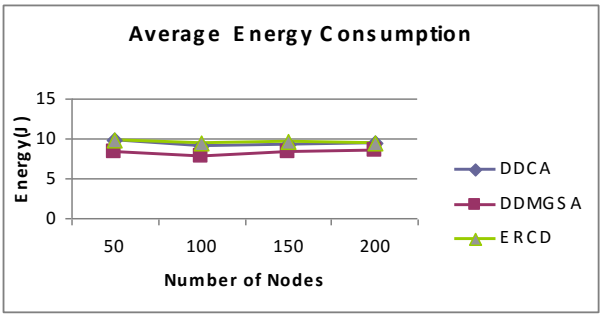

Figure 11. Nodes Vs Energy Consumption

Figure 11 shows the results of energy consumption by varying the nodes from 50 to 200 for all the 3 techniques. When comparing the performance of the techniques, we infer that DDMGSA has the least energy consumption among the 3 techniques followed by DBCA and ERCD. DDMGSA outperforms DBCA by 12% and ERCD by 13%.

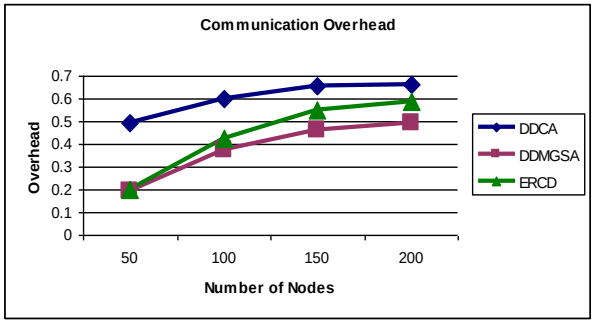

Figure 12. Nodes Vs Communication Overhead

Figure 12 shows the results of communication overhead by varying the nodes from 50 to 200 for all the 3 techniques. When comparing the performance of the techniques, we infer that DDMGSA has the least overhead among the 3 techniques followed by DBCA and ERCD. DDMGSA outperforms DBCA by 38% and ERCD by 11%.

5. CONCLUSION

In this paper, we have proposed a Distributed Defense Mechanism for Clone Attacks based on Gravitational Search Algorithm (GSA) in WS. For efficient detection of the suspect nodes, the nodes in the channel are divided into witness node and the claimer node. The witness node verifies the Node ID received from the claimer node along with the sequence and timestamp for efficient detection of clone attack. If a node contains same ID but different random sequences, it indicates that clone attack has occurred. In addition, to select the best witness node, GSA is used. GSA is actually a memory-less algorithm but works efficiently like algorithm with memory. It gives the one of the best optimal solution by following mass and change in velocity of the object. Once the clone attack is detected, revocation procedure is triggered to revoke the clone attack in the witness nodes. By simulation results, we have shown the proposed algorithm provides better protection to clone attacks by reducing the packet drop and increasing the packet delivery ratio. In future, we planned to extend the proposed work by analyzing and comparing several other related algorithms.

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PRIKAZ RADA MOTORA ZRAKOPLOVA

REVIEW OF HOW AERO ENGINES WORK

Amar Singh, Shubham Bharadwaj, Sunny Narayan

Stručni članak

Sažetak: *Motori koji se koriste u zrakoplovima pogonskog su tipa koji rade na osnovi potisne sile koja djeluje na njih. U ovom članku prikazan je rad različitih motora. Raspravljeni su razni problemi koji se povezuju s tim motorima s budućim mjerama za uklanjanje tih grešaka.*

Ključne riječi: *zrakoplovni motori, izrada*

Professional paper

Abstract: *Engines used in aircrafts are propulsion type which work on the basis of thrust force acting on them. In this paper working of various engines has been reviewed. Various problems associated with these engines have been discussed with future remedies to rectify these faults.*

Key words: *Aero engines, Manufacturing*

1. INTRODUCTION

The main function of any aeroplane propulsion system is to provide a force to overcome the aircraft drag, this force is called thrust. Both propeller driven aircraft and jet engines derive their thrust from accelerating a stream of air - the main difference between the two is the amount of air accelerated [1]. A propeller accelerates a large volume of air by a small amount, whereas a jet engine accelerates a small volume of air by a large amount. This can be understood by Newton's 2nd law of motion which is summarized by the equation

$$F = m \times a \quad \text{(force = mass x acceleration)} \qquad (1)$$

Basically the force or thrust (F) is created by accelerating the mass of air (m) by the acceleration (a). Given that thrust is proportional to airflow rate and that engines must be designed to give large thrust per unit engine size, it follows that the jet engine designer will generally attempt to maximize the airflow per unit size of the engine [2]. This means maximizing the speed at which the air can enter the engine, and the fraction of the inlet area that can be devoted to airflow. Gas turbine engines are generally far superior to piston engines in these respects; therefore piston-type jet engines have not been developed.

The gas turbine engine is essentially a heat engine using air as a working fluid to provide thrust. To achieve this, the air passing through the engine has to be accelerated; this means that the velocity or kinetic energy of the air must be increased [3]. First, the pressure energy is raised, followed by the addition of heat energy, before final conversion back to kinetic energy in the form of a high velocity jet.

2. PARTS OF ENGINE

The basic mechanical arrangement of a gas turbine is relatively simple. It consists of only four parts[4]:

1) The compressor which is used to increase the pressure (and temperature) of the inlet air.

2) One or a number of combustion chambers in which fuel is injected into the high-pressure air as a fine spray, and burned, thereby heating the air. The pressure remains (nearly) constant during combustion, but as the temperature rises, each kilogram of hot air needs to occupy a larger volume than it did when cold and therefore expands through the turbine.
3) The turbine which converts some of this temperature rise to rotational energy. This energy is used to drive the compressor.
4) The exhaust nozzle which accelerates the air using the remainder of the energy added in the combustor, producing a high velocity jet exhaust.

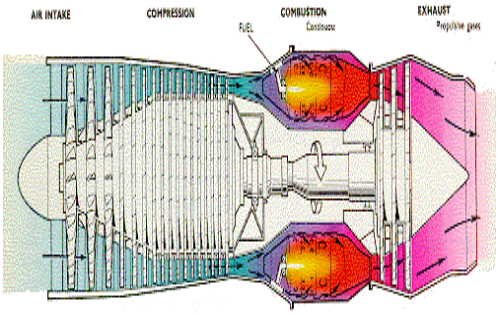

Figure 1. Turbojet engine

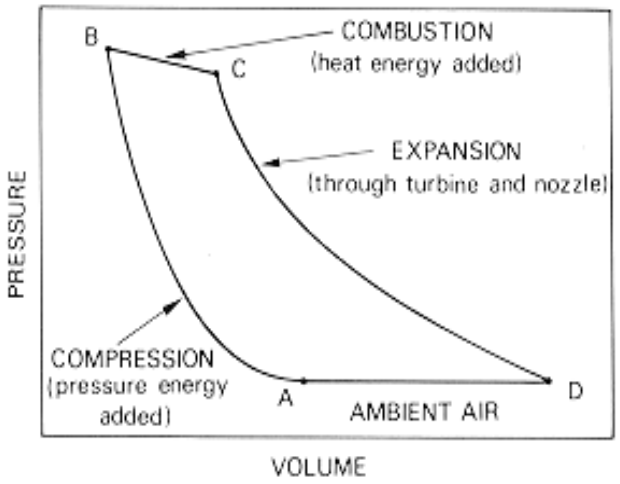

Figure 2. Operation cycle of a turbojet engine

This generalization, however, does not extend to the detailed design of the engine components, where account has to be taken of the high operating temperatures of the combustion chambers and turbine; the effects of varying flows across the compressor and turbine blades; and the design of the exhaust system through which the gases are ejected to form the propulsive jet[6].

3. COMPRESSORS

In the gas turbine engine, compression of the air is effected by one of two basic types of compressor, one giving centrifugal flow and the other axial flow. Both types are driven by the engine turbine and are usually coupled direct to the turbine shaft[7]. The centrifugal flow compressor employs an impeller to accelerate the air and a diffuser to produce the required pressure rise. Flow exit's a centrifugal compressor radially (at 90° to the flight direction) and it must therefore be redirected back towards the combustion chamber, resulting in a drop in efficiency[8]. The axial flow compressor employs alternate rows of rotating (rotor) blades, to accelerate the air, and stationary (stator) vanes, to diffuse the air, until the required pressure rise is obtained. The pressure rise that may be obtained in a single stage of an axial compressor is far less than the pressure rise achievable in a single centrifugal stage. This means that for the same pressure rise, an axial compressor needs many stages, but a centrifugal compressor may need only one or two. An engine design using a centrifugal compressor will generally have a larger frontal area than one using a axial compressor[9].

This is partly a consequence of the design of a centrifugal impeller, and partly a result of the need for the diffuser to redirect the flow back towards the combustion chamber[10].

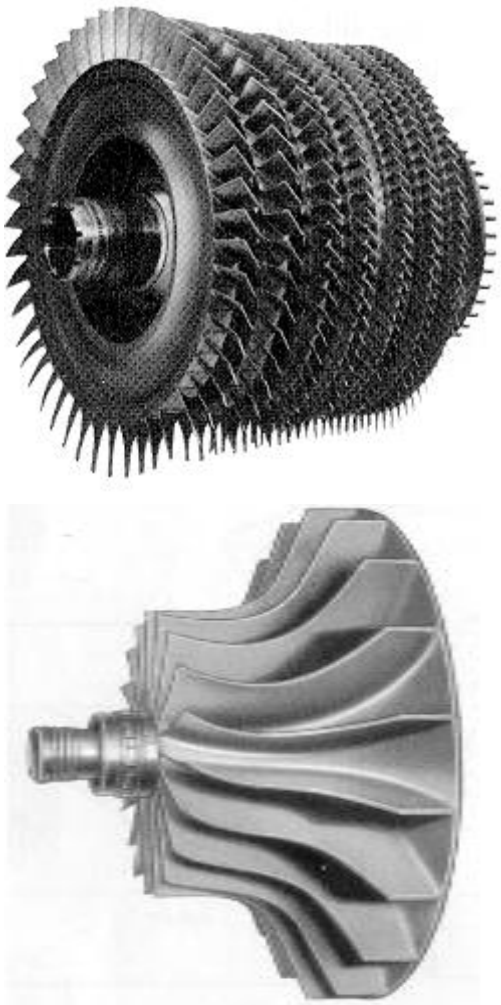

Figure 3. Centrifugal compressor and impeller

As the axial compressor needs more stages than a centrifugal compressor for the equivalent pressure rise, an engine designed with an axial compressor will be longer and thinner than one designed using a centrifugal compressor[11]. This, plus the ability to increase the overall pressure ratio in an axial compressor by the addition of extra stages, has led to the use of axial compressors in most engine designs, however, the centrifugal compressor is still favored for smaller engines where it's simplicity, ruggedness and ease of manufacture outweigh any other disadvantages[12].

4. COMBUSTION CHAMBER

The combustion chamber has the difficult task of burning large quantities of fuel, supplied through fuel spray nozzles, with extensive volumes of air, supplied by the compressor, and releasing the resulting heat in such a manner that the air is expanded and accelerated to give a smooth stream of uniformly heated gas. This task must be accomplished with the minimum loss in pressure and with the maximum heat release within the limited space available[13]. The amount of fuel added to the air will depend upon the temperature rise required.

However, the maximum temperature is limited to within the range of 850˚C to 1700˚C by the materials from

which the turbine blades and nozzles are made. The air has already been heated to between 200˚C and 550˚C by the work done in the compressor, giving a temperature rise requirement of 650˚C to 150 ˚C from the combustion process. Since the gas temperature determines the engine thrust, the combustion chamber must be capable of maintaining stable and efficient combustion over a wide range of engine operating conditions. The temperature of the gas after combustion is about 1800˚C to 2000 ˚C, which is far too hot for entry to the nozzle guide vanes of the turbine[14]. The air not used for combustion, which amounts to about 60 percent of the total airflow, is therefore introduced progressively into the flame tube. Approximately one third of this gas is used to lower the temperature inside the combustor; the remainder is used for cooling the walls of the flame tube. There are three main types of combustion chamber in use for gas turbine engines. These are the multiple chambers, the can-annular chamber and the annular chamber[15].

4.1. Types of combustion chambers [16]

(A) MULTIPLE CHAMBER: This type of combustion chamber is used on centrifugal compressor engines and the earlier types of axial flow compressor engines. It is a direct development of the early type of Whittle engine combustion chamber. Chambers are disposed radially around the engine and compressor delivery air is directed by ducts into the individual chambers. Each chamber has an inner flame tube around which there is an air casing. The separate flame tubes are all interconnected. This allows each tube to operate at the same pressure and also allows combustion to propagate around the flame tubes during engine starting.

(B) CAN ANNULAR CHAMBER

This type of combustion chamber bridges the evolutionary gap between multiple and annular types. A number of flame tubes are fitted inside a common air casing. The airflow is similar to that already described. This arrangement combines the ease of overhaul and testing of the multiple system with the compactness of the annular system.

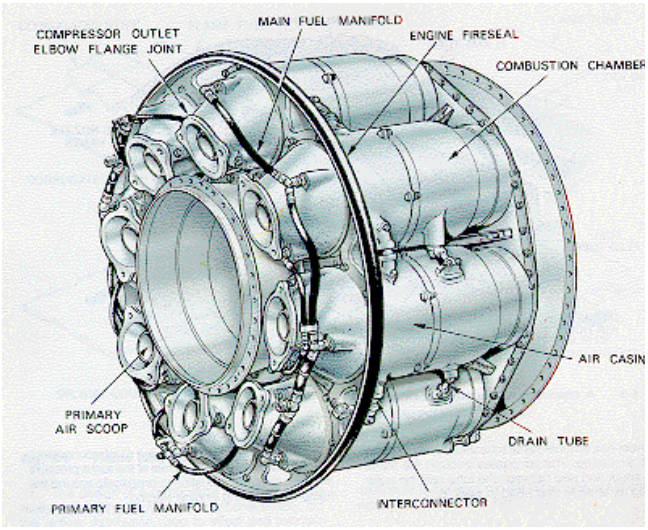

Figure 4. Combustion chamber

(C)ANNULAR CHAMBER

This type of combustion chamber consists of a single flame tube, completely annular in form, which is contained in an inner and outer casing. The main advantage of the annular combustion chamber is that for the same power output, the length of the chamber is only 75 per cent of that of a can-annular system of the same diameter, resulting in a considerable saving in weight and cost. Another advantage is the elimination of combustion propagation problems from chamber to chamber

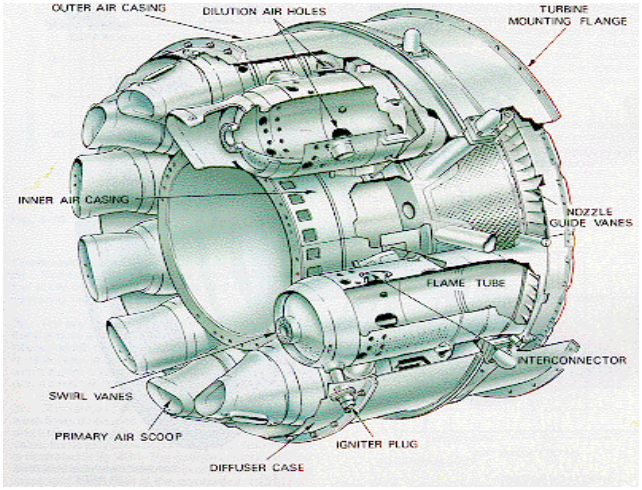

Figure 5. Can annular chamber

5. TURBINE

The turbine has the task of providing power to drive the compressor and accessories. It does this by extracting energy from the hot gases released from the combustion system and expanding them to a lower pressure and temperature. The continuous flow of gas to which the turbine is exposed may enter the turbine at a temperature between 850˚Cand 1700˚C which is far above the melting point of current materials technology. To produce the driving torque, the turbine may consist of several stages, each employing one row of stationary guide vanes, and one row of moving blades. The number of stages depends on the relationship between the power required from the gas flow, the rotational speed at which it must be produced, and the diameter of turbine permitted[17].

The design of the nozzle guide vanes and turbine blade passages is broadly based on aerodynamic considerations, and to obtain optimum efficiency, compatible with compressor and combustor design, the nozzle guide vanes and turbine blades are of a basic aerofoil shape. The desire to produces a high engine efficiency demands a high turbine inlet temperature, but this causes problems as the turbine blades would be required to perform and survive long operating periods at temperatures above their melting point. These blades, while glowing red-hot, must be strong enough to carry the centrifugal loads due to rotation at high speed. To operate under these conditions, cool air is forced out of many small holes in the blade[18]. This air remains close to the blade, preventing it from melting, but not detracting significantly from the engine's overall performance. Nickel alloys are used to construct the turbine blades and the nozzle guide vanes because these

materials demonstrate good properties at high temperatures.

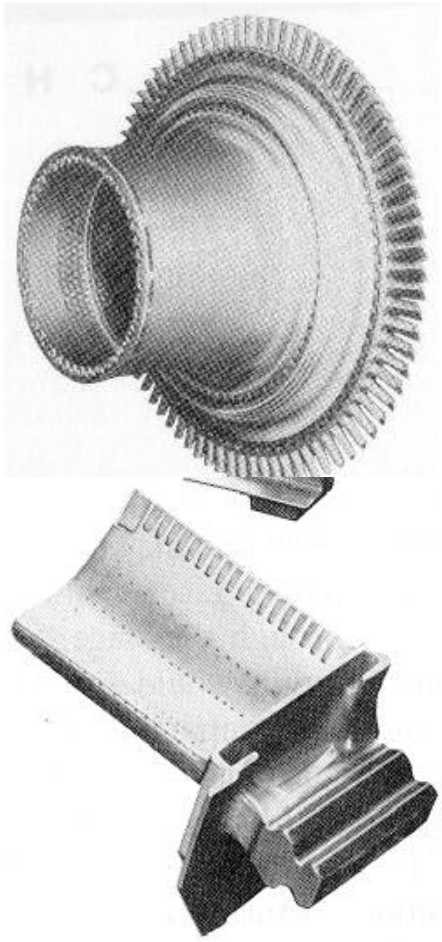

Figure 6. HP-Turbine an a turbine blade

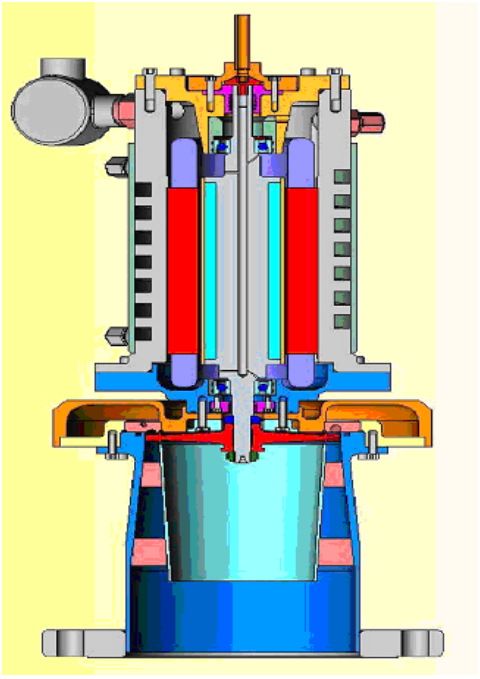

Figure 7. Cross-section of turbo starter of R—29B

6. EXHAUST NOZZLE

Gas turbine engines for aircraft have an exhaust system which passes the turbine discharge gases to atmosphere at a velocity in the required direction, to provide the necessary thrust. The design of the exhaust system, therefore, exerts a considerable influence on the performance of the engine. The cross sectional areas of the jet pipe and propelling or outlet nozzle affect turbine entry temperature, the mass flow rate, and the velocity and pressure of the exhaust jet. A basic exhaust system function is to form the correct outlet area and to prevent heat conduction to the rest of the aircraft. The use of a thrust reverser (to help slow the aircraft on landing), a noise suppresser (to quite the noisy exhaust jet) or a variable area outlet (to improve the efficiency of the engine over a wider range of operating conditions) produces a more complex exhaust system [19].

7. AFTERBURNER

In addition to the basic components of a gas turbine engine, one other process is occasionally employed to increase the thrust of a given engine. Afterburning (or reheat) is a method of augmenting the basic thrust of an engine to improve the aircraft takeoff, climb and (for military aircraft) combat performance. Afterburning consists of the introduction and burning of raw fuel between the engine turbine and the jet pipe propelling nozzle, utilizing the unburned oxygen in the exhaust gas to support combustion [20]. The resultant increase in the temperature of the exhaust gas increases the velocity of the jet leaving the propelling nozzle and therefore increases the engine thrust. This increased thrust could be obtained by the use of a larger engine, but this would increase the weight, frontal area and overall fuel consumption. Afterburning provides the best method of thrust augmentation for short periods. Afterburners are very inefficient as they require a disproportionate increase in fuel consumption for the extra thrust they produce. Afterburning is used in cases where fuel efficiency is not critical, such as when aircraft take off from short runways, and in combat, where a rapid increase in speed may occasionally be required. The big advantage of an afterburner is that we can significantly increase the thrust of the engine without adding much weight or complexity to the engine

An afterburner is nothing but a set of fuel injectors, a tube and flame holder that the fuel burns in, and an adjustable nozzle. A jet engine with an afterburner needs an adjustable nozzle so that it can work both with the afterburners on and off.[21]

The disadvantage of an afterburner is that it uses a lot of fuel for the power it generates. Therefore most planes use afterburners sparingly. For example, a military jet would use its afterburners when taking off from the short runway on an aircraft carrier. The following pictures show some of the details of an afterburner-equipped engine. This particular engine comes from an F-4.

This includes the compressor, combustion chamber and exhaust turbine. At the exhaust end of the engine, we can see a ring of injectors for the afterburner.

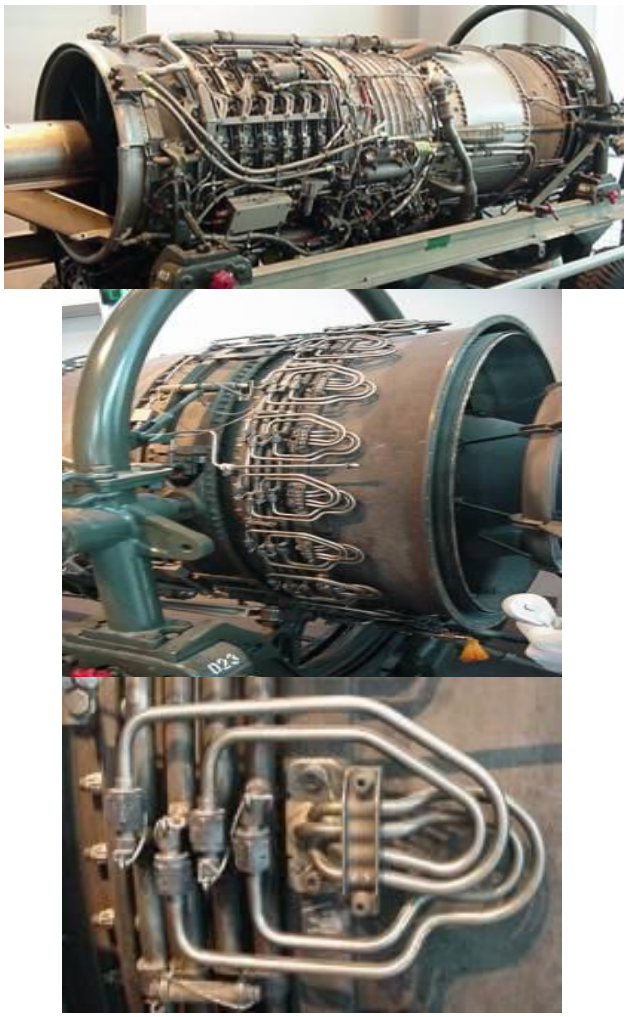

Figure 8. Fuel injectors

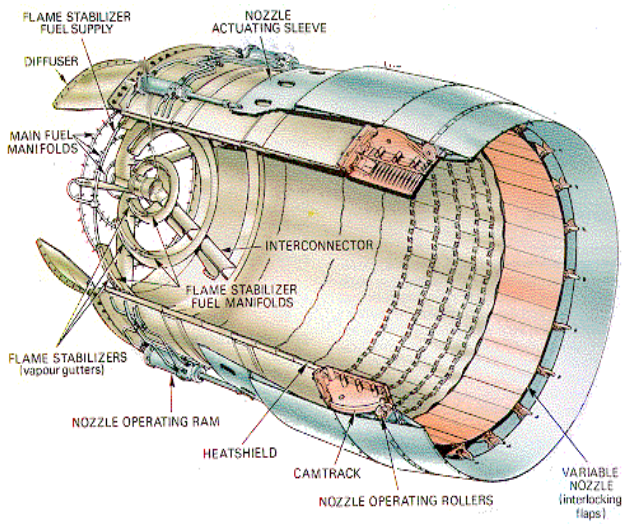

Figure 9. Afterburner

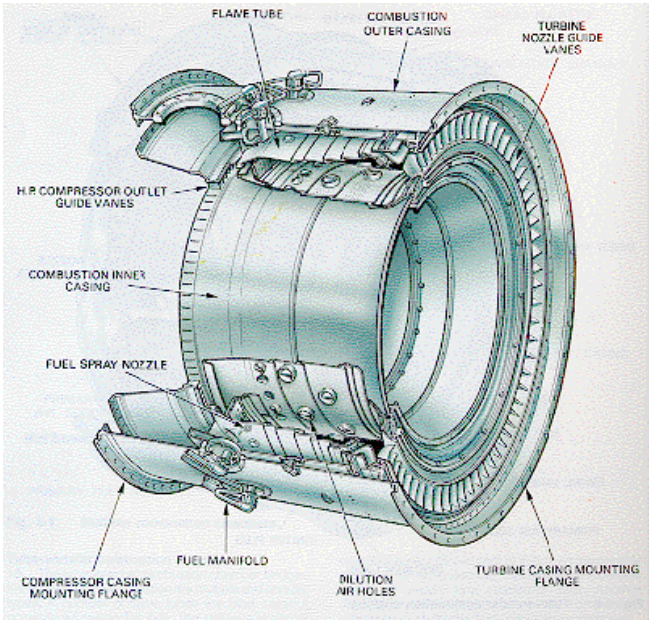

Figure 10. Annular chamber

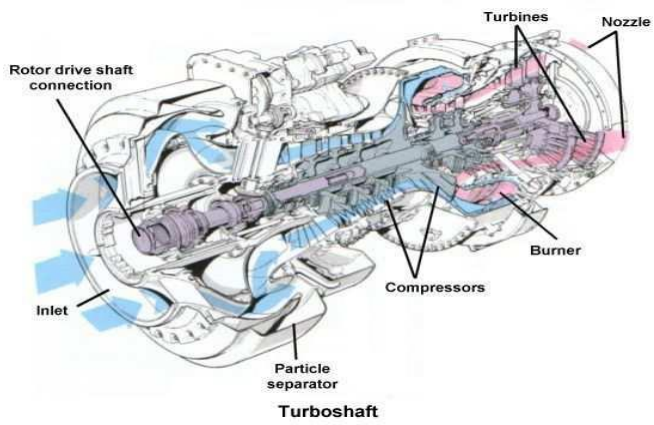

Figure 11. Cross section of a turbo-jet engine

8. COOLING OF TURBO-JET

Various components of-jet engines need to be cooled to ensure safe and efficient operation. This is particularly true for the combustor, for the *turbine* blades and for various accessories. Because of the direct relationship between turbine inlet temperature and engine operating efficiency, much development emphasis has been given to combustor and turbine blade materials and designs which can tolerate such high temperatures. In fact, many of today's turbine engines operate at turbine inlet temperatures which are above the melting point of the materials used in the turbine blades. Hence adequate cooling techniques are a must[22].

Several engine accessories, in particular the engine generator, must also be cooled. In flight, this is done by ducting outside air from special cooling air intakes toward the accessories. During ground operation this does not work and low pressure air is tapped from the compressor and ducted to the accessories. This would hurt the efficiency of the engine in flight and therefore a valving system is used to switch from external air to compressor air and vice-versa.

A schematic of an arrangement for cooling the engine generator is shown in figure given:

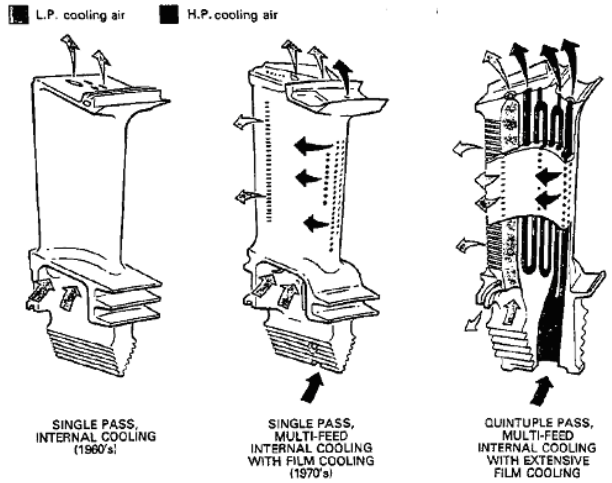

Figure 12. Development of Turbine Blade Cooling

The design of the nacelle which cowls the engine must be taken into consideration. It should be expected that if large power outputs are required for the accessory drive system, they will tend to require a significant amount of volume. This in turn will affect the size and shape of the nacelle which in turn affects the weight and drag of the airplane. Also structural provisions must be made to mount the engine to the airframe. These structural provisions must take into account the weight and the thrust output of the engine. This also requires additional volume in the nacelle[23].

9. CONCLUSIONS

In- flight icing is a serious hazard. It destroys the smooth flow of air, increasing drag, degrading control authority and decreasing the ability of an airfoil to lift. The actual weight of the ice on the aeroplane is secondary to the airflow disruption it causes. As power is added to compensate for the additional drag and the nose is lifted to maintain altitude, the angle of attack increases, allowing the underside of the wings and fuselage to accumulate additional ice. Ice accumulates on every exposed frontal surface of the aeroplane – not just on the wings, propeller, and windshield, but also on the antennas, vents, intakes, and cowlings. It builds in flight where no heat or boots can reach it. It can cause antennas to vibrate so severely that they break. In moderate to severe conditions, a light aircraft can become so iced up that continued flight is impossible. The aeroplane may stall at much higher speeds and lower angles of attack than normal. It can roll or pitch uncontrollably, and recovery may be impossible[24].

Once a tail plane stall is encountered, the stall condition tends to worsen with increased airspeed and possibly may worsen with increased power settings at the same flap setting. Airspeed, at any flap setting, in excess of the aero plane manufacturer's recommendations for the flight and environmental conditions, accompanied by uncleaned ice contaminating the tail plane, may result in a tail plane stall and uncommanded pitch down from which recovery may not be possible.

Tail plane stall symptoms include:

a) Elevator control pulsing, oscillations, or vibrations.
b) Abnormal nose down trim change.
c) Any other unusual or abnormal pitch anomalies (possibly resulting in pilot induced oscillations).
d) Reduction or loss of elevator effectiveness.
e) Sudden change in elevator force (control would move nose down if unrestrained).
f) Sudden uncommanded nose down pitch.

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NUMERIČKO ISTRAŽIVANJE UTJECAJA RADIJALNE ZRAČNOSTI NA PERFORMANSE KOMPRESORA S KOMBINIRANIM TOKOM

NUMERICAL INVESTIGATION OF INFLUENCE OF TIP CLEARANCE IN MIXED-FLOW COMPRESSOR PERFORMANCE

Guo-jie Zhang, Yi-min Li, Zhong-ning Zhou

Izvorni znanstveni članak

Sažetak: *Kod kompresora s kombiniranim tokom, protok rasipanja kroz radijalnu zračnost stvara vršni vrtlog rasipanja zbog interakcije s glavnim tokom te uzročno tok u prolazu rotora čini kompleksnijim. Različite veličine radijalne zračnosti uzrokuju različiti intenzitet smetnje glavnom toku. U ovom članku, numerička analiza provodi se korištenjem komercijalnog koda kako bi se istražio utjecaj radijalne zračnosti na glavni tok. Ocjenjene su performanse rotora kombiniranog toka sa četiri različite radijalne zračnosti između rotora i stacionarnog kućišta te su uspoređene s eksperimentalnim rezultatima. Krivulje performansa rotora dobivene su za različite parametre masenog protoka sa različitim radijalnim zračnostima pri konstrukcijskoj brzini. Rezultati pokazuju kako protok vršnog rasipanja ima snažno međudjelovanje s glavnim tokom i da pridonosi potpunom gubitku tlaka i smanjenju performansa. Smanjenje tlaka i performansi približno je linearno proporcionalno razmaku između rotora i stacionarnog kućišta. Kroz raspored vektora brzine, računalni izračuni otkrivaju kako intenzitet smetnja koje se stvaraju kod međudjelovanja protoka rasipanja i glavnog toka, ima priličan utjecaj na efikasnost. Kvantiteta protutoka je minimalna kad radijalna zračnost iznosi 0.5mm, a usporedno tome, kad je radijalna zračnost 0.75mm, ima značajan utjecaj na glavni tok kroz međudjelovanje s protokom rasipanja.*

Ključne riječi: *kompresor s kombiniranim tokom, radijalna zračnost, efikasnost, proto vršnog rasipanja, numerička analiza*

Original scientific paper

Abstract: *In mixed-flow compressor, the leakage flow through the tip clearance generates the tip leakage vortex by the interaction with the main flow, and consequently makes the flow in the impeller passage more complex. Different tip clearances generate different intensity of disturbance to main flow. In this paper, numerical analysis is performed using a commercial code to investigate tip clearance effects on main flow. The performance of mixed-flow impeller with four different clearances between impeller and stationary shroud are evaluated and compared with experimental results. The impeller performance curves are obtained for different mass flow parameters with different tip clearances at design speed. The results show that the tip leakage flow strongly interacts with main flow and contributes to total pressure loss and performance reduction. The pressure and performance decrement are approximately linearly proportional to the gap between impeller and stationary shroud. Though the velocity vectors distribution, the computed results reveal that the intensity of the disturbance generated by the leakage flow interacts with the main flow has rather a large influence over efficiency. And the quantity of backflow is minimum when the tip clearance is 0.5 mm, while the 0.75mm tip clearance, by contrast, has a considerable effect on main flow by the interaction with leakage flow.*

Keywords: *Mixed-flow compressor, tip clearance, efficiency, tip-leakage flow, numerical analysis*

1 INTRODUCTION

A mixed-flow compressor is favored for applications in small gas turbine engines as it provides smaller frontal area and higher thrust to weight ratio. Maintaining a gap (i.e., tip clearance) between the blade tip and stationary shroud is necessary to ensure the relative motion be-tween the rotor and stationary shroud in a mixed-flow compressor. However, the tip clearance provides a channel for fluid to leak from the pressure surface to the suction surface, which leads to a tip leakage flow, and the tip-leakage flow has a considerable effect on the stage pressure ratio and efficiency, Besides, the efficiency and reliability of the compressor depend to a great extent on flow behavior in its flow passage and flow near shroud (tip) gap. It is well known that the interaction between impeller and shroud has substantially influence over the flow field and performance of the compressor. It is therefore necessary to study and under-stand the complex flow field inside the flow channel of the mixed-flow compressor [1].

King and Glodeck [2] experimentally investigated a parallel cut-off mixed impeller with 0.89 mm (0.3500) frontal clearance to study the performance of the compressor. A very low value of maximum adiabatic efficiency, 0.76, is reported. Wilcox and Rabbins [3] tested an impeller pre-whirl vanes designed using Goldstein's method. The impeller has a maximum tip diameter of about 176 mm and has a peak pressure ratio of 3.7 with impeller adiabatic efficiency of 0.78, which is a very low value. Dallenbach [4] presented a method for aerodynamic design for centrifugal and mixed-flow compressors to achieve prescribed impeller blade-loading distri-butions for impellers with radial blade elements. He also presented experimental velocity-distribution results for 12 impellers including four mixed-flow impellers de-signed with this method. Only one impeller gives satisfactory blade loading. Experimental investigations were carried out by D Ramesh Rajakumar to study the effect of tip clearance (between impeller and stationary shroud) in a mixed-flow compressor stage. Two configurations, namely constant and variable clearance gaps, between impeller and stationary shroud were considered [5].

In a centrifugal compressor, the leakage flow through the tip clearance generates the tip leakage vortex by the interaction with the main flow, and consequently makes the flow in the impeller passage more complex by the interaction with the passage vortex [5]. The influence of the interaction of the tip leakage vortex with the shock wave on the performance of axial compressor is clari-fied by many studies [6, 7], Masanao Kaneko and Hoshio Tsujita [8] clarified the influences of the tip leakage flow on the behavior of secondary flow, the formation of shock wave and the loss generation in the transonic centrifugal compressor at the design condition by using the commercial CFD code, but that in the mixed-flow compressor has not been fully clarified yet.

The objective of this work is to determine the effect of different tip clearances at design rotational speed on the performance of a mixed-flow compressor stage, and the reason will be discussed. The objectives are achieved by using the commercial CFD code.

2 NUMERICAL METHOD

2.1 Physical model

Fig. 1 shows a schematic of the study object: the mixed-flow compressor which was designed by D Ramesh Rajakumar [5]. The design rotational speed is 39,836r/min, and the design pressure ratio and the design mass flow rate are 3.8 and 2.72kg/s, respectively. The impeller had 11 main blades with a cone angle of 60°. Table 1 lists the main parameters of the mixed-flow compressor.

Figure 1 Schematic diagram for the mixed-flow compressor

In the present study, the maximum thickness of the blade tip is 1.15 mm. Software of BladeGen is applied to design the mixed-flow compressor model. Software of TurboGrid is employed to establish fluid calculation area and generate the grid according to the practical size of mixed-flow compressor blade. Then the grid is imported to CFX to calculate the distribution of fluid field around the blade tip, the total pressure ratio (π_{12}) and isentropic efficiency (η_{12}). π_{12} is the ratio of the total pressure mass-averaged on the cross section at the impeller outlet to that at the inlet (=P_{t2}/P_{t1}). η_{12} is defined by

$$\eta_{12} = \left[(P_{t2}/P_{t1})^{(k-1)/k} - 1\right]/(T_{t2}/T_{t1} - 1) \times 100\% \quad (1)$$

Where T_{t1} and T_{t2} are the total temperature mass-averaged on the cross section at the impeller inlet and outlet, respectively, and κ is the specific heat ratio.

Table 1 Specifications of the mixed-flow impeller

	value
impeller inlet parameter	
Impeller inlet tip diameter d_{1it} (m)	0.156
Impeller inlet hub diameter d_{1ih} (m)	0.0625
Impeller rotational speed N (rpm)	39836
Hub-to-tip diameter ratio d_{1ih}=d_{1it}	0.4
Relative blade angle at tip β_{1it} (°)	61.8
Relative blade angle at hub β_{1ih} (°)	36.7
Impeller exit parameter	
Impeller exit tip diameter d_{2it} (m)	0.253
Impeller exit hub diameter d_{2ih} (m)	0.239
Impeller exit blade height f b_{2i}(m)	0.0141
Relative blade angle at tip β_{2it} (°)	58.5
Relative blade angle at hub β_{2ih} (°)	46.8
Absolute flow angle α_{2it} (°)	70
Number of blade Z_m/Z_s(Main/Splitter)	11/11

2.2 Computational model and boundary conditions

The CFD (computational fluid dynamics) software CFX is used to simulate the internal flow of mixed-flow compressor with the assumption that the flow is the steady state compressible flow. The κ − ε turbulence model is widely employed for simulating complex flows, including swirling flow, secondary flow and boundary layer separation under adverse pressure gradient and this model properly reflect the effects of transient flow and streamline curvature; additionally, the simulated results are verified

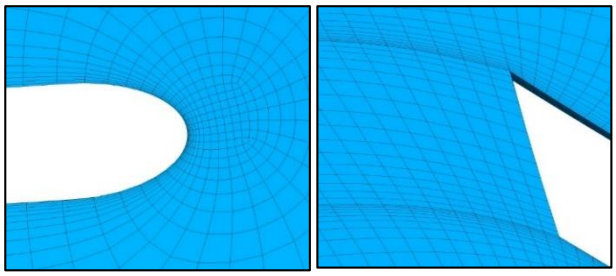
to agree well with experimental results [10, 11]. Thus, the $\kappa - \varepsilon$ turbulence is chosen to solve the three-dimensional steady Reynolds-averaged equations in this study. And air is considered as an ideal gas. The CFD solution adopted SIMPLE method. The boundary condition of the inlet are total temperature and total pressure, and mass flow of the outlet. The MRF (multiple reference frame) model is selected to couple the rotating impeller and stationary shroud [11]. The blade wall is set to the no slip boundary condition, and Counter Rotating Wall is used for shroud. The calculation can be reliably considered to have converged when the residuals of the parameters and velocity in all directions are less than 10-4, the volume flow rate difference between the inlet and outlet reaches 10-5 simultaneously.

2.3. Mesh generation and independence verification

Structured high-resolution hexahedral meshes are used for the discretization of the one-passage model (see Figure 2a). ANSYS Turbogrid 15.0 with ATM optimized option was used for grid generation of rotor domains and tip clearance. For the surrounding of the blades, an O-Grid is built up to give a satisfactory resolution for the boundary layer near them and the value of y^+ is approximately 25. Therefore, near-wall mesh resolution is acceptable. While for the blade passage, an H-Grid is applied. The detailed grid information near the leading and trailing edges of main blades are enlarged in Fig.2b for better views. The numbers of elements in the streamwise, pitchwise and spanwise directions are 380, 88 and 56, respectively. The number of cell in the tip clearance region for TC is 5 in the spanwise direction.

To eliminate the effect of the mesh number on simulated results, the mesh independence is verified using the mixed-flow compressor with eleven groups of different mesh numbers, the tip clearance is 0.9-mm. Fig. 3 indicates that when the mesh number exceeds 90 thousand, the simulation results for both the total pressure ratio and the isentropic efficiency are almost maintain unchangeable. Thus, the mesh number of 90 thousand meets the requirements of computation accuracy and is selected for the mixed-flow compressor in the present investigation.

(a) The mesh of one-passage at 60% span



(b) Grids near leading edge and trailing edge of main blade

Figure 2 The mesh of the mixed-flow compressor

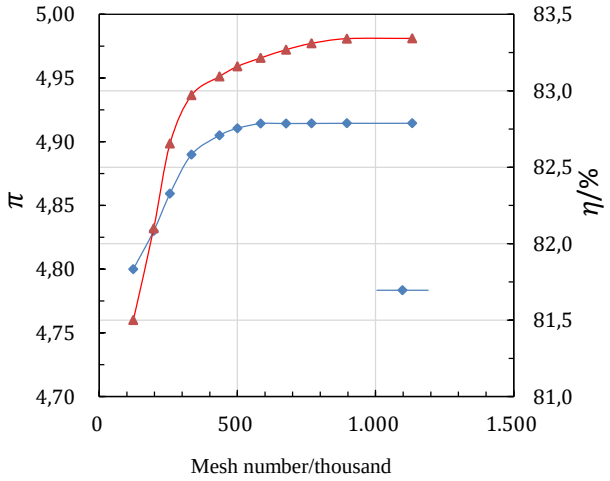


Figure 3 Independence verification of mesh number

2.4. Comparison of the mixed-flow compressor performance

Before change the tip clearance, the simulated and experimental performance curves of the mixed-flow compressor with 0.9mm tip clearance at 65% of design speed are compared for Mass flow parameter of 0.9~1.3, as shown in Fig. 4. Where

$$\text{Mass flow parameter}=m\sqrt{\frac{T_{01}}{T_{01\,ref}}/\frac{P_{01}}{P_{01\,ref}}}. \quad (2)$$

The experimental performance curves were reported in the reference [5]. The calculated total pressure ratio and isentropic efficiency curves are reasonably close to the experimental data, showing a slight shift toward low mass flow parameter. The difference between numerical values and experiments is within an arguably acceptable range. In particular, under the design mass flow rate $q_m = 2.72\ kg/s$ and the relative errors are less than 2% and 4%. Therefore, the present numerical results are considered to be reliable.

CFX is used to simulate the internal flow characteristics of the mixed-flow compressor with different blade tip clearances, 0.5mm, 0.75mm 0.9mm and 1.15mm, respectively.

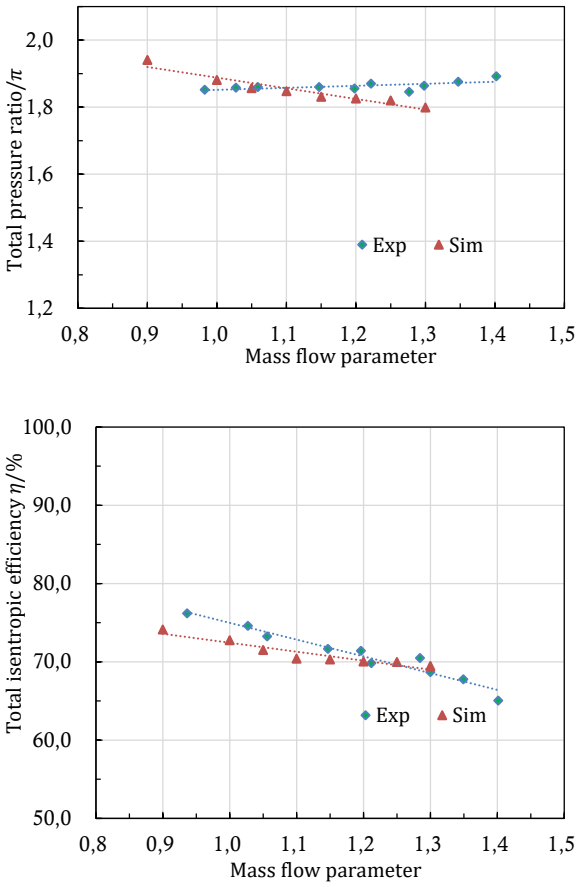


Figure 4 Comparison of simulated and experimental performance curves

3 RESULTS AND DISCUSSIONS

3.1 Performance characteristics of different tip clearances

The performance of the compressor estimated from the CFX analysis is shown in Fig.5. The total to total pressure ratio is plotted against mass flow parameter for four tip clearances at design speed.

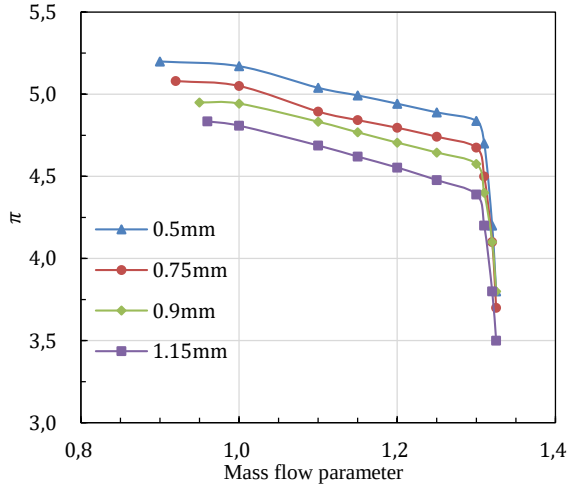


Figure 5 The total pressure ratio of the compressor

It is observed from Fig.5 that at design speed and at various clearances compressor choke mass flow parameter varies from 1.28 to 1.33 whereas surging mass flow parameter is varies from 0.9 to 0.95. Hence compressor at design speed has 10% to 15% surge margin for four tip clearances. The increase in choke mass flow parameter for higher tip clearance is due to increase in inlet area with same impeller tip diameter. Surge occurs earlier in the impeller with higher clearance as the flow has large tendency to separate with cross flow in the clearance spaces interacting with the main flow.

The total isentropic efficiency of the impeller was calculated. The variation of impeller total isentropic efficiency for different tip clearances at design speed is shown in Fig.6.

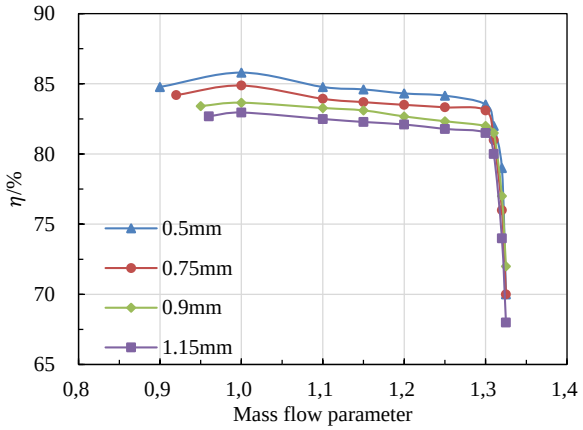


Figure 6 The total isentropic efficiency of the compressor

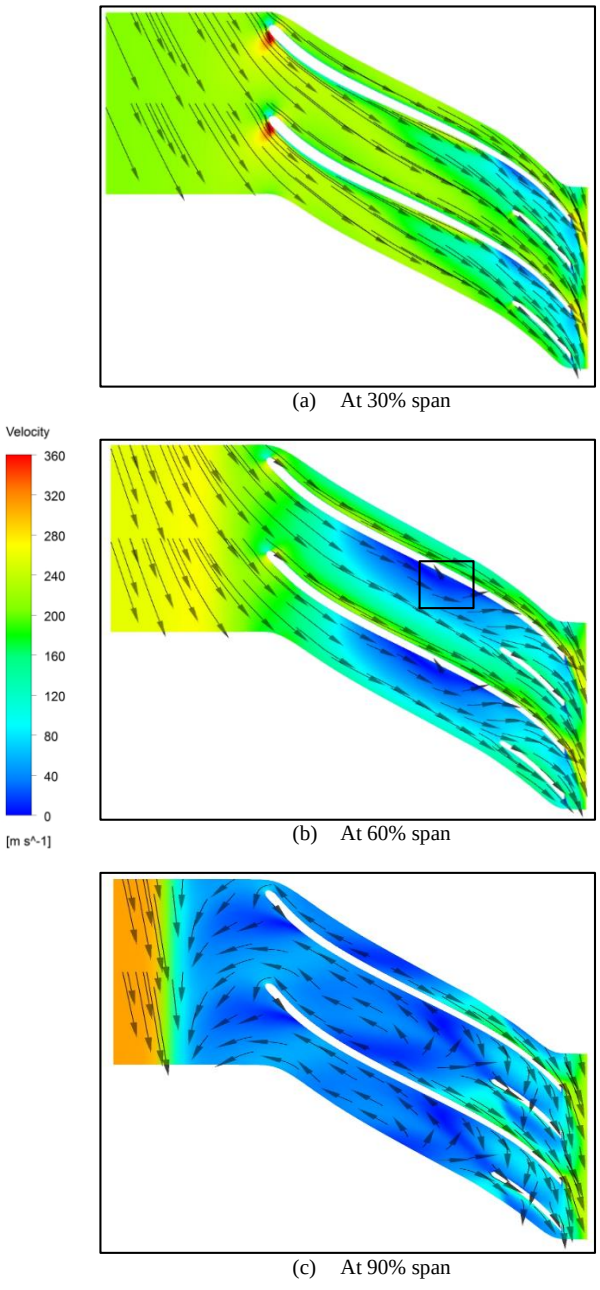
The peak efficiency of the impeller for 0.5mm tip clearances is around 85%. However, the peak efficiency drops marginally with the tip clearance increases. For the maximum tip clearance the impeller peak efficiency is 82.95%. The impeller efficiency at the larger mass flow parameter is smaller than the value at a lower mass flow parameter. This is because the incidence angle for the main blade is largely negative with a possibility of flow separation on the blades. With the mass flow parameter increased, the impeller efficiency decreased sharply due to choking. Tip leakage flow strongly interacts with mainstream flow and contributes to pressure loss and efficiency reduction. It is observed that the pressure ratio and efficiency drop are nearly linear proportion to the tip clearance.

3.2 Distribution of flow field at different spans

The relative velocity vectors and streamlines can show vortex structures of the flow field perfectly. And in principle, the velocity vectors should tangent to blade surface in ideal circumstances. Fig. 7 illustrates the distribution of the relative velocity vectors on the blade-to-blade surface at the different spans with 0.9mm tip clearance.

As shown in Fig. 7a, the airflow which the direction of velocity from the leading edge to trailing edge is relatively uniform, and this is what we want to see. While a small amount of backflow flow is grew along the suction surface of the main blade at 60% span (Fig. 7b), and other most flow is acceptable. With the increase of span, a large amount of reflux is formed in flow channel and the flow

at 90% span becomes complex and disorder (Fig. 7c), which will lead to the decrease of the efficiency of compressor and is unacceptable. This is due to the fact that the tip leakage flow induced by the high loading at the leading edge of the main blade is suddenly attenuated by the interaction with the main flow. Through above analysis, the intensity of the disturbance have rather a large influence over efficiency and should be focused closely.



(a) At 30% span

(b) At 60% span

(c) At 90% span

Figure 7 Velocity vectors distribution at different spans

3.3 The influence of different tip clearances on flow field

The relative velocity vectors at different tip clearances for design speed are plotted in Fig. 8. At 30% span, the velocity vectors with different tip clearances are similarly distributed and all comparatively uniform. However, with the increase of span, the direction of relative velocity vectors change in local region. For the different tip clearances, the span which appeared backflow for the first time is different, so is the region.

As for four tip clearances, the backflow primarily emerges is 0.75 mm tip clearance at 45% span, while 0.5mm tip clearance which the early backflow shows at the leading edge of 77% span exhibits acceptable distribution of flow field. For the significative phenomenon, the reason may be the leakage and intensity, when the tip clearance is small, the leakage is little but intensity is tremendously high, while the leakage increase and intensity decrease slowly with the enlargement of tip clearance. The span where the backflow begins to take shape increases gradually with the increment of tip clearance. At 90% span, a large amount of backflow is all appeared in flow channel for four tip clearances. In contrast, the quantity of backflow is minimum when the tip clearance is 0.5 mm.

With the support of the flow physics, the authors cautiously suggest that 0.5 mm tip clearance can be accept completely, 0.75 mm should be avoided.

4 CONCLUSION

Simulation was carried out for mass flow parameter ranging from 0.9 to 1.35 at 65% design speed. The total pressure ratio and isentropic efficiency are achieved. The calculated curves are reasonably close to the experimental data, the present numerical results are considered to be reliable.

The study reveals that the total-to-total pressure ratio and isentropic efficiency decrease with the increment of tip clearance. The drop in impeller efficiency is more outstanding with the change of tip clearance. 0.5mm tip clearance provides better performance in terms of pressure ratio and efficiency than those of other three tip clearances.

The loss generation in the mixed-flow centrifugal compressor with the tip clearance is mainly caused by the backflow on the passage of the impeller due to the interaction of the tip leakage flow from the tip clearance of the main blade with the main flow, and the interaction enhances with the tip clearance increases to 0.75mm, then weakens with the tip clearance increases to 1.15mm.

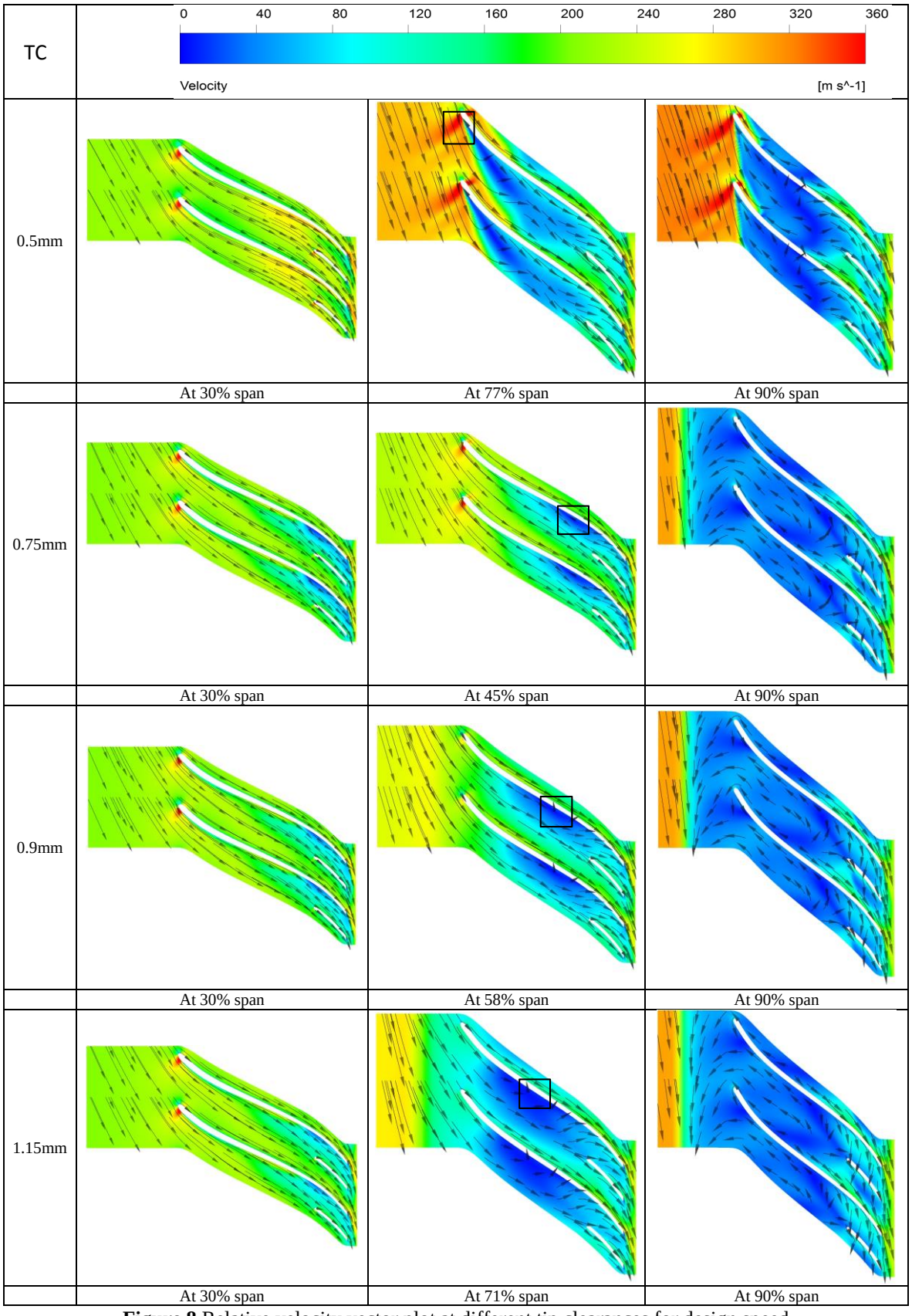


Figure 8 Relative velocity vector plot at different tip clearances for design speed

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MODELIRANJE PUŽNOG PARA I GENERIRANJE TEHNIČKE DOKUMENTACIJE

MODELING WORM GEAR AND GENERATE THE TEHNICAL DOCUMENTATION

Nurdin Ćehajić

Stručni članak

Sažetak: *U radu je prikazana izrada 3D modela puža, pužnog kotača i glavčine. Uz podršku softverskog programa CATIA V5 i njegovih namjenskih skupova modula Assembly Design i Drafting izvršeno je sklapanje generiranih 3D komponenti u sklop, kao i generiranje 2D tehničke dokumentacije. Na ovaj način stvorene su pretpostavke za izradu proizvoda i njegovu funkcionalnu provjeru u stvarnim uvjetima rada i upotrebe.*

Ključne riječi: *puž, pužni kotač glavčina, 3D modeliranje, tehnička dokumentacija, CATIA V5*

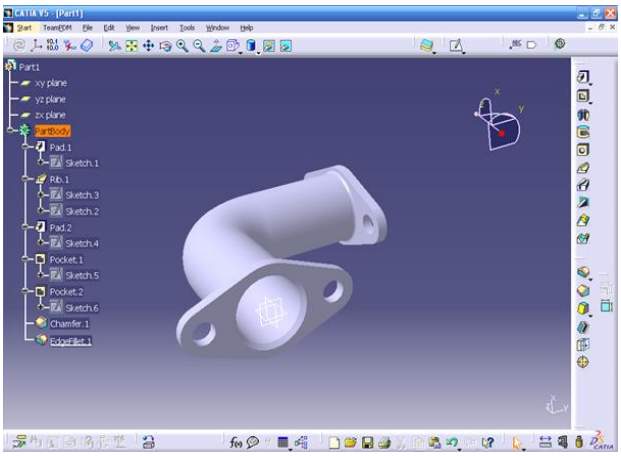
Professional paper

Abstract: *This paper presents the creation of 3D models of snail, worm wheel and hub. With the support of the software CATIA V5 and its, of earmarked sets of modules Assembly Design and Drafting, the connection of the generated 3D components in the assembly was made, as well as 2D drawings generated. In this way, conditions have been created for the development of the product and its functional verification in the actual operating conditions and usage.*

Keywords: *snail, worm wheel, hub, 3D modeling, technical drawings, CATIA V5*

1. UVOD

Današnje modeliranje nezamislivo je bez upotrebe suvremenih CAD (Computer Aided Design) sistema. CAD sistem u širem smislu omogućava 3D modeliranje dijelova, izradu sklopova, generiranje tehničke dokumentacije, simulaciju rada i analizu strojnih elemenata i sistema. Na temelju navedenog prikazana je izrada 3D modela i 2D tehničke dokumentacije pužnog para. U tu svrhu korišten je softverski program CATIA V5, koji pored ostalog, omogućava napredne tehnike modeliranja i generiranja tehničke dokumentacije (slika 1.).



Slika 1. Radno okruženje softvera Catia V5

S obzirom da se radi o veoma zahtjevnim grafičkim alatima neophodna je upotreba višejezgrenih procesora kako bi se postigla odgovarajuća brzina procesa prilikom kreiranja virtualnih 3D modela.

2. PUŽNI PAR

Za prijenos obrtnog kretanja (momenta) između vratila čije se ose mimoilaze ili su okomite, pored cilindričnih zupčanika sa zavojnim zupcima i hipoidnih zupčanika upotrebljavaju se i pužni parovi. Pužni par se sastoji od puža i pužnog kola. Puž ima oblik sličan zavrtnju sa trapeznim navojem, a koristi se kao pogonski element.

Prema obliku tjemenih i podnožnih površina puža postoje:

- Cilindrični i
- Globoidni pužni parovi.

U radu će se modelirati cilindrični pužni parovi kod kojih i tjemena i podnožna površina puža ima oblik cilindra, kao što je prikazano na slici 2.

Slika 2. Pužni par

Prijenosni omjer se računa kao i za ostale zupčaste parove:

$$i = \frac{\omega_1}{\omega_2} = \frac{z_1}{z_2} \quad (1)$$

gdje su: ω_1 i ω_2 ugaone brzine, a z_1 i z_2 brojevi zubaca puža i pužnog kola respektivno.

3. MODELIRANJE PUŽNOG PARA

3.1. Modeliranje puža

Za postupak modeliranja puža uzete su sljedeće karakteristike:
- modul: $m = 4\ mm$
- pužni broj: $q = 10$
- broj hodova: $z_1 = 1\ hod$
- dužina puža: $b_1 = 50\ mm$

Na osnovu zadatih podataka računaju se [1]:
- Promjer srednjeg kruga:
$d_m = m \cdot q = 4 \cdot 10 = 40\ mm$
- Promjer diobeni kruga:
$d_1 = d_m + 2 \cdot x \cdot m = 40 + 2 \cdot 0 \cdot 4 = 40\ mm$
- Promjer tjemenog kruga:
$d_{a1} = d_m + 2 \cdot m = 40 + 2 \cdot 4 = 48\ mm$
- Promjer podnožnog kruga ($c = 0{,}2$):
$d_{f1} = d_m - 2m \cdot (1 + c) = 40 - 8 \cdot 1{,}2 = 30{,}4\ mm$
- Kut zavojnice:

$$tg\ \gamma_m = \frac{z_1}{q} = \frac{1}{10} = 0{,}1$$

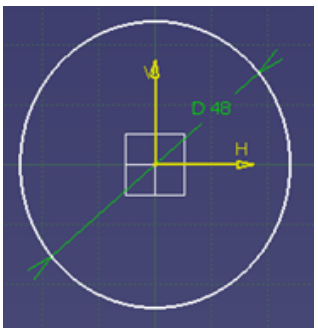
$$\gamma_m = arc\ tg 0{,}1 = 5{,}7106$$

- Hod zavojnice:
$L = d_m \cdot \pi \cdot tg\ \gamma_m = 40 \cdot \pi \cdot 0{,}1 = 12{,}566\ mm$

- Debljina zupca puža na srednjem cilindru u pravcu normale:

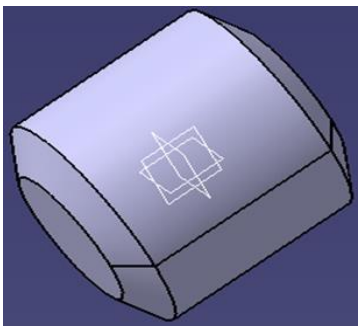
$$s_1 = \frac{m \cdot \pi \cdot cos\ \gamma_m}{2} = 6{,}252\ mm$$

Proces modeliranja puža započinje u radnom okruženju za crtanje skica - *Sketcher*, gdje je u ravnini yz izrađena skica, kao na slici 3.



Slika 3. Skica profila puža

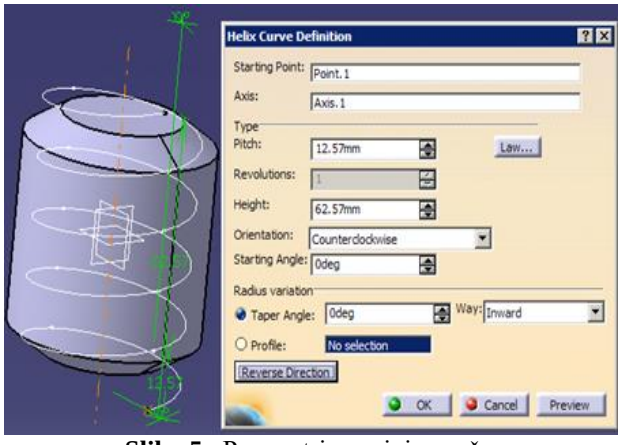
Materijal se nanosi u modulu *Part Design* pomoću opcije *Pad*, gdje se u prozoru *Pad Definition* unosi vrijednost ekstrudiranja od $25\ mm$, uz prethodno selektiranje skice (*Sketch.1*) sa slike 3. Opcijom *Chamfer* se obaraju rubovi u iznosu $8{,}8/30°$ te model puža dobiva oblik kao na slici 4.



Slika 4. Izgled modela puža nakon ekstrudiranja i obaranja rubova

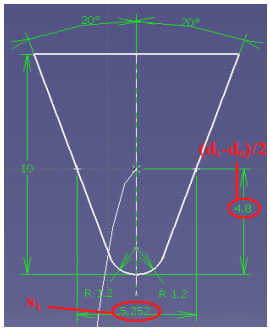
Početna točka zavojnice se određuje opcijom *Point* te se u prozoru za dijalog *Point Definition* unose koordinate točke: x = 31,28 mm i y =20 mm.

Zavojnica se definira naredbom *Helix* koja se nalazi u izborniku *Mechanical Design - Wireframe And Surface Design*, pri čemu se u okviru za dijalog *Helix Curve Definition* unesu parametri:
- dužina zavojnice: $b1 + L = 50 + 12{,}57 = 62{,}57\ mm$ i
- korak: $L = 12{,}57\ mm$, što je prikazano na slici 5.



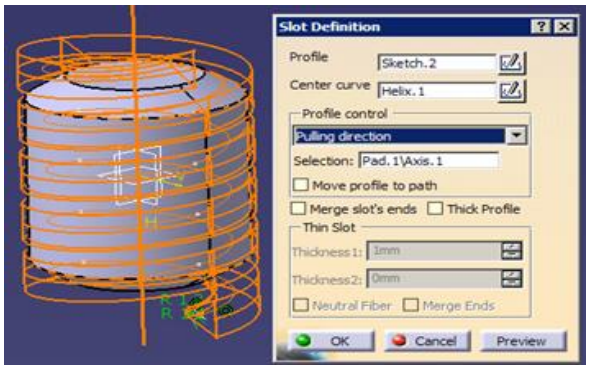
Slika 5. Parametri zavojnice puža

Pomoću opcija *Profile*, *Corner*, *Constraint* i *Constraint Defined in Dialog Box* u Sketcher-u u ravnini xy je izrađena 2D skica profila zavojnice puža, slika 6.

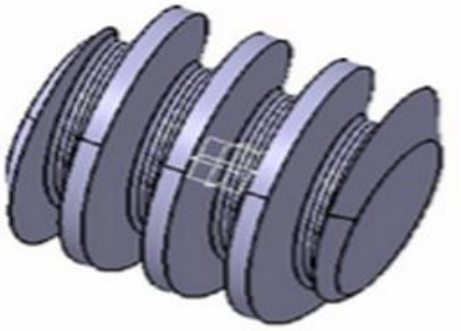


Slika 6. Skica profila zavojnice

Opcijom *Slot* u prozoru za dijalog *Slot Definition* podese se parametri kao na slici 7. te se dobiva izgled modela puža kao na slici 8.

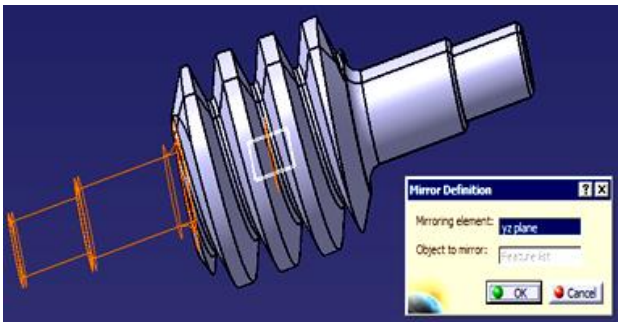


Slika 7. Nanošenje materijala zavojnice opcijom Slot



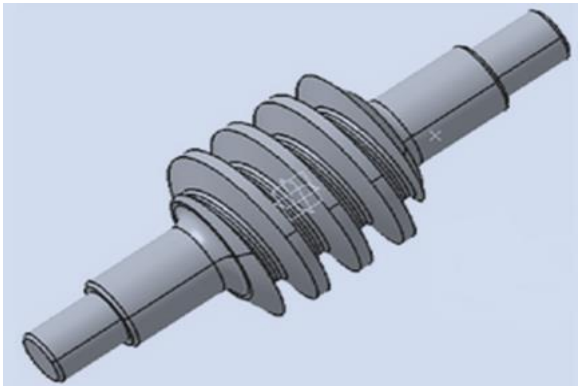
Slika 8. Izgled zavojnice 3D modela puža

U *Sketcher*-u se opcijama *Circle* i *Constraint* nacrtaju dvije uzastopne skice krugova promjera $D = 20\ mm$ i $D = 16\ mm$ te se njihovim ekstrudiranjem funkcijom *Pad* za vrijednosti 30 mm i 20 mm respektivno, kao i obaranjem i zaobljavanjem rubova opcijama *Chamfer* (3/45°) i *Fillet* (R=4mm), model puža transformira u oblik kao na slici 9.



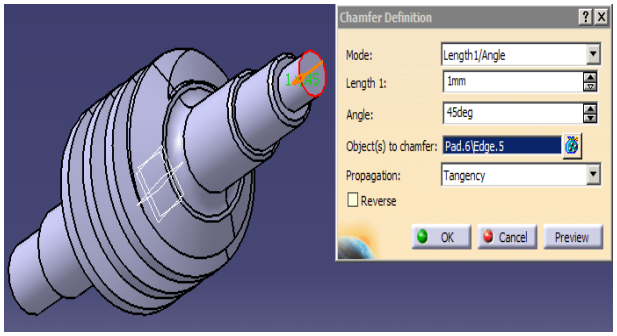
Slika 9. Izgled modela puža nakon ekstrudiranja i modificiranja

Selektiranjem posljednja četiri *Feature*-a pomoću konfiguracijskog stabla te njihovim preslikavanjem preko yz-ravnine opcijom *Mirror*, dobiva se novi izgled modela puža, koji je prikazan na slici 10.



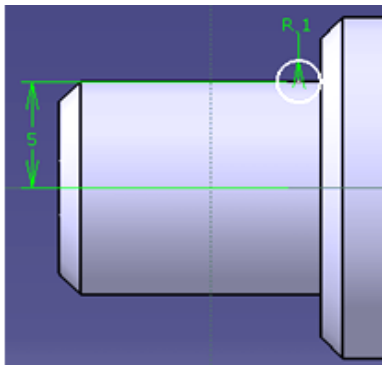
Slika 10. Izgled modela puža nakon preslikavanja

Nakon pozicioniranja u ogovarajuću ravninu i crtanja i dimenzioniranja kružnice promjera 10 mm opcijama *Circle* i *Constraint* te njenim ekstrudiranjem za 12 mm i obaranjem ruba za 1/45° dobiva se model puža kao na slici 11.



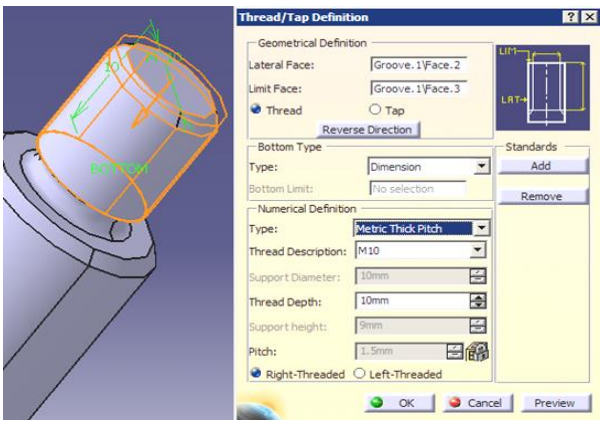
Slika 11. Izgled modela puža nakon ekstrudiranja i obaranja ruba

Selektiranjem ravnini xy u *Sketcher-u* i upotrebom naredbi *Circle i Constraint* nacrtan je krug radijusa R=1mm (slika 12.), koji je osnova za uklanjanje materijala s obujma modela upotrebom funkcije *Groove* sa podešenim pripadajućim parametrima.



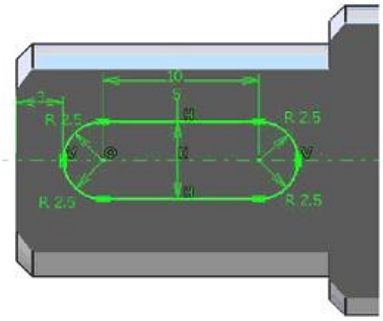
Slika 12. Skica kruga u ravnini xy

Na posljednjem Feature-u se dodaje metrički navoj funkcijom *Thread/Tap*, gdje se definiraju geometrijske i numeričke veličine navoja, kako je prikazano na slici 13.



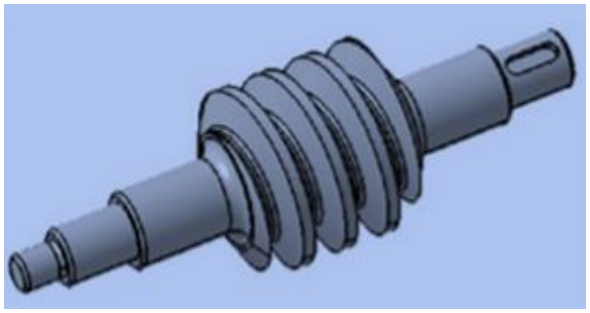
Slika 13. Parametri metričkog navoja

Opcijom *Plane* dodaje se nova ravnina u kojoj se crta žlijeb za klin. Referentna ravnina je xy, a vrijednost *Offset*-a je 4,6 mm. Pozicioniranjem na novokreiranu ravninu, u *Sketcher*-u se nacrta skica žlijeba za klin, kao što je prikazano na slici 14.



Slika 14. Skica žlijeba za klin

Novonacrtana skica žlijeba i prethodno dodana nova ravnina osnove su za skidanje materijala s modela upotrebom funkcije *Pocket* te 3D model puža poprima konačni oblik prikazan na slici 15.



Slika 15. 3D model puža

3.2. Modeliranje pužnog kola

Pužni zupčanik se najčešće izrađuje iz dva dijela koji se međusobno spajaju vijcima. Ti dijelovi su:
- pužni kotač i
- tijelo pužnog zupčanika (glavčina).

Veza pužnog točka i glavčine se ostvaruje uvrtnim ili podešenim vijcima.

U procesu modeliranja pužnog kola uzete su njegove sljedeće karakteristike:

- modul: $m = 4\ mm$
- broj zubaca pužnog kotača: $z_2 = 34$
- Širina pužnog kotača:

$b_2 = (0{,}75 \div 0{,}8) \cdot d_1 = \ 0{,}8 \cdot 40 = \ 32\ mm$

Na osnovu zadatih podataka određuje se:
- Promjer diobenog kruga:

$d_2 = m \cdot z_2 = 4 \cdot 34 = 136\ mm$

- Osni razmak:

$$a = \frac{d_1 + d_2}{2} = \frac{40 + 136}{2} = 88\ mm$$

- Promjer tjemenog kruga:

$$d_{a2} = d_2 + 2m \cdot (1 + x) = 136 + 2 \cdot 4 \cdot (1 + 0) = \\ = 144\ mm$$

- Promjer podnožnog kruga ($c = 0{,}2$):

$$d_{f2} = d_2 - 2m \cdot (1 + c - x) \\ = 136 + 2 \cdot 4 \cdot (1 + 0{,}2 - 0) = \\ = 126{,}4\ mm$$

- Promjer tjemenog cilindra pužnog kotača:

$d_k \geq d_{a2} + m = 144 + 4 = 148\ mm$

- Polumjer kruga tjemenog torusa pužnog kotača:

$$r_k \geq a - \frac{d_{a2}}{2} = 88 - \frac{144}{2} = 16\ mm$$

- Kut zavojnice:

$$tg\ \gamma_m = \frac{z_1}{q} = \frac{1}{10} = 0{,}1$$

$$\gamma_m = arc\ tg 0{,}1 = 5{,}7106$$

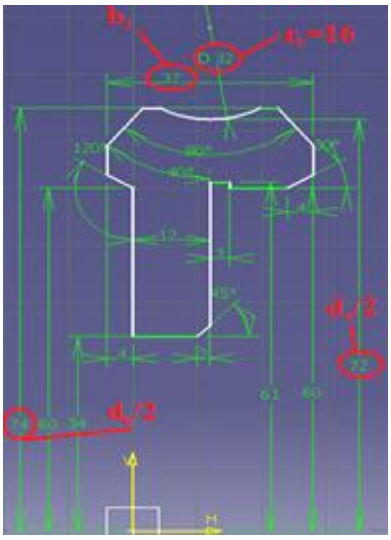
- Hod zavojnice:

$$L = d_m \cdot \pi \cdot tg\ \gamma_m = 40 \cdot \pi \cdot 0{,}1 = 12{,}566\ mm$$

- Debljina zupca puža na srednjem cilindru u pravcu normale:

$$s_1 = \frac{m \cdot \pi \cdot cos\ \gamma_m}{2} = 6{,}252\ mm$$

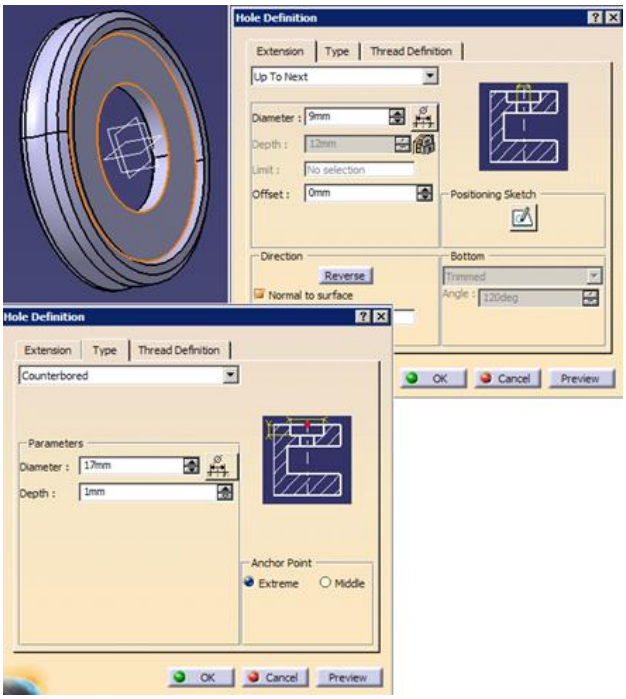
Korištenjem paleta alata *Profile*, *Constraint* i *Operation* u modulu za izradu skica *Sketcher* u ravni xy je nacrtan polazni oblik profila pužnog kotača, slika 16.



Slika 16. Polazni oblik profila pužnog kotača

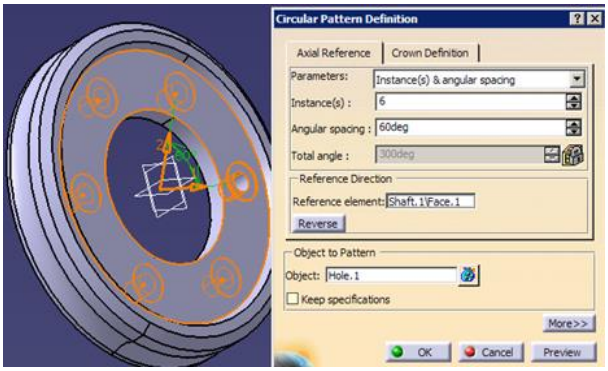
Izlaskom iz *Sketcher-a* i upotrebom funkcije *Shaft* rotira se profil sa slike 16. oko osi *Hdirection* za kut od

360°. Na tako dobivenom modelu se opcijom *Hole* podese parametri otvora prema slici 17., sa koje se vidi trenutni izgled 3D modela pužnog kotača.



Slika 17. Model pužnog kotača nakon upotrebe funkcija *Shaft* i *Hole*

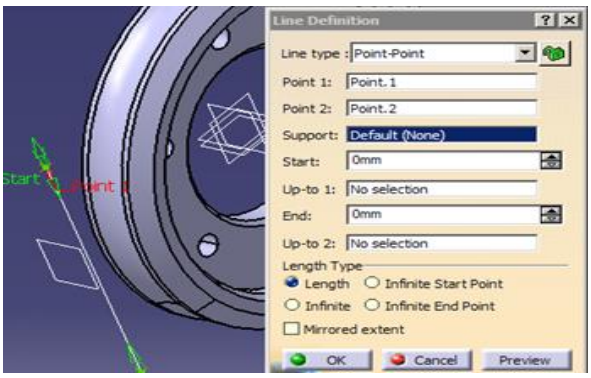
Izradom skice kruga promjera 9 mm sa centrom na udaljenosti od 47 mm od H-ose kao osnovom za upotrebu opcije *Hole*, izrađuje se otvor. Umnožavanjem otvora opcijom *Circular Pattern* dobivaju se potrebni otvori po obujmu za vijčanu vezu, što se vidi na slici 18.



Slika 18. Izrada otvora po obujmu za vijčanu vezu

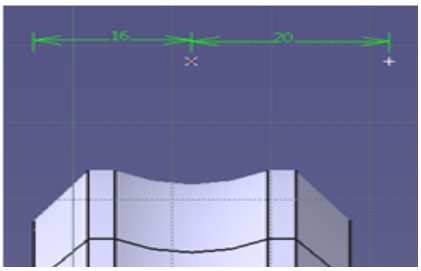
Pomoću funkcija *Body* i *Geometrcal Set* se u *Part Editoru* pojavljuju ikone *Body.2* i *Geometrical Set.1*. Opcijom Plane dodaju se dvije ravnine tipa *Offset from plane*. Prva ravnina je u odnosu na referentnu xy-ravninu sa iznosom offset-a od 3,142 mm, dok je druga ravnina u odnosu na referentnu zx ravninu sa offset-om od 38 mm.

Dodavanjem dviju točaka opcijom *Point* sa koordinatama: T_1 (12,88,-50) i T_2 (12,88,50) te njihovim spajanjem linijom**,** model izgleda kao na slici 19.



Slika 19. Izgled modela nakon definiranja ravnina, dviju točaka i linije

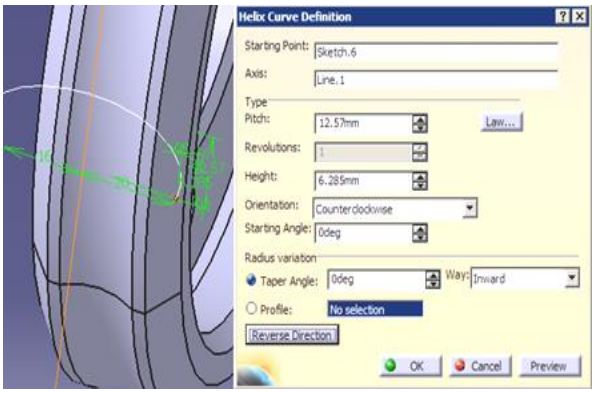
Crtanjem početne točke zavojnice u ravni *Plane.1* kako je prikazano na slici 20. omogućeno je definiranje parametara zavojnice.



Slika 20. Početna točka zavojnice

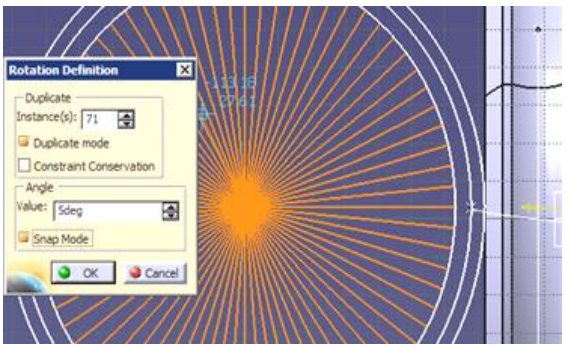
Zavojnica se definira opcijom *Helix* te se u dijalog prozoru *Helix Curve Definition* podese parametri zavojnice (slika 21.):

- dužina zavojnice: $L/2 = 6{,}285\ mm$
- korak: $L = 12{,}57\ mm$



Slika 21. Definiranje parametara zavojnice

Pozicioniranjem u ravninu *Plane.2* opcijom *Circle* se nacrtaju tri kružnice sljedećih promjera: 144 *mm,* 136 *mm i* 126,4 *mm.* Podjelom podnožne kružnice (d_{f2}*=126,4mm*) na 72 jednaka dijela opcijom *Line* koja polazi iz centra do podnožne kružnice, a zatim njenim umnožavanjem funkcijom *Rotate* dobiva se stanje kao na slici 22.



Slika 22. Podjela podnožne kružnice na 72 dijela

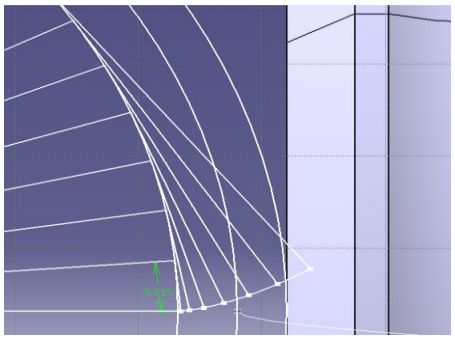
Iz dobivenih točaka na mjestima presjeka linija sa podnožnom kružnicom povlače se tangente dužina kako slijedi:

$$t_1 = \frac{d_{f2} \cdot \pi}{72} = \frac{126{,}4 \cdot \pi}{72} = 5{,}515\ mm$$

$t_2 = 2 \cdot t_1$

$t_3 = 3 \cdot t_1$ itd.

Crtanjem tangenti i spajanjem njihovih krajeva pomoću funkcije *Spline* pri isključenoj opciji *Construction/Standard Element*, dobiveno je stanje kao na slici 23.

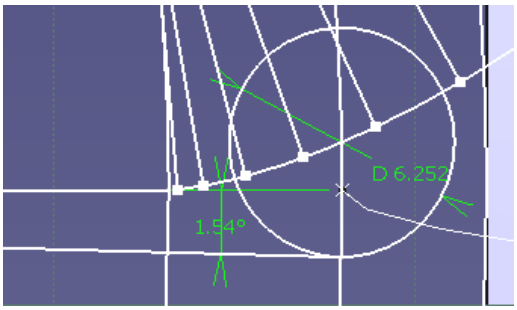


Slika 23. Crtanje tangenti i spajanje vrhova tangenti u evolventu

Opcijom *Circle* se nacrta kružnica promjera:

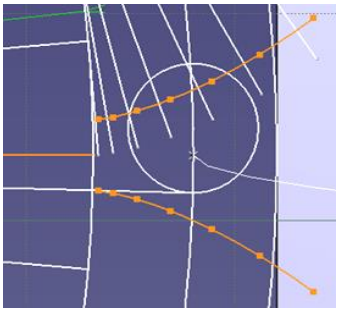
$$s_1 = \frac{m \cdot \pi \cdot cos\ \gamma_m}{2} = 6{,}252\ mm$$

s centrom u presjeku evolvente i diobene kružnice te se opcijom *Line* spaja točka presjeka tako dobivene kružnice i diobene kružnice s centrom. Opcijom *Constraint* se izmjeri kut od 1,54°, slika 24.



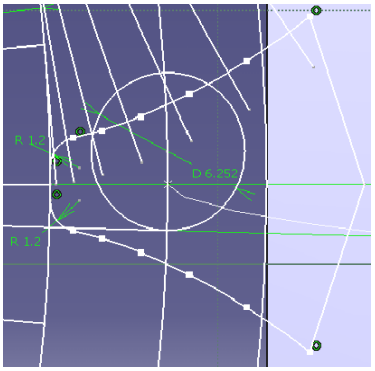
Slika 24. Kružnica sa centrom u presjeku evolvente i diobene kružnice i izmjereni kut

Selektiranjem evolvente i njenim rotiranjem opcijom *Rotate* za kut od 1,54° te preslikavanjem opcijom *Mirror* oko horizontalne ose, dobiva se skica na modelu pužnog kotača kao na slici 25.



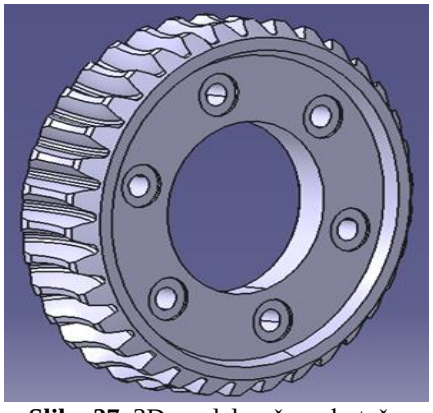
Slika 25. Bokovi zubaca pužnog kotača

Funkcijama *Profile*, *Corner* i *Quick Trim* skica sa slike 25. se dorađuje te dobiva izgled kao na slici 26.



Slika 26. Konačni izgled skice za dodavanje materijala

Nacrtana skica sa slike 26. osnova je za dodavanje materijala opcijom *Slot* , gdje se u prozoru za dijalog *Slot Definition* u nesu sljedeći parametri: Profil je *Sketch.9*, centar krivulje je *Helix.2*, a za kontrolu profila se bira *Pulling direction* sa selektiranom *Line.2*. Kopiranjem dobivenog zuba 34 puta po obujmu pužnog kotača pomoću opcije *Circular Pattern*, pužni kotač dobiva svoj konačan oblik, slika 27.

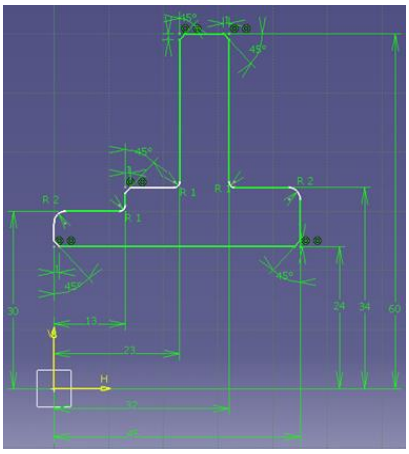


Slika 27. 3D model pužnog kotača

3.3. Modeliranje glavčine

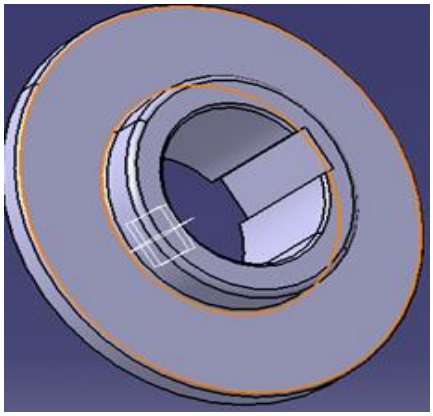
Selektiranjem ravnine zx u modulu za izradu skica *Sketcher* naredbom *Profile* i *Constraint* nacrta se i

dimenzionira polazni oblik skice kao osnove za modeliranje glavčine, slika 28.



Slika 28. Skica profila glavčine

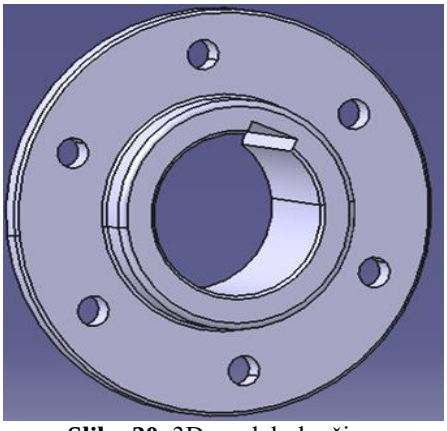
Dodavanjem materijala opcijom *Shaft* za kut od 360° uz prethodno selektirani profil i os (slika 28.), kao i izradom žlijeba opcijama *Rectangle*, *Constraint* i *Pocket* dobije se oblik modela glavčine kao na slici 29.



Slika 29. Izgled modela glavčine nakon dodavanja materijala i izrade žlijeba

Opcijom *Hole* - *Hole Definition* se definira otvor promjera 9 mm, dok se opcijom *Positioning Sketch* definira njegov položaj na tijelu glavčine (kružnica promjera D=94 mm).

Opcijom *Circular Pattern* izrađeni otvor umnožimo po površini glavčine, nakon čega se dobiva konačan izgled 3D modela glavčine, slika 30.

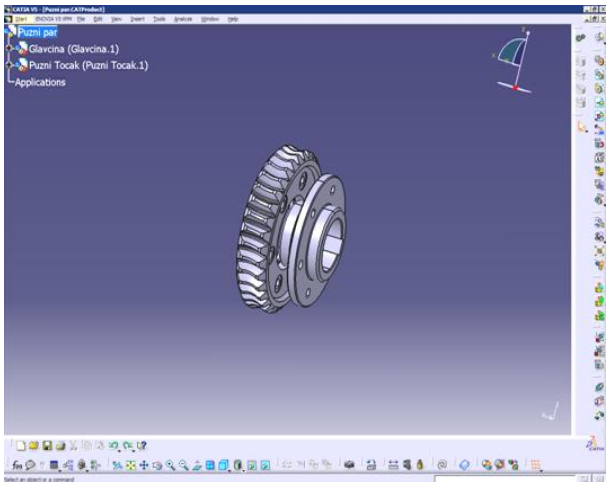


Slika 30. 3D model glavčine

3.3. Izrada 3D modela sklopa pužnog para

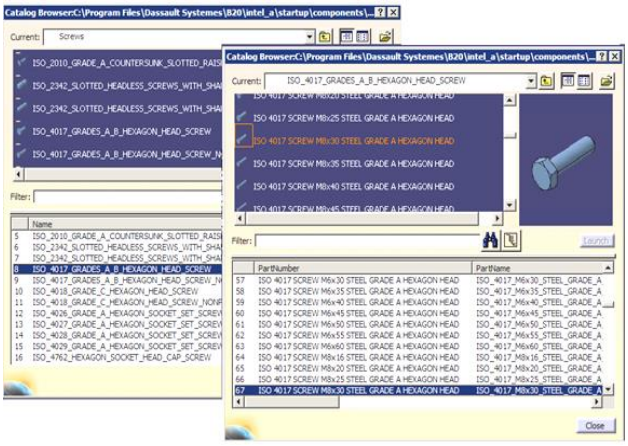
U modulu za rad sa sklopovima *Assembly Design* izvršeno je povezivanje svih generiranih komponenti u sklop. Sve izmodelirane komponente su importirane u radno okruženje *Assembly Design*, te je upotrebom palete alata *Product Structure, Constraints, Move, Manipulation, Fix i Update* omogućena organizacija, navigacija i konstrukcija dijelova s namjerom da se dobije konačni sklop.

Na slici 31. je prikazano sklapanje pužnog točka i glavčine, gdje se za vezu koriste vijci M8x30 (6 komada), navrtke i podloške Ø8.



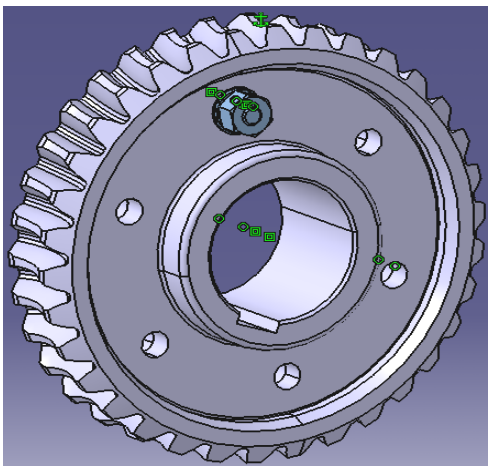
Slika 31. Pužni kotač i glavčina u Assembly Design

Katalogu gotovih dijelova se pristupa pomoću *Catalog Browser*, gdje se u prozoru *Catalog Browser:* bira vijak *ISO_4017 Screws M8x30 Steel grace a hexagon head,* slika 32. Izabrani vijak je vidljiv u desnom dijelu dijalog prozora.



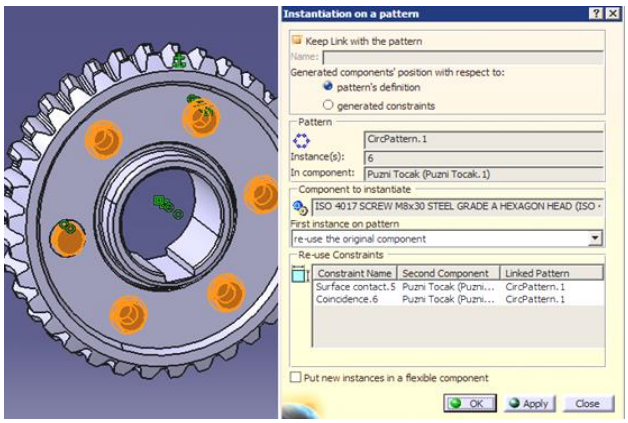
Slika 32. Catalog Browser

Drag&Drop postupkom se vijak ubaci u *Product.* Na isti način se iz kataloga uvezu podloška **(***ISO 7089 plain washer a normal series*) i navrtka (*ISO 4034 hexagon nut*) te se izvrši njihovo sklapanje, slika 33.



Slika 33. Ubacivanje vijka, podloške i navrtke u sklop

Vijci, podloške i navrtke za ostale otvore se umnožavaju opcijom *Reuse Pattern*, gdje se u dijalog prozoru *Instantiation on a pattern* selektira jedan od otvora, a zatim i komponenta koju treba umnožiti (vijak, podloška, navrtka), slika 34.

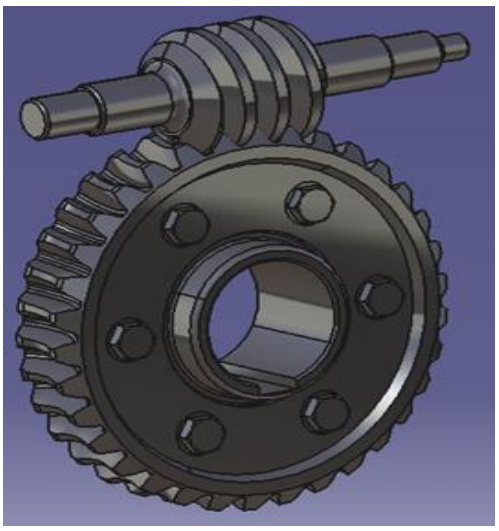


Slika 34. Umnožavanje vijka, podloške i navrtke po obimu pužnog točka

Ubacivanjem puža u *Product* koristeći funkciju *Existing component*, kao i njegovim pozicioniranjem u odnosu na pužni točak pomoću dva *Constraint-a*:

- *Offset Constraint* između xy ravni pužnog točka i yz ravni puža, a na rastojanju $s_1 = 6{,}252\ mm$ i
- *Coincidence Constraint* između ose puža i *Line.1* na pužnom točku, završeno je dobijanje sklopa pužnog para.

Izgled sklopa pužnog para nakon dodavanja materijala funkcijom *Apply material* i izborom čelika (*Steel*), 3D model sklopa pužnog para sa teksturom izabranog materijala je prikazan na slici 35.

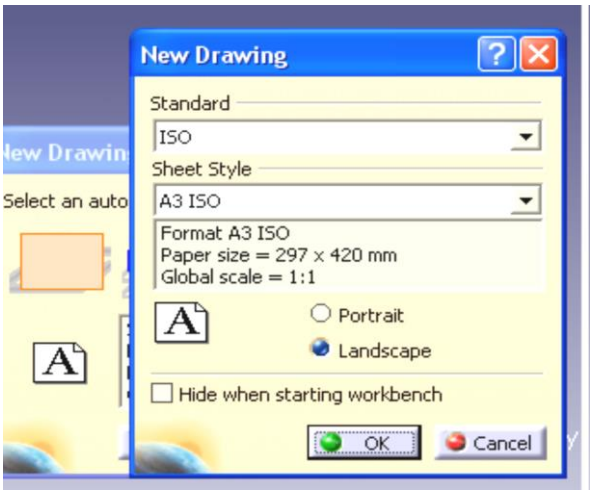


Slika 35. 3D model pužnog para

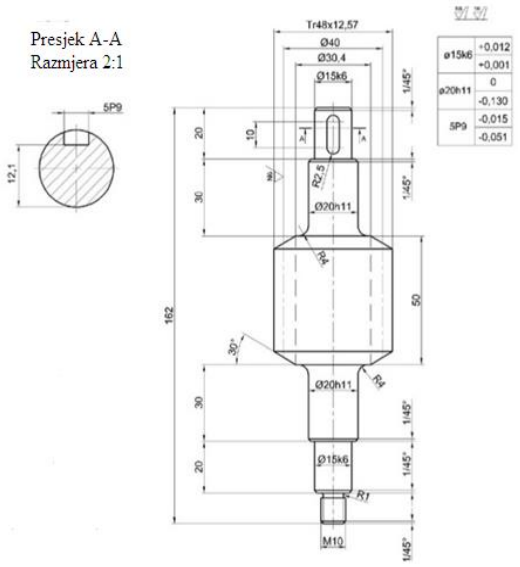
4. GENERIRANJE TEHNIČKE DOKUMENTACIJE

Generiranje 2D dokumentacije na temelju 3D modela izvodi se u modulu *Drafting* CATIA V5 softverskog programa. Korišten je generativni način izrade tehničkih crteža, što znači da se 2D pogledi u sklopu crteža kreiraju na osnovu 3D modela i ostaju međusobno povezani [2]. Zbog toga je neophodno još u fazi izrade 3D modela imati na umu kako će on izgledati u okviru tehničkog crteža, i kako s njega izvući što više informacija koje će biti prikazane na 2D crtežu [3].

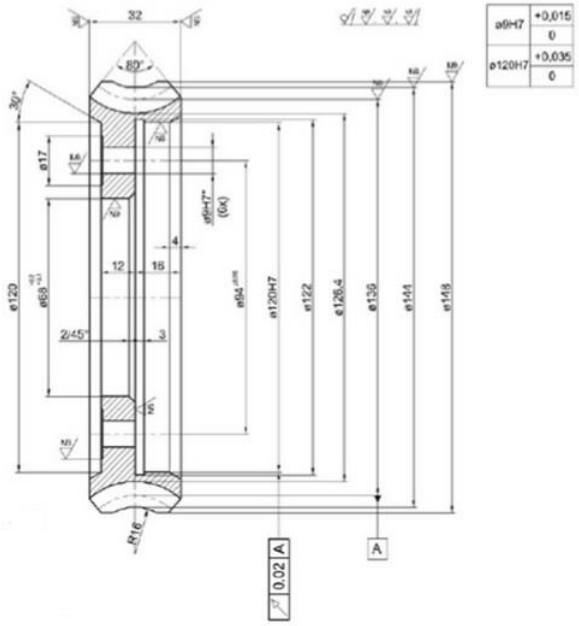
Otvaranjem novog dokumenta tipa *Drawing*, kao i modela čija se 2D tehnička dokumentacija generira uz prethodno podešavanja standarda, stila stranice i orijentacije papira za radionički crtež (slika 36.), pristupa se izradi tehničke dokumentacije kreiranih dijelova (slika 37., 38. i 39.).



Slika 36. Odabir formata, razmjere i orijentacije papira



Slika 37. 2D crtež puža



Slika 38. 2D crtež pužnog kotača

4. ZAKLJUČAK

Izradom 3D modela pužnog para upotrebom CAD sistema, te njegovom fizičkom izradom upotrebom dostupnih CAM sistema znatno se smanjuju troškovi projektiranja i razvoja te se skraćuje vrijeme izrade prototipa proizvoda.

Prikazani su postupci proračuna puža i pužnog točka, neophodni kao ulazni parametri u procesu njihovog 3D modeliranja uz pomoć programskog alata CATIA V5.

Izrađeni 3D model pužnog para može se koristiti za daljnju analizu i poboljšanja. Prikazan je i postupak izrade 2D tehničke dokumentacije. Generirani 2D crteži mogu biti osnova za izradu prototipa proizvoda i provjeru prije svega njegove ergonomske i funnkcionalne komponente u realnim uvjetima rada.

5. LITERATURA

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AUTOMATIZACIJA BAZENA ZA KUPANJE

SWIMMING POOL AUTOMATION

Tihomir Glatki, Zoran Vrhovski, Igor Petrović

Stručni članak

Sažetak: *U ovom radu opisana je automatizacija bazena za kupanje. Opisano je programiranje i upravljanje cirkulacijskim crpkama, rasvjetom, efektima za masažu i elektromagnetnim ventilom. Nabrojani su i objašnjeni energetski elementi korišteni u projektu automatizacije bazena. Programiranje Twido PLC-a izvodi se u programskom alatu TwidoSuite. U radu je opisan SCADA sustav općenito te konkretni programski alat VijeoCitect u kojem se izvodi vizualizacija i upravljanje crpkama, efektima i rasvjetom.*

Ključne riječi: *automatizacija bazena, PLC, TwidoSuite, SCADA, VijeoCitect*

Professional paper

Abstract: *This paper describes the automation of swimming pools. Programming and management of circulation pumps, lighting, massage-related effects and electromagnetic valve are described. Energetic components used in the swimming pool automation project are listed and explained. The TwidoSuite tool was used for the purpose of Twido PLC programming. This thesis includes a general description of the SCADA system, as well as a description of the VijeoCitect tool used for designing the visualization and the control of pumps, effects and lighting.*

Key words: *swimming pool automation, PLC, TwidoSuite, SCADA, VijeoCitect*

1. UVOD

Automatizacija prati razvoj tehnologije u proizvodnji i upravlja procesima bez izravnog ljudskog djelovanja. Automatizirane proizvodne linije koriste moderne računalne tehnologije upravljanja. Automatizacija stvara mogućnost rasta u proizvodnji uz smanjenje troškova proizvodnje, poboljšanje kvalitete proizvoda i mogućnost povećanja učinkovitosti kontrole proizvodnje. U konačnici, automatizacija rezultira većom produktivnosti i smanjenjem ljudske radne snage, a time smanjenje mogućnosti ljudske pogreške u proizvodnji.

Automatizacija bazena opisana u ovom radu izvedena je u suradnji s tvrtkom Elektro-Čelik d.o.o. Zadatak automatizacije bazena odnosio se na nadopunu kompenzacijskog bazena vodom, prepumpavanje vode iz kompenzacijskog bazena u bazen za kupanje, uključivanje crpki koje usmjerenim mlazom vode masiraju posjetitelje bazena, stvaranje kružnog vrtloga upuhivanjem zraka u vodu te uključivanjem rasvjete kada se smanji dnevna svjetlost. Rad traži poznavanje programskog jezika kojim se programiraju programirljivi logički kontroleri. Kroz rad se upoznaje način automatizacije bazena na način da bazen bude zanimljiviji korisnicima.

Rad je strukturiran na sljedeći način. U drugom poglavlju opisani su bazeni i potreba automatizacije bazena, a u trećem su poglavlju opisani oprema i alati korišteni za automatizaciju bazena. Programski automatizacije bazena prikazan je u četvrtom poglavlju dok je SCADA sustav automatizacije bazena prikazan u petom poglavlju.

2. BAZEN

Bazen je prostor ispunjen vodom koji služi za kupanje, plivanje i rekreaciju. Kada se bazen koristi u hotelima, pansionima, wellnes-centrima i seoskim turizmima smatra se objektom u javnoj uporabi, odnosno javnim bazenom [1]. Javni bazen za kojeg je izrađen sustav automatizacije prikazan je na slici 1.

Slika 1. Javni bazen

Javni se bazeni grade na drugačiji način od kućnih bazena. Zahtjevi za javne bazene kreću se u pravcu sposobnosti filtriranja velike količine vode te dezinfekciju velikog kapaciteta vode koja jamči visoku kvalitetu vode

u bazenu. Kvalitetu bazenske vode nadziru i reguliraju automatske centrale koje se nalaze u strojarnici bazena [1], [2]. Automatska centrala za nadzor i regulaciju kvalitete vode prikazana je na slici 2.

Slika 2. Automatska centrala za nadzor i regulaciju kvalitete vode [2]

2.1. Kako bazen učiniti zanimljivim?

Kako se razvija društvo tako raste i želja za atraktivnim i zanimljivim sadržajima na bazenu. Kupanje i plivanje više nije dovoljno privlačno za velik broj posjetitelja. Zbog toga su osmišljeni različiti sadržaji koji bazen čine zanimljivijim mjestom za odmor i rekreaciju. Masažeri, umjetno stvorene rijeke i razni vizualni efekti stvoreni pomoću svjetla su sastavni dio današnjih bazena. Dodatnim sadržajima bazena otvoren je prostor za upotrebu automatizacije i programirljvih logičkih kontrolora (PLC) [3], [4], [5]. PLC omogućuje kontrolu i nadzor bazena s jednog mjesta pomoću SCADA sustava [5], [6]. SCADA sustavom se vrši vizualizacija i upravljanje bazenom.

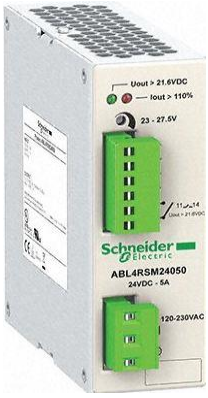
3. OPREMA KORIŠTENA U AUTOMATIZACIJI BAZENA

Oprema korištena u izradi automatizacije bazena može se podijeliti na upravljački dio kojem pripada PLC i izvršni dio kojem pripadaju elektromagnetni ventil, pumpe, puhalo, rasvjeta i ostalo.

3.1. Upravljački dio opreme korištene u automatizaciji bazena

PLC korišten za automatizaciju bazena je TWIDO PLC proizvođača Schneider Electric kataloškog broja TWDLCDE40DRF (slika 3). Karakteristike PLC-a navedene su u [7] i [8]. Napajanje PLC-a ima kataloški broj ABL8REM24050 (slika 4). Ulazni napon napajanja kreće se od 100 do 240 V (AC), a izlazni napon napajanja iznosi stabilnih 24 V (DC).

Slika 3. TWIDO PLC proizvođača Schneider Electric kataloškog broja TWDLCDE40DRF



Slika 4. Napajanje kataloškog broja ABL8REM24050

3.2. Izvršni dio opreme korištene u automatizaciji bazena

Za zatvaranje i propuštanje radnog medija, ovisno o potrebi, korišteni su elektromagnetni ventili (slika 5). Elektromagnetnim ventilom se upravlja pomoću elektromagnetnog svitka kojim upravlja PLC.

Slika 5. Elektromagnetni ventil [7]

Cirkulacijske crpke korištene u automatizaciji bazena su proizvođača Grundfos (slika 6). Crpke ovog tipa proizvode se malog, srednjeg i velikog kapaciteta. Opremljene su komunikacijskim modulom i elektroničkom regulacijom brzine [7]. Ova crpka prikladna je za sustave s konstantnim i promjenjivim protocima, sustave s promjenjivim temperaturama i sustave koji zahtijevaju noćni rad.

Slika 6. Cirkulacijska crpka Grundfos [7]

Za svjetlosne efekte u bazenu korišteni su podvodni reflektori. U bazene se ugrađuju specijalni vodonepropusni reflektori (slika 7). Napon na koji se priključuje rasvjeta za bazen je bezopasnog iznosa za zdravlje ljudi. Stupanj zaštite reflektora je IP 68. Napon napajanja LED reflektora iznosi 12 V. Kućište reflektora izrađeno je od aluminija [7].

Slika 7. Podvodni LED reflektor [7]

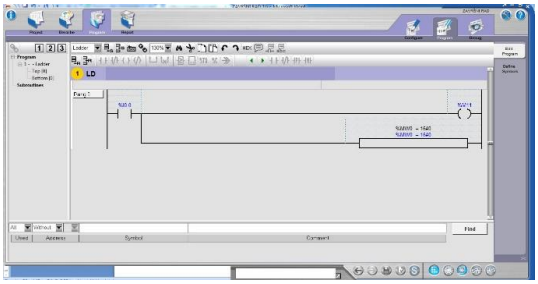
Za zračnu masažu u bazenu korištena su turbo-puhala. Turbo-puhala u bazenu imaju zadatak upuhivanje zraka u vodu i stvaranja usmjerenog mlaza koji se koristi za masažu. Snaga puhala odabire se na osnovu željene količine izbačenog zraka i dubine vode u bazenu. Za javne bazene preporuča se upotreba turbo-puhala zbog svoje robusnosti. Turbo-puhalo korišteno u automatizaciji bazena je snage 2200 W. Količina zraka koju turbo-puhalo upuhuje u bazen iznosi 178 m^3/h pri tlaku od 1,75 bar [7]. Turbo-puhalo je prikazano na slici 8.

Od ostalih izvršnih elemenata za automatizaciju bazena korištene su sklopke, automatski osigurači, termomagnetni motorni prekidači, sklopnici, releji, i pomoćni kontakti [7].

Slika 8. Turbo-puhalo za masažu [7]

4. PROGRAM AUTOMATIZACIJE BAZENA

Za izradu programa automatizacije bazena korišten je programski alat TwidoSuite (slika 9). Programski alat TwidoSuite je potpuno opremljeno, grafičko razvojno okruženje za stvaranje, konfiguriranje i održavanje programa automatizacije. Ovaj se programski alat koristi za programiranje TWIDO PLC.



Slika 9. Programski alat TwidoSuite

Programom automatizacije bazena prati se razina vode u kompenzacijskom bazenu i u glavnom bazenu, nadopunjava se razina vode u kompenzacijskom bazenu uključivanjem elektromagnetnog ventila te se nadopunjava i filtrira vodu u glavnom bazenu uključivanjem crpki. Crpke se uključuju naizmjenično svakih 24 sata. Ukoliko jedna od crpki nije ispravna, automatski se uključuje ispravna crpka i nastavlja se s radom. U programom zadanim vremenskim intervalima uključuju se turbo-puhala za masažu i stvaranje umjetne rijeke. Programom je omogućeno i ručno uključenje turbo-puhala. Uključenje rasvjete omogućeno je automatski pomoću senzora i ručno pomoću prekidača. PLC je spojen s računalom opremljenim SCADA sustavom gdje se izvršava vizualizacija sustava. Pomoću SCADA sustava upravlja se vremenom uključenja i isključenja crpki, rasvjete i efekata. Vrijeme u PLC-u je sinkronizirano s vremenom SCADA sustava pomoću sustava stvarnog vremena (eng. Real time clock) [7].

4.1. Korišteni ulazi, izlazi i memorijske adrese PLC-a

Ovisno o zahtjevu sustava automatizacije u programskom alatu TwidoSuite po potrebi se koriste određeni ulazi, izlazi i memorijske riječi PLC-a. Osoba koja piše program mora se držati točno zadanih uputa projektanta i koristiti ulaze i izlaze PLC-a koji su navedeni u projektu. Ukoliko programer želi nešto promijeniti, mora se konzultirati s projektantom i zabilježiti svaku promjenu ulaza i izlaza kako bi promjene bile evidentirane u shemama. Memorijske riječi i memorijske adrese programer koristi prema potrebama zadatka koji mora izvršiti. Memorijske adrese mogu imati lokaciju po želji, a obično se adresiraju po logici koja je najjasnija programeru kod pisanja programa. Memorijske riječi (%MW) slažu se u grupe tako da ih je jednostavnije zapamtiti i koristiti kod pisanja programa. Na primjer, za prikaz greške rada crpki, efekata i rasvjete koristi se memorijska riječ %MW1.

Korišteni ulazi PLC-a jesu:

- %I0.0 – nivostat maksimum,

- %I0.1 – nivostat minimum,
- %I0.2 – senzor osvjetljenja,
- %I0.3 – zaštita crpke od rada na suho,
- %I0.4 – crpka 1 greška,
- %I0.5 – crpka 2 greška,
- %I0.6 – efekt 1 greška,
- %I0.7 – efekt 2 greška,
- %I0.8 – efekt 3 greška,
- %I0.9 – rasvjeta 1 greška,
- %I0.10 – rasvjeta 2 greška.

Korišteni izlazi PLC-a jesu:

- %Q0.0 – crpka 1,
- %Q0.1 – crpka 2,
- %Q0.2 – ventil elektromagnetni,
- %Q0.3 – efekt 1,
- %Q0.4 – efekt 2,
- %Q0.5 – efekt 3,
- %Q0.6 – rasvjeta bazena 1,
- %Q0.7 – rasvjeta bazena 2.

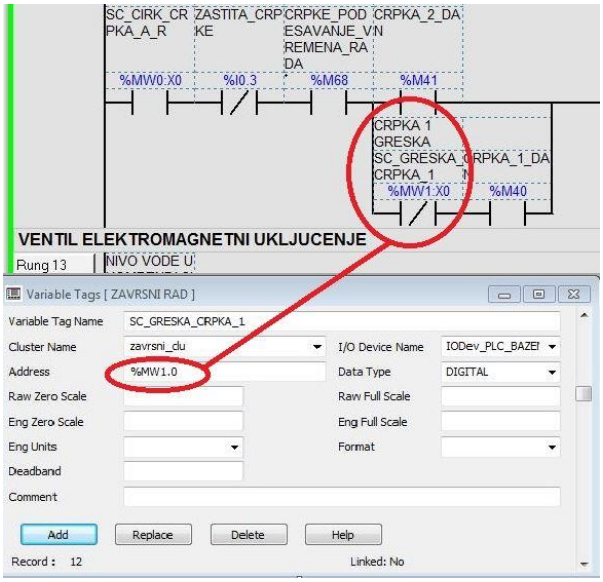
Neke od korištenih memorijskih riječi prikazane su na slici 10.

Address	Symbol	Comment
%MW0:X0	SC_CIRK_CRPKA_A_R	CRPKE ZA PREPUMPAVANJE VODE
%MW0:X1	SC_CIRK_CRPKA_1_R	CIRKULACIJSKA CRPKA 1 U RUCNOM RADU
%MW0:X2	SC_CIRK_CRPKA_2_R	CIRKULACIJSKA CRPKA 2 U RUCNOM RADU
%MW0:X3	SC_EFEKTI_A_R	TURBOPUHALA ZA MASAZU
%MW0:X4	SC_EFEKT_1_R	EFEKT 1 U RUCNOM RADU
%MW0:X5	SC_EFEKT_2_R	EFEKT 2 U RUCNOM RADU
%MW0:X6	SC_EFEKT_3_R	EFEKT 3 U RUCNOM RADU
%MW0:X7	SC_RASVJETA_R_A	RASVJETA BAZENA
%MW0:X8	SC_RASVJETA_1_R	RASVJETA 1 U RUCNOM RADU
%MW0:X9	SC_RASVJETA_2_R	RASVJETA 2 U RUCNOM RADU
%MW1:X0	SC_GRESKA_CRPKA_	
%MW1:X1	SC_GRESKA_CRPKA_	
%MW1:X2	PROTUSTRUJNO_PLI	
%MW1:X3	STOJECA_MASAZA_G	
%MW1:X4	MASAZA_IZ_SJEDIST	
%MW1:X5	SC_RASVJETA_1_GR	
%MW1:X6	SC_RASVJETA_2_GR	
%MW2:X0	SC_UKLJUCENJE_CR	
%MW2:X1	SC_UKLJUCENJE_CR	
%MW2:X2	SC_PROUSTRUJNO_	
%MW2:X3	SC_GEJZIR_STOJECA	
%MW2:X4	SC_MASAZA_IZ_SJEDI	
%MW2:X5	SC_RASVJETA_1_RA	
%MW2:X6	SC_RASVJETA_2_RA	

Slika 10. Memorijske riječi korištene u programu automatizacije bazena

Memorijske riječi korištene u projektu automatizacije bazena u programu TwidoSuite povezuju se sa SCADA sustavom pomoću oznaka (eng. Tag). Memorijske riječi se koriste za spremanje bitovnih logičkih vrijednosti u podatkovnu memoriju.

Primjer povezivanja memorijskog bita u memorijskoj riječi sa SCADA sustavom putem oznake prikazan je na slici 11. Program automatizacije bazena pomoću PLC-a prikazan je u [7].



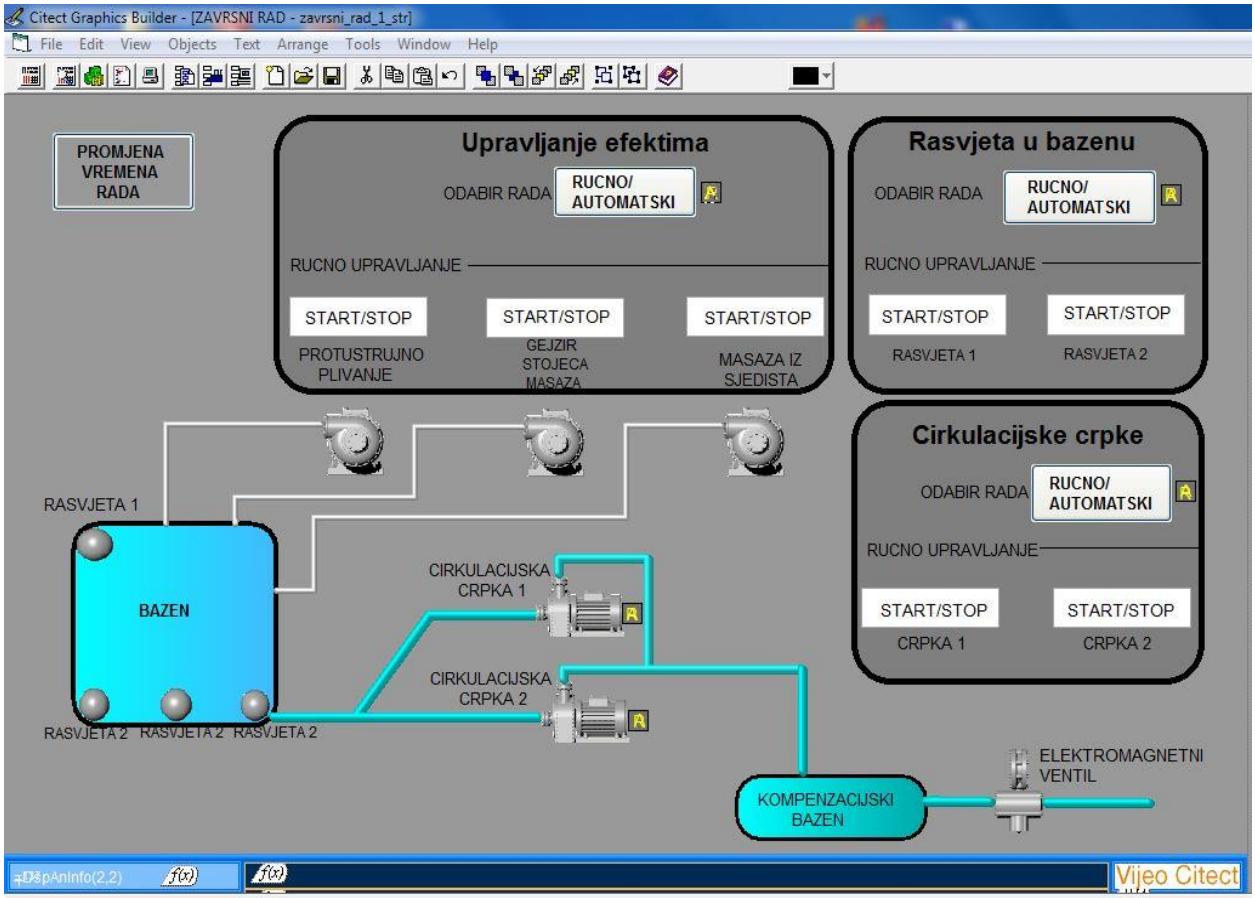
Slika 11. Primjer povezivanja memorijske riječi u PLC sa SCADA sustavom

5. SCADA SUSTAV BAZENA

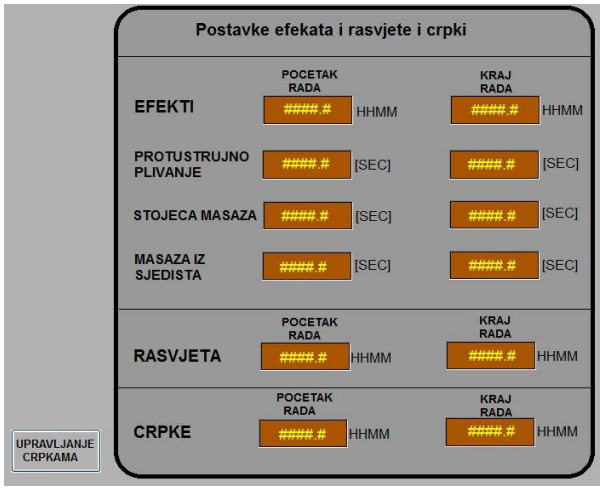
SCADA sustavi (eng. Supervisory Control And Data Acquisition) su sustavi koji prikupljaju, prikazuju, pohranjuju i upravljaju podacima u industrijskim postrojenjima. SCADA sustavi se koriste za sakupljanje podataka i ostvarivanje kontrole na nivou nadzora. Pojedini SCADA sustavi služe samo za praćenje i nemaju mogućnosti kontrole, ali svejedno spadaju u skupinu SCADA sustava. Pod SCADA sustavom podrazumijeva se računalo opremljeno odgovarajućom programskom podrškom za vizualizaciju. SCADA sustavi omogućuju upravljanje, kontroliranje i nadzor procesa u industrijskoj proizvodnji s jednog mjesta. SCADA sustavom upravlja operator. Operator je osoba zadužena za nadzor i kontroliranje cjelokupnog proizvodnog procesa [6].

SCADA sustav bazena izveden je u programskom alatu VijeoCitect. Ovaj programski alat omogućuje konfiguraciju komunikacijske mreže, oznaka, alarma, trendova, virtualnih servera i redundantnog SCADA sustava. Slika 12 prikazuje vizualizaciju crpki, turbo-puhala, elektromagnetnog ventila i rasvjete. Na istoj slici se nalaze i tipke kojima se uključuju i isključuju crpke, turbo-puhala i rasvjeta. Upravljanje vremenima rada rasvjete, turbo-puhala i crpki uz upis vremena prikazano je na slici 13.

Upravljanje efektima, rasvjetom i cirkulacijskim crpkama u bazenu može biti u ručnom i automatskom režimu rada (slika 12). Ako je režim rada ručni, tada se crpkama, rasvjetom i turbo-puhalima upravlja pomoću START/STOP gumbova prikazanih na slici 12. U slučaju da je odabran automatski režim rada rasvjete, turbo-puhala i crpki tada njihovim radom upravlja PLC sukladno namještenim vremenima u prozoru prikazanom na slici 13. Početak i kraj rada efekata, rasvjete i crpki unosi se u obliku sata i minuta, dok se trajanje rada pojedinih uređaja definira u sekundama (slika 13).



Slika 12. SCADA sustav automatizacije bazena



Slika 13. Postavke vremena rada efekata u baznu

6. ZAKLJUČAK

Automatizacija bazena zahtjeva puno rada i poznavanje principa rada pojedinih elemenata koji se koriste u automatizaciji bazena. U automatizaciji bazena nema strogo definiranog načina na koji se mora programirati PLC. Najbitnije je da napisani program odrađuje sve ono što je definirano zadatkom. Kada je program napisan u programu TwidoSuite programskom alatu potrebno ga je testirati te otkloniti eventualne pogreške u samom programu kako bi program koji se unesi u PLC radio sve što se od njega zahtjeva. Obzirom da se neki od uređaja nalaze u vodi, jako je bitno poštivati upute kako ne bi došlo do opasnosti po zdravlje ljudi zbog eventualnog dodira vode u bazenu i električne struje. Gdje god je moguće koristi se napon iznosa 24 V (DC) koji nije opasan za ljudsko zdravlje. Cilj automatizacije bazena je učiniti boravak u bazenu što zanimljivijim i ugodnijim. Automatizaciju bazena potrebno je prilagoditi korisnicima bazena. Cijeli SCADA sustav se mora prilagoditi operateru koji upravlja crpkama, rasvjetom i efektima. SCADA sustav mora biti intuitivan i jednostavan za upravljanje. U automatizaciji bazena se koristi dinamični SCADA sustav pomoću kojeg se regulira automatski rad pojedinih elemenata.

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TOPLINSKI AKTIVIRANO SAMOOBNAVLJANJE IONOMERA NAKON BALISTIČKOG TESTA - MEHANIČKA SVOJSTVA

MECHANICAL PROPERTIES OF A THERMALLY ACTIVATED SELF-HEALING IONOMER AFTER BALLISTIC PENETRATION

Antonija Zimak, Tatjana Haramina, Daniel Pugar

Izvorni znanstveni članak

Sažetak: *Ionomer Surlyn® 8940 je kopolimer etilena i metakrilne kiseline sa svojstvom samoobnavljanja uz pomoć topline. Nakon provedenog balističkog udara, istražena su mehanička, optička i toplinska svojstva ovog kopolimera prije i nakon oštećenja izazvanog prostrjeljivanjem. Premda je balistički test bio uspješan i materijal je trenutno zacijelio, oštećenje je vidljivo, a neka mehanička svojstva se mijenjaju. Krivulje naprezanje-istezanje nastale statičkim rasteznim ispitivanjem materijala prije oštećivanja pokazuju izraženu granicu tečenja i veliku duktilnost. Nakon balističkog testa svojstva su neujednačena, granica tečenja iščezava, rastezna čvrstoća i duktilnost se smanjuju, dok modul elastičnosti tek neznatno pada.*

Ključne riječi: *Samoobnavljajući polimeri, ionomeri, mehanička svojstva, balističko ispitivanje, E/MAA, etilen, metakrilna kiselina*

Original scientific paper

Abstract: *Surlyn® 8940 ionomer is a copolymer of ethylene and methacrylic acid with thermally activated self-healing capacity. After ballistic impact was performed, mechanical, optical and thermal properties of the copolymer before and after the damage caused by the passage of bullet were examined. The ballistic test was successful and the material was immediately healed, but the damage is evident and its mechanical properties have changed. Stress-strain curves measured by means of tensile testing showed that the material has the yield point and large ductility. After the ballistic impact, characteristics are less uniform, the yield point vanishes, tensile strength and ductility are reduced and modulus only slightly decreases.*

Key words: *Self-healing polymers, ionomer, mechanical properties, ballistic testing, E/MAA, ethylene, methacrilic acid*

1. UVOD

Biološki materijali su evolucijski optimirani funkcionalni sustavi. Jedno od njihovih najistaknutijih svojstava je mogućnost samoobnavljanja i regeneracije funkcije nakon nastanka oštećenja uslijed vanjskog mehaničkog opterećenja. U prirodi se samoobnavljanje odvija na razini pojedinih molekula (npr. samoobnavljanje DNK), ali i na makroskopskoj razini. Pod obnavljanjem na makroskopskoj razini se podrazumijeva zarastanje kostiju ili pak zatvaranje i zacjeljivanje ozljeda krvnih žila. Za razliku od bioloških materijala, većina sintetičkih ne posjeduju to važno svojstvo.

Biološki materijali i njihovo svojstvo samozacjeljivanja poslužili su kao inspiracija za razvoj sintetičkih materijala s ovim važnim svojstvom. Kod sintetskih polimera postoje različiti mehanizmi samozacjeljivanja, odnosno samoobnavljanja. Dio samoobnavljajućih materijala može biti u mogućnosti „osjetiti“ oštećenje, a zatim isporučiti „ljekovito“ sredstvo na oštećeno područje putem jednog, od mnogih, mehanizama obnavljanja. Dok ne dođe do oštećenja „ljekovito“ sredstvo mora biti neaktivno i ne smije ugroziti primarnu funkciju materijala. Drugi se materijali mogu samoobnoviti uz pomoć faznih promjena nastalih uslijed dovođenja energije uz pomoć udara pri čemu se oslobađa toplina.

Samoobnavljajući se materijali mogu podijeliti u dvije osnovne skupine, ovisno o potrebnom okidaču i samoj prirodi procesa samoobnavljanja. Osnovne su skupine ne-autonomni i autonomni samoobnavljajući materijali. Ne-autonomni materijali zahtijevaju vanjski poticaj, tj. okidač kao što su npr. toplina ili svjetlost, a dodatna energija može se razviti kao rezultat radnih uvjeta ili se može dostaviti ciljanim vanjskim podražajima (npr. laserska zraka). Za razliku od ne-autonomnih, autonomni samoobnavljajući materijali ne zahtijevaju vanjski podražaj kako bi proces zacjeljivanja započeo, već je samo oštećenje dovoljan stimulans za popravak. Obično zacjeljuju sitnija oštećenja i pukotine izazvane zamorom materijala.

Ionomeri su skupina polimera koji pokazuju sposobnost samoobnavljanja. Imaju do 20 mol.% ionskih vrsta uključenih u polimernu strukturu, uz pomoć kojih dolazi do međudjelovanja među molekulama, odnosno stvaraju se agregati [1] koji utječu na mehanička [2,3] i

fizička svojstva [4]. Ovi se agregati sastoje od više ionskih parova koji stvaraju fizički umrežena područja smanjene pokretljivosti [5]. Prednost je fizičkih umreženja što su reverzibilna. Prema modelu kojeg je predložio Tadano sa suradnicima [6] radi se o dvofaznom sustavu u kojem su ionski klasteri disprezirani u kristalastoj polimernoj matrici. Prilikom zagrijavanja iznad temperature Tord polimer prelazi iz uređene u neuređenu strukturu, no usprkos neuređenoj strukturi i padu mehaničkih svojstava, klasteri iona se zadržavaju. Daljim zagrijavanjem iznad temperature tališta Tm kristalasta faza se tali, premda zahvaljujući ionskim klasterima taljevina zadržava čvrstoću [7]. Ovi reverzibilni prijelazi imaju ključnu ulogu nakon udara, pri čemu dolazi do disipacije topline, nakon čega dolazi do brzog očvršćivanja, premda klasteri tek naknadno prelaze u uređenu strukturu. U radovima [8-11] pokazalo se da kombinacija elastične fleksibilnosti, visoke čvrstoće taljevine i spontanog fizičkog umreživanja daje ionomerima sposobnost samoobnavljanja nakon provedenih balističkih udara. Po prolasku metka, rupe se zatvaraju, a nastali ožiljci su nepropusni za kapljevine i plinove. Zaključeno je da su pri samoobnavljanju ionomera elastični i viskozni odgovor u ravnoteži.

U ovom radu provedena su balistička ispitivanja ploča načinjenih od ionomera poznatog pod nazivom Surlyn 8940 prostrjeljivanjem uz pomoć pištolja metkom od 9 mm. Prostrijelna je „rana“ trenutno zacijelila, a potom su ispitana mehanička i optička svojstva ovog ionomera prije i poslije oštećivanja.

2. EKSPERIMENTALNI DIO

2.1. Materijal

Surlyn® 8940 proizvođača DuPont™ termoplastična je smola kopolimera etilena i metakrilne kiseline (E/MAA). Sadrži 5,4 mol.% metakrilskih kiselinskih grupa kojih je 30 % neutralizirano natrijevim ionima. Iznos MAA i razine neutralizacije optimiraju se kako bi se dobila izuzetna prozirnost i visoka krutost. Surlyn® 8940 može se preraditi injekcijskim prešanjem, a ekstruzijom se može oblikovati u različite folije i oblike. (Web-1)

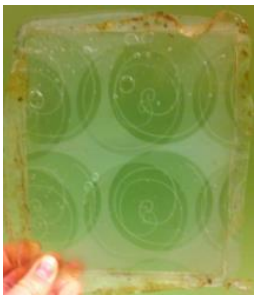
Ovaj materijal ujedinjuje mnoga svojstva kopolimera na bazi etilena, kao što su kemijska otpornost, temperaturni interval taljenja, gustoća i osnovne karakteristike obrade. Međutim, izvedba Surlyn®-a 8940 poboljšana je u sljedećim karakteristikama:

- udarna žilavost pri niskim temperaturama
- otpornost na trošenje
- kemijska otpornost
- prozirnost (Web-2)

Surlyn® 8940 obično se prerađuje pri temperaturama taljenja u rasponu od 185 °C do 285 °C. (Web-3)

2.2. Izrada ploča

Ploče za balističko ispitivanje izrađene su u peći izravnim prešanjem u kalupu. Kalup se sastoji od čeličnog okvira debljine 4 mm smještenog između dviju čeličnih ploča, koji definira debljinu polimerne ploče, odnosno ispitnih tijela. Čelične su ploče obložene silikonskim podlogama proizvođača IKEA koje sprječavaju lijepljenje rastaljenog ionomera za čelične ploče. U tako pripremljen kalup stavljeno je oko 74 g granulata prethodno držanog u termostatu pri temperaturi od 50 °C kako bi se reducirala vlaga. Granulat je s kalupom stavljen u peć kako bi se granule rastalile. Zahvaljujući viskoznosti površine i površinskoj napetosti, visina taljevine prelazi visinu okvira. Potom su na granulat u kalupu položene silikonska podloga i čelična ploča koja je dodatno opterećena utezima mase 20 kg kako bi se istisnuli zaostali mjehurići zraka i vlage. Temperatura u peći iznosila je 230 °C, a vrijeme držanja poklopljenog kalupa u peći 10 minuta. Poslije 10 minuta kalup je bio izvađen iz peći te je bio hlađen komprimiranim zrakom. Ohlađene polimerne ploče su lako odvojene od kalupa. Kako su silikonske podloge sadržavale uzorak, zbog razlike u hrapavosti dobivena je ploča s mjestimično smanjenom prozirnošću. Izgled ploče izrađene u peći prikazuje slika 1.



Slika 1. Polimerna ploča izrađena izravnim prešanjem taljevine u peći

2.3. Balističko ispitivanje

Ispitivanje udarom provedeno je prostrjeljivanjem polimernih ploča iz pištolja metcima Sellier&Bellot, kalibra 9 mm. Masa čahure metka iznosi 8 grama, a radi se o zrnu ovalnog oblika s punom košuljicom (eng. *Full-jacketed bullet*), odnosno njegova jezgra je obložena metalnom košuljicom. Krutost konstrukcije zrno čini glatko penetrirajućim zbog čega prodor zrna ne razara tkivo/materijal kao što se, također, ni sam metak ne deformira pri udaranju u ciljani objekt. (Web-4) Također, ovakav metak ima šiljasti prednji dio čime se smanjuju zračne turbulencije na balističkoj putanji te je samim time poboljšan domet i preciznost. Pucanje je izvedeno s udaljenosti od 10 metara.

Slika 2. Samoobnovljeno oštećenje nakon probijanja metkom

Svaka ploča prostrijeljena je jednom (slika 2.) i dio ploče na kojem je ostao trag od metka, izrezan je u epruvetu za ispitivanje.

2.4. Statičko rastezno ispitivanje

Epruvete za statičko rastezno ispitivanje su izrezane kružnom pilom debljine 4 mm. Rezanjem razdvojen materijal iza rezne fronte nije bio u dodiru te nije došlo do spajanja ploha uslijed efekta samoobnavljanja. Izrezane su po dvije epruvete iz svake polimerne ploče, jedna epruveta je sadržavala samoobnovljen „ožiljak“ od metka dok je druga epruveta bila bez oštećenja (slika 3.). Izbor mjesta iz kojih su izrezivane epruvete uvjetovan je položajem traga metka (ovisi o preciznosti strijelca) uz nastojanje da se izbjegnu mjesta s mjestimično nastalim mjehurićima.

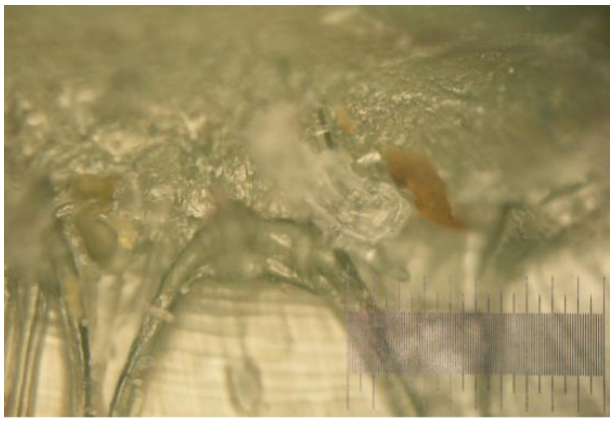
Slika 3. Par izrezanih epruveta

Kao smjernica pri odluci o dimenzijama i brzini ispitivanja uzeta je norma HRN EN ISO 527, no nje se zbog ograničenja uslijed dimenzija ploča i položaja prostrijeljenih mjesta nije bilo moguće pridržavati u potpunosti. Epruvete su u skladu s mogućnostima izrezane u raznim smjerovima. Širina ispitnog tijela iznosila je 15 mm, a razmak između čeljusti pri rasteznom ispitivanju iznosio je 70 mm. Brzina istezanja bila je 50 mm/min.

3. REZULTATI

3.1. Optička svojstva

Svjetlosnim mikroskopom tipa BX51-P, proizvođača Olympus, utvrđivana su optička svojstva materijala.



Slika 4. Mikroskopska snimka

Slika 4. prikazuje područje kroz koje je prošao metak. Može se zamijetiti kako je prolazak metka unio uključine (smeđa boja na slici) koje su ostale „zarobljene“ u materijalu i nakon samoobnavljanja. U materijalu su se također mogli uočiti mjehurići zraka koji su nastali pri samoj izradi polimernih ploča, a ne balističkim testom. Razlika u prozirnosti materijala, koja je pak posljedica neravnomjernosti hrapavosti površine silikonske podloge za odvajanje ploča od kalupa, može se uočiti i golim okom. Na području silikonske podloge koje je imalo glatku površinu epruveta je ostala prozirna, dok je područje s hrapavom površinom izazvalo matiranost dijela ploče, a time i izrezane epruvete. S obzirom da su epruvete debele nekoliko mm, utjecaj hrapavosti na mehanička svojstva je zanemariv.

3.2. Određivanje intervala taljenja

Interval taljenja je određen u skladu s normom HRN EN ISO 3146.

Dobiveni rezultati prikazani su tablicom 1.

Tablica 1. Rezultati određivanja intervala taljenja

Mjerenje br.	Interval taljenja °C	
	Komponenta 1	Komponenta 2
1	91-93	110-115
2	91-93	110-115

Rezultati mikroskopiranja kod polimernih materijala prikazuju se intervalom taljenja, budući da se taljenje ne odvija pri konstantnoj temperaturi. Posljedica je to heterogenosti, odnosno polidisperznosti makromolekulnih sustava. Sekundarne veze u materijalu ne pucaju pri istoj temperaturi. Obzirom da se radi o kopolimernom materijalu pojavljuju se dva intervala taljenja što je vidljivo u tablici 1.

3.2. Određivanje tvrdoće E/MAA metodom utiskivanja kuglice

Zbog ograničenog broja provedenih balističkih udara i male površine zahvaćene jednim hicem, ispitana je samo tvrdoća materijala prije balističkog ispitivanja. Postupak mjerenja tvrdoće proveden je na tvrdomjeru s kuglicom promjera *D* koji iznosi 5 mm, proizvođača Zwick, uz silu utiskivanja od 63,8 N te korekciju od 0,01 mm. Budući da se radi viskoelastičnom materijalu, rezultat je vremenski ovisan i dubina otiska *h* raste s vremenom opterećenja utiskivanjem kuglicom. Posljedica viskoznog odziva je niži iznos tvrdoće s vremenom utiskivanja.

Prema normi HRN EN ISO 2039-1 tvrdoća utiskivanjem kuglice se izračunava prema izrazu:

$$H = \frac{1}{D\pi}\frac{F}{h} \quad (1)$$

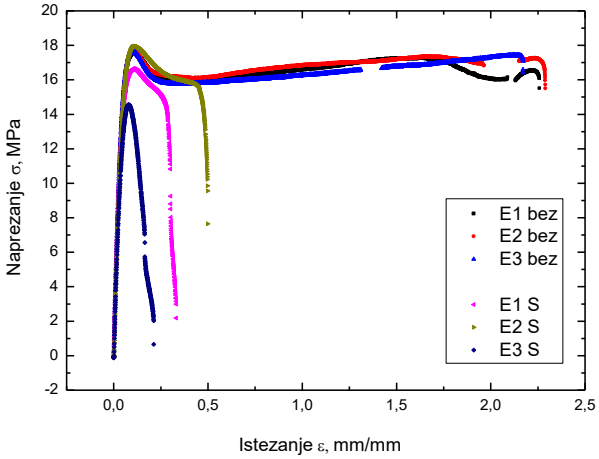
Rezultati ispitivanja tvrdoće, H izmjerene nakon 10, 30 i 60 s prikazani su u tablici 2.

Tablica 2. Rezultati mjerenja tvrdoće

Epruveta	Očitanje	10 s		30 s		60 s	
		h [mm]	**H [N/mm^2]**	h [mm]	**H [N/mm^2]**	h [mm]	**H [N/mm^2]**
2	1	0,250	16,9	0,270	15,6	0,280	15,1
	2	0,280	15,1	0,300	14,0	0,310	13,5
	3	0,270	15,6	0,258	16,4	0,300	14,0
	4	0,275	15,3	0,295	14,3	0,305	13,8
	5	0,275	15,3	0,295	14,3	0,305	13,8
5	6	0,310	13,5	0,325	12,9	0,345	12,1
	7	0,255	16,6	0,275	15,3	0,290	14,5
	8	0,220	19,4	0,235	18,1	0,250	16,9
	9	0,270	15,6	0,285	14,8	0,300	14,0
	10	0,290	14,5	0,310	13,5	0,320	13,1

3.3. Statičko rastezno ispitivanje

Rastezno ispitivanje materijala provedeno je uz pomoć kidalice Messphysik Beta 50-5 s maksimalnom silom opterećenja od 50 kN. Potrebno je naglasiti da u provedenom ispitivanju za praćenje produljenja nije korišten ekstenzometar, već se pratio pomak vretena. Brzina ispitivanja iznosila je 50 mm/min. Zajedničkim dijagramom (slika 5.) prikazani su rezultati ispitivanja na kidalici.



Slika 5. Dijagram Naprezanje-Istezanje za ispitna tijela prije (bez) i poslije (s) balističkog ispitivanja

Ujednačenost krivulja dobivenih ispitivanjem epruveta prije balističkog testa pokazuje kako priprema ploča izravnim prešanjem nije narušila izotropnost materijala. U elastičnom području krivulje se gotovo potpuno preklapaju, što znači da je krutost materijala izražena kroz koeficijent smjera pravca u približno linearnom području, odnosno modul elastičnosti, ujednačen. Moduli elastičnosti su približno 310 MPa. Kod ovog polimernog materijala izražena je granica tečenja. Dok se gornja granica tečenja odlično preklapa kod svih epruveta, vidljivo je manje rasipanje kod donje granice tečenja, a manje rasipanje vidljivo je i u području plastične deformacije.

Krivulje samoobnovljenih materijala se, kao što je jasno vidi, oblikom značajno razlikuju od onih prije prostrjeljivanja. Kod ovih epruveta nije vidljiva granica tečenja, a vrijednosti rastezne čvrstoće se značajno razlikuju. Vidljiva je i velika neujednačenost u istezljivosti s maksimalnom razlikom od preko 100 % (epruvete E2 i E3). Za bolju statistiku i izražavanje greške potrebno je napraviti veći broj ispitivanja.

Početno linearno područje je približno jednako kod svih epruveta i prije i poslije balističkog udara. To znači da je krutost materijala nakon samoobnavljanja nepromijenjena, no ipak je vidljivo da je prostrjeljivanje zrnom znatno utjecalo na svojstva materijala, u prvom redu istezljivost (duktilnost) i žilavost koja je proporcionalna površini ispod krivulja. Prostrijeljene epruvete mogu podnijeti znatno manje naprezanje, odnosno smanjena im je čvrstoća.

4. ZAKLJUČAK

Ovim radom prikazana su svojstva dobivena ispitivanjem materijala ionomera E/MAA. Ovaj materijal spada u skupinu intrinzičnih samoobnavljajućih polimera koji zacjeljuje uz pomoć topline.

Uspješno proveden balistički test pokazuje trenutno zacjeljenje rupa nakon prolaska metka od 9 mm od čega ostaje vidljiv ožiljak. Mikroskopskom analizom ožiljka utvrđeno je da je prolazak metka uzrokovao onečišćenje materijala česticama s metka, no potrebna je detaljnija analiza kako bi se utvrdilo utječe li ono i u kojoj mjeri na svojstva.

Budući da su prisutna dva temperaturna intervala taljenja, analiza intervala taljenja potvrdila je postojanost dvaju polimera u ovom kopolimeru.

Ispitivanje tvrdoće potvrdilo je ujednačenost svojstava po površini ploče.

Statički rastezni pokus materijala prije balističkog ispitivanja pokazuje da je materijal prerađen izravnim prešanjem izotropan. Nakon prostrjeljivanja usprkos samozacijeljivanju svojstva slabe. Utjecaj na krutost je mali, čvrstoća je neujednačena, a najviše je oslabljena duktilnost. Dobiveni dijagrami pokazali su kako se svojstva samoobnovljenih materijala mogu predvidjeti u elastičnom području dok to nije slučaj u plastičnom području. Granica tečenja je kod materijala prije prostrjeljivanja jasno izražena što nije slučaj sa

samoobnovljenim materijalom kroz kojeg je prošao metak.

Zahvala:

Balistička ispitivanja provedena su u suradnji sa Časničkom školom Hrvatskog vojnog učilišta, a ispitivanje mehaničkih svojstava s Laboratorijem za eksperimentalnu mehaniku FSB-a. Zahvaljujemo na suradnji.

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TRIBOLOGIJA KLIPNIH PRSTENA KOD MOTORA SUI

TRIBOLOGY OF PISTON RINGS IN INTERNAL COMBUSTION ENGINES

Tajana Vaško, Vinko Višnjić

Stručni članak

Sažetak: *Funkcija klipnih prstena u motorima s unutarnjim izgaranjem je višestruka i ovisi o vrsti klipnog prstena. Koriste se kompresijski i uljni klipni prsteni koji su u uvjetima rada motora izloženi raznim tribološkim procesima zbog kojih nastaju različite greške u radu i funkcionalnosti klipnih prstena. Opisane su pojave koje se događaju zbog trenja i trošenja tokom rada klipnih prstena kao što su mikrozavarivanje te pojava zagorjelih površina prstena. Također su obrađene greške pri radu od kojih su najznačajnije zaglavljivanje, lepršanje te lom. Izbjegavanjem ovih grešaka te triboloških učinaka na klipne prstene znatno se može doprinijeti optimiranju potrošnje goriva, rada motora te povećanju snage motora s unutarnjim izgaranjem.*

Ključne riječi:*, Klipni prsten, Kompresijski prsten, Trenje, Tribologija, Trošenje, Uljni prsten*

Professional paper

Abstract: *The function of piston rings in internal combustion engines is versatile and depends on the type of piston ring. There are compression and scraper rings which are exposed to different tribological processes that are described in this paper, and because of them different types of defects appear in the exploitation and functionality of piston rings. Occurrences that appear because of wear and friction are described, such as microwelding and scruffing on the surface of the piston rings. Also, there are mentioned malfunctions, just as sticking, fluttering and breaking. By avoiding these malfunctions and effects of tribology, there can be made a large contribution in optimizing fuel consumption, engine function and increase in the power of internal combustion engines.*

Key words: *Piston ring, Compression ring, Friction, Tribology, Wear, Scraper ring*

1. UVOD

Motori s unutarnjim izgaranjem pripadaju grupi toplinskih motora koji toplinsku energiju izgorjelog goriva pretvaraju u mehaničku. Radna tvar su sami izgorjeli plinovi. Proces izgaranja goriva, odvajanje topline radnoj tvari i transformiranje jednog dijela topline u mehaničku energiju odvija se unutar cilindra motora te se zbog toga nazivaju motori s unutarnjim izgaranjem (SUI).

Klipna grupa je jedan od glavnih motornih mehanizama. Sastoji se od klipa, klipnih prstenova i osovinice klipa. U gornjem dijelu plašta klipa nalaze se kanali za klipne prstenove. Broj kanala ovisi o tlaku u taktu izgaranja i broju okretaja koljenastog vratila. U gornje kanale smještaju se kompresijski prsteni, a u donje uljni, s time da trebaju minimalno biti dva kompresijska i jedan uljni prsten. [1]

Klipni prsteni su metalne brtve koje imaju zadatak odvojiti komoru izgaranja od kućišta koljenaste osovine i osigurati prijenos topline sa klipa prema košuljici cilindra. Osim toga, trebaju spriječiti prolaz ulja, koje nije potrebno za podmazivanje, iz kućišta prema komori izgaranja i osigurati jednoliki sloj maziva na površini cilindra.

Zbog tlaka plina u komori izgaranja, povećavaju se radijalna i aksijalna komponenta sile u žlijebu klipnog prstena te se time povećava mogućnost brtvljenja. Aksijalni kontakt se može mijenjati između vrha i donjeg dijela žlijeba zbog interakcije tlaka plina, inercije i sila trenja.

Klipni prsteni mogu se izraditi iz slitine lijevanog željeza (dodaci kroma i nikla za čvrstoću, mangan za žilavost i otpornost na habanje), sivog i nodularnog lijeva, u toplinski neobrađenom stanju ili kaljeni, ovisno o tlakovima i primjeni kao kompresijski ili uljni prsteni. Često se provodi površinska zaštita kromiranjem.

Radne karakteristike klipnih prstena, tj. nesmetano brtvljenje protiv plinova izgaranja i ulja za podmazivanje, ovise o konstrukciji motora, toplinskom utjecaju i opterećenju zbog izgaranja, konstrukciji cilindra i njegovoj izradi, klipu, korištenom ulju za podmazivanje, gorivu i o kvaliteti i konstrukciji samih prstena. [2]

2. VRSTE KLIPNIH PRSTENA I SPOJEVI

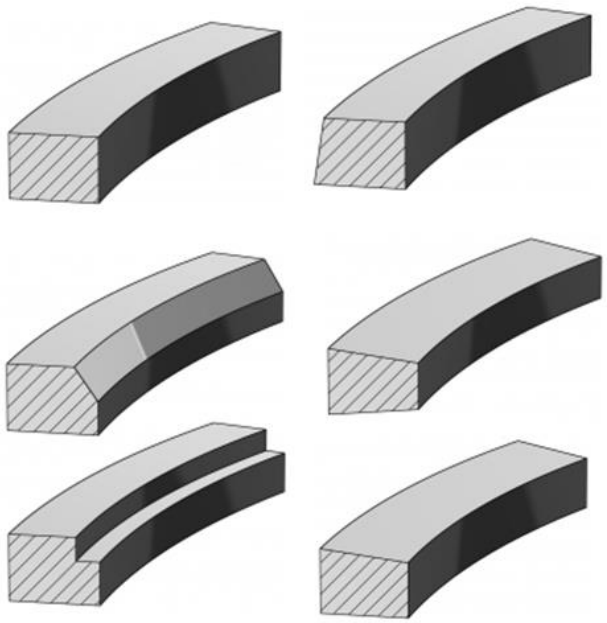
2.1. Kompresijski prsteni

Glavna uloga kompresijskih prstena je razdvajanje komore izgaranja od kućišta koljenaste osovine i prijenos topline sa klipa prema cilindru. Ugrađuju se u kanale u gornjem dijelu plašta klipa. Uz stijenku cilindra drži ih sila

zbog tlaka plinova i vlastita opružna sila koja nastaje kod svođenja promjera prstena na promjer cilindra jer je promjer slobodnog prstena nešto veći. Za osiguranje radijalne elastičnosti, prsteni imaju žlijeb koji i u ugrađenom stanju mora osigurati odgovarajuću zračnost. Veća zračnost znači i veće gubitke plinova iz radnog prostora, a kod nedovoljne zračnosti može doći do uklinjavanja, odnosno zaglavljivanja prstena u cilindru. [1]

Treba postojati određena zračnost između prstena i njegovog kanala, s tim da što je zračnost veća, to je pojačano utiskivanje ulja u radni prostor cilindra. Na sličan način prolaze i plinovi u kućište motora zbog čega je povećana potrošnja goriva i ulja, smanjena snaga motora i povećana količina goriva i ulja u ispušnim plinovima. Te vrijednosti se moraju držati u određenim granicama.

Kompresijski prsteni mogu imati različite oblike poprečnih presjeka (slika 1).

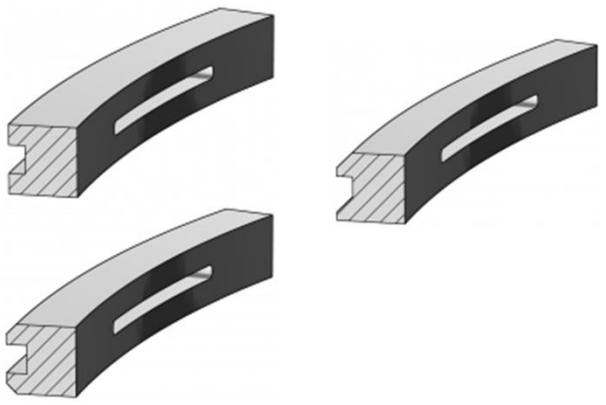


Slika 1. Oblici poprečnih presjeka kompresijskih prstena [2]

2.2. Uljni prsteni

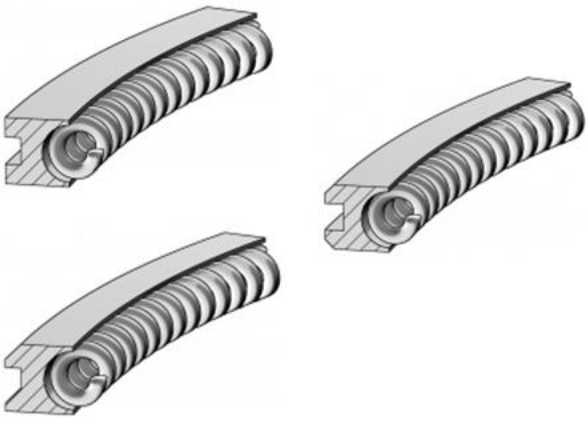
Zadatak uljnih prstena je struganje ulja sa košuljice cilindra i njegovo vraćanje u kućište motora. Zbog toga oni imaju velik utjecaj na potrošnju ulja u motoru SUI. Imaju otvore u sredini prstena za odvod ulja. [1] Mogu biti izrađeni iz jednog, dva ili tri dijela.

Jednodijelni uljni prsteni ostvaruju tangencijalnu silu iz vlastite opružne sile. Mogu biti različitih presjeka.



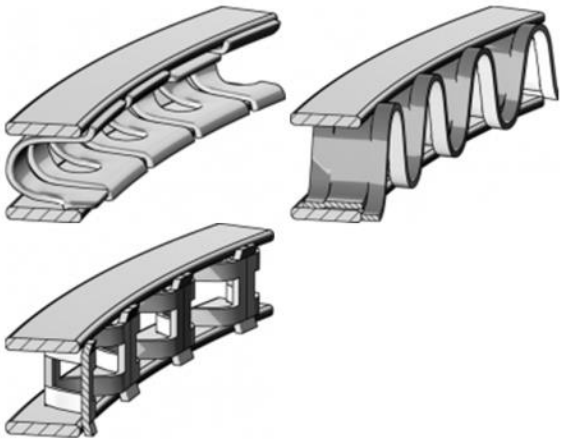
Slika 2. Oblici poprečnih presjeka jednodijelnih uljnih prstena [2]

Dvodijelni uljni prsteni sastoje se od lijevanog tijela prstena ili profiliranog čelika i savojne opruge koja djeluje na cijelom opsegu.



Slika 3. Oblici poprečnih presjeka dvodijelnih uljnih prstena [2]

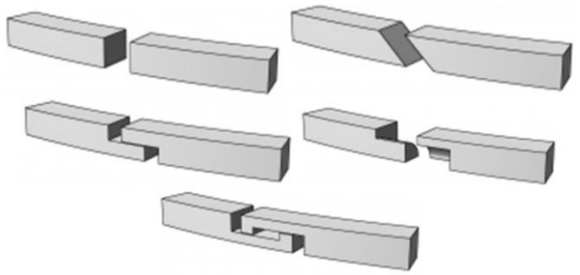
Trodijelni uljni prsteni izrađeni su iz dva tanka čelična prstena i opruge koja ih razdvaja na određenoj udaljenosti te istodobno pritišće prstene prema plaštu cilindra.



Slika 4. Oblici poprečnih presjeka trodijelnih uljnih prstena [2]

2.3. Spojevi prstena

Najčešća vrsta spoja (žlijeba) je sučeoni. Na slici 5 su prikazane različite vrste spojeva prstena.



Slika 5. Oblici spojeva prstena [2]

3. UVJETI EKSPLOATACIJE

3.1. Trenje

Pogonski sustav unutar klipnih motora (klip, klipni prsteni, košuljica cilindra, klipnjače, koljenaste osovine, ležaji, ulja) je pod utjecajem trenja koje je uzrok dijelu mehaničkih gubitaka u motorima SUI.

Trenje se očituje kao otpor prema relativnom gibanju površina u kontaktu. Kontakt može biti direktan (suho trenje), indirektan (podmazano, mokro trenje) ili kombinacija (mokro-suho, mješovito trenje). Sila trenja ovisi o svojstvima materijala i fizičkim i kemijskim svojstvima sustava. Također utječe i struktura površine, što se uočava kod površine prstena koja je u dodiru sa cilindrom, hrapavosti i odstupanja od idealnog cilindričnog oblika. Kod takvih odstupanja površine nisu u potpunom međusobnom kontaktu, tako da se lokalni kontaktni tlakovi znatno razlikuju od specifičnog kontaktnog tlaka. Uz suho i mješovito trenje javljaju se mehanizmi trošenja koji su popraćeni gubitkom energije. Nastala toplina lokalno može doseći velike vrijednosti te može doći do oštećenja materijala što dovodi do otkaza tribološkog sustava (zagorene površine klipnih prstena, struganje itd.).

U području mrtvih točaka, klipni prsteni rade pod utjecajem mješovitog trenja, sile trenja su tada najveće u radnom ciklusu, ali one neznatno doprinose gubicima trenja jer tu zbog promjene smjera gibanja relativna brzina doseže nulu.

Smanjenje trenja se vrši optimiranjem funkcionalnog ponašanja klipnih prstena kako bi se smanjila potrošnja goriva motora. Taj postupak je često u suprotnosti sa smanjenjem potrošnje maziva i „blowby“ efekta („lepršanje“ klipnih prstena).

Glavne mjere za smanjenje trenja i trošenja su:

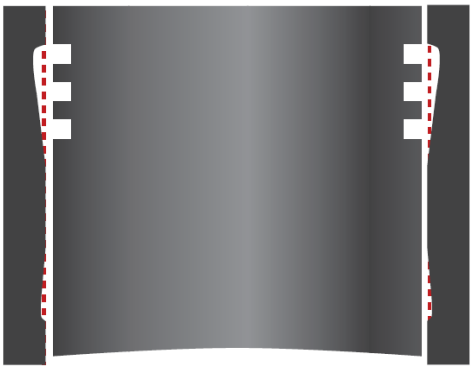
- Zahvati na klipnom prstenu:
  - Redukcija tangencijalne sile, odnosno površinskog pritiska
  - Optimiranje geometrije površina u dodiru
  - Smanjenje broja klipnih prstena po cilindru
  - Primjena drugih materijala za izradu klipnog prstena
- Zahvati vezani za cilindar:
  - Poboljšavanje uvjeta podmazivanja
  - Primjena različitih materijala košuljice cilindra
  - Optimiranje uvjeta hlađenja cilindra
- Zahvati vezani za klip
- Kontrola ulja za podmazivanje i usavršavanje motora [2]

3.2. Trošenje

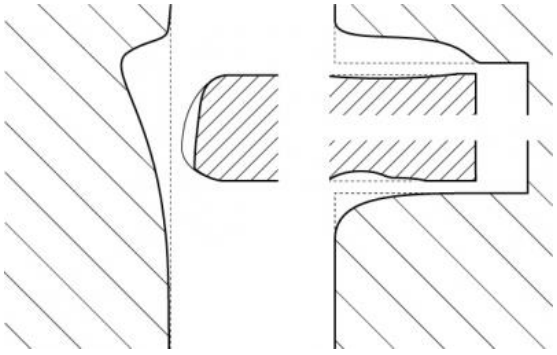
Tribološko opterećenje spregnutih elemenata očituje se gubitkom materijala zbog korozivnih, adhezivnih ili abrazivnih procesa i/ili deformacije komponenata u dodiru ili kombinacije tih efekata uz promjenu kemijskih svojstava površina. Ovakve promjene se mogu svesti pod naziv „trošenje“.

Međutim, tribološko opterećenje se ne bi trebalo poistovjećivati sa vanjskim opterećenjem međudjelujućih komponenti, već ono proizlazi iz vanjskog opterećenja i funkcija je samih komponenti.

Kod sustava klipni prsten/cilindar javlja se trošenje vanjske površine prstena i površine košuljice cilindra u dodiru s njom, dok se kod sustava klip/klipni prsten govori o bočnom trošenju. [2]



Slika 6. Shema trošenja cilindra za sve uobičajene motore SUI [3]



Slika 7. Prikaz trošenja u gornjoj mrtvoj točki na košuljici cilindra, klipnom prstenu i utoru u klipu [2]

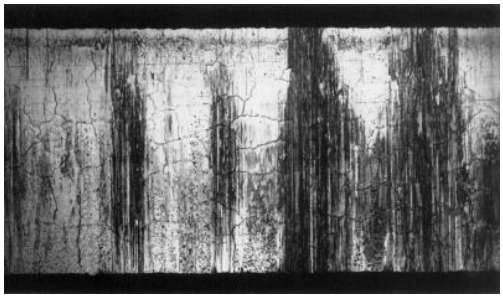
Maksimalno trošenje javlja se oko područja gdje se mijenja smjer gibanja, a pojačano je tlakom pogotovo u gornjoj mrtvoj točki. Nešto malo trošenja javlja se i u donjoj mrtvoj točki, ali zbog daleko manjeg iznosa tlaka manja je dubina istrošenog dijela. Bočno trošenje

smanjuje vijek trajanja motora povećavajući potrošnju ulja i tzv. „blowby“ efekt koji predstavlja količinu plinova izgaranja koja prođe pokraj klipnih prstena u kućište koljenaste osovine. [3]

3.3. Zagorena površina klipnih prstena („Scruffing“)

Pojam za zagorene površine klipnog prstena („scruffing“, „Brandspuren“) izvorno je bio definiran prema pojavi na površini kromiranih klipnih prstena koja je u dodiru sa cilindrom. Promjena boje na kromiranoj površini je indikator za termičko preopterećenje. Ako se ovaj pojam proširi i na druge materijale, tada se mogu sve pojave koje ukazuju na termičko preopterećenje vanjske površine klipnog prstena svesti pod ovaj.

Zajedničko zagorenim površinama klipnih prstena i struganju je tribološko preopterećenje. Kod jakog struganja se na površini klipnog prstena mogu vidjeti duboki zarezi i/ili tragovi drugog materijala.

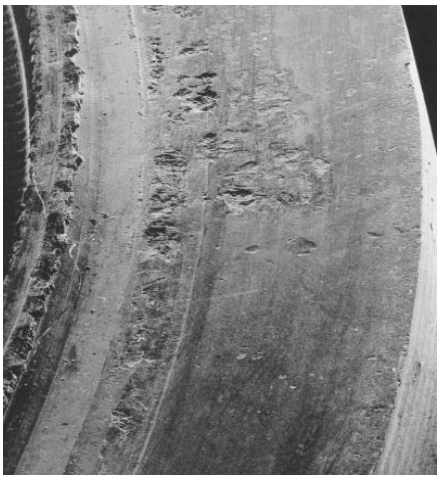


Slika 8. Zagorena vanjska površina kromiranog klipnog prstena [2]

3.4. Mikrozavarivanje („Microwelding“)

Pod „microwelding“ se podrazumijeva poseban oblik oštećenja utora klipa i klipnog prstena koje već nakon kratkog vremena nastaje na gornjem kompresijskom prstenu željeznog materijala, odnosno pirpadajućem utoru u aluminijskom klipu.

Karakteristično za ovaj oblik oštećenja je lokalno zavarivanje materijala popraćeno odlomljivanjem materijala i prijenosom materijala sa klipa na stranu klipnog prstena, pogotovo donju stranu prstena.



Slika 9. Oštećenje klipnog kanala – povećanje 25x [2]

Slika 10. Mikrozavarivanje aluminija na strani klipnog prstena – povećanje 100x [2]

Kada se prstenu zbog takvog oštećenja ograniči gibanje u klipu ili se čak ukliješti, tada to utječe također na daljnje trošenje i funkcionalne karakteristike prstena („blowby“ efekt i povećana potrošnja ulja), a u krajnjem slučaju dovodi do kvara motora. [2]

4. GREŠKE PRI RADU

4.1. Zaglavljivanje

Kod zaglavljivanja prstena treba razlikovati „toplo zaglavljivanje“ i „hladno zaglavljivanje“. [2]

Hladno zaglavljivanje se odnosi na prstene koji se zaglave u utorima klipa samo u „hladnom“ stanju, npr. kod rastavljanja klipa.

Toplo zaglavljivanje se događa kada su prsteni ometani u svom gibanju ili je gibanje potpuno spriječeno u uvjetima rada motora. Do zaglavljivanja dolazi kada se mazivo sa ostacima izgaranja skruti i tada se ono ne može isprati.

4.2. „Lepršanje“ klipnih prstena („Blowby efekt“)

Kod „blowby“ efekta se anomalije u gibanju prstena redovno nazivaju „lepršanje“ i u osnovi mogu imati dva različita razloga ili kombinaciju oba:

- Radijalni kolaps klipnog prstena,
- Aksijalno podizanje prstena sa donjeg dijela utora klipa. [2]

Radijalni kolaps klipnog prstena se događa kada se između vanjskog i unutarnjeg promjera pojavi razlika u radijalnim opterećenjima. Raspodjela tog opterećenja i smjer ovisi o radijalnoj sili klipnog prstena, njenoj raspodjeli i o tlaku koji zbog izgaranja nastaje ispred i iza klipnog prstena.

Kod aksijalnog podizanja, promjenjivi kontakt prstena u utoru klipa je određen prvo inercijom i silama trenja, a drugo tlakom koji djeluje iznad i ispod klipnog prstena. Razlika tlakova (ispod i iznad prstena) može uzrokovati

podizanje istih sa donjeg dijela utora klipa u taktu ekspanzije, što dovodi do povećanja „blowby“ efekta.

4.3. Lom prstena

Do loma prstena može doći čak iako nisu prethodno oštećeni tijekom sklapanja. Lom klipnog prstena može se javiti kod graničnih radnih uvjeta motora – nepravilnog izgaranja kod benzinskih i diesel motora itd. – i s druge strane, zbog geometrijskih graničnih uvjeta – udarna zračnost klipnog prstena je premala, aksijalna zračnost u utoru klipa prevelika, premali presjek prstena (pogotovo zbog utora u uljnim prstenima), posebne izvedbe spojeva prstena itd. Razlikuju se lomovi zbog preopterećenja i lomovi zbog zamora. [2]

5. ZAKLJUČAK

Klipni prsteni imaju višestruku ulogu u motorima s unutarnjim izgaranjem. Oni odvajaju komoru izgaranja od kućišta koljenaste osovine, osiguravaju prijenos topline sa klipa prema košuljici cilindra, sprječavaju prolaz ulja, koje nije potrebno za podmazivanje iz kućišta prema komori izgaranja i osiguravaju jednoliki sloj maziva na površini cilindra. Razlikuju se kompresijski i uljni klipni prsteni pri čemu jedni služe za razdvajanje komore izgaranja od kućišta koljenaste osovine i prijenos topline sa klipa prema cilindru, a drugi za struganje ulja sa košuljice cilindra i njegovo vraćanje u kućište motora.

U eksploatacijskim uvjetima, klipni prsteni izloženi su raznim uvjetima i promjenama zbog pojave trenja, trošenja, zagorenih površina klipnih prstena i pojave mikrozavarivanja. Uslijed navedenih promjena može doći do raznih grešaka pri radu klipnih prstena. Opisane su greške zaglavljivanja prstena, „lepršanje“ klipnih prstena i lom prstena koje mogu biti uzrok smetnji u radu motora s unutarnjim izgaranjem kao što su veća potrošnja goriva i ulja, nepravilan rad motora, smanjenje snage motora i sl. te zbog toga konačno do prestanka rada samog motora.

Zbog toga je bitno obratiti pažnju na smanjivanje loših triboloških učinaka na klipne prstene što se postiže raznim vrstama površinske zaštite, odgovarajućim odabirom materijala triboloških parova te poboljšanjem same konstrukcije klipnih prstena i klipne grupe što može optimirati potrošnju goriva i ulja u motoru s unutarnjim izgaranjem te povoljno utjecati na rad motora i povećanja snage.

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ANALYSIS OF LONGITUDINAL OSCILLATIONS FOR SYSTEMS WITH CONTINUOUS VARIABLE PARAMETERS USING FORCE INTEGRATION METHOD

ANALYSIS OF LONGITUDINAL OSCILLATIONS FOR SYSTEMS WITH CONTINUOUS VARIABLE PARAMETERS USING FORCE INTEGRATION METHOD

Yurii Krutii

Pregledni rad

Abstract: *Force integration method for systems with continuous variable parameters analysis is described. The method is based on analytical solutions of according differential equations. Method substance is shown on the problem of free longitudinal vibrations of straight rod with random continuous variable of longitudinal stiffness and mass per unit length taking into account resistance. Equations for rod condition dynamic parameters and the efficient way of its numerical realization are shown. Free lateral vibrations of cantilever wedge are researched.*

Keywords: *analytical solutions, vibrations of cantilever wedge, force integration method, rod longitudinal vibrations, oscillation frequencies, vibrations factors.*

Review article

Sažetak: *U članku je opisana metoda integracija sile za analizu sustava s kontinuirano varijabilnim parametrima. Metoda se temelji na analitičkim rješenjima odgovarajućih diferencijalnih jednadžbi. Suština metode prikazana je na problemu slobodnih uzdužne vibracija ravnog štapa sa slučajnim kontinuiranim varijablama uzdužne krutosti i jedinične linijske mase, uzimajući u obzir čvrstoću. Prikazane su jednadžbe za dinamičke parametre stanja štapa i učinkovit način njihovog rješavanja. Istražene su slobodne uzdužne vibracije konzolnog klina.*

Ključne riječi: *analitičko rješenje, vibracije konzolnog klina, metoda integracije sile, uzdužne vibracije štapova, frekvencije titranja, faktori vibracije.*

1. INTRODUCTION

Systems with variable parameters occur in different branches of industry and agriculture. It is primarily rods with variable cross-section, which are applied as structural components or spatial patterns. Multipurpose steel poles, which are widely applied in municipal engineering, power engineering (power transmission lines supports, windmill towers, wind-powered generators supports), television, radio and astronautics (antennas of different structures), etc., are examples of such structures. Beam type structure elements should be particularly mentioned, whose stiffness, mass per unit length, parameters of elastic foundation (at it existence), loads or other parameters vary on length by some rule.

Systems with variable parameters occur at plate bending with thickness, which vary in the direction of one or both coordinates, or plates with variable stiffness laying on elastic foundation that can be described by Winkler model or by two elastic parameters. In construction, there are many objects with variable stiffness, such as chimneys, stacks, water towers, cooling towers etc.

From the mathematic point of view, problem of strength, rigidity, vibrations analysis of mentioned above systems lead to differential equations with variables factors. As a rule, if there is a general integral of equation found, initial problem has its solution too. In such cases, it is often said that the problem is solved by force integration method. This article is devoted problem of free vibrations of straight rod with random continuous variable lateral stiffness and random continuous variable muss per unit length taking into account resistance.

2. MAIN SECTION

2.1. Analysis of recent researches and publications

There are many papers devoted to the problem of rod vibrations. It means that it is an actual and applied problem. Among recent publications works [1-13] should be noted. Most attention is paid to vibrations of rods with continuous variable parameters [6, 8, 9, 12, 13]. Despite the fact that the analytical solutions have undoubtedly the advantage, they occur only for a few kinds of rods. In fact, it is about cases where the factors of the corresponding differential equations change by binomial rules [2, 6, 12]. In that cases solution is expressed through Bessel functions. For the general case it is stated, that analytical solutions are unknown [12] or noted that they cannot be

found [9]. That is why researches are mainly based on approximate methods.

In papers [14-16] for the first time analytical solutions for general differential equation of structural mechanic with random variable parameters are formed. The essence of applied integration method is described detailed in [16]. In the author's view, the existence of such method opens up new perspectives how to solve a variety of the above-mentioned technical problems and, in the first place, the problems of calculating systems with continuous variable parameters.

2.2. Free longitudinal vibrations of rod

The general scheme of vibrations is shown in figure 1.

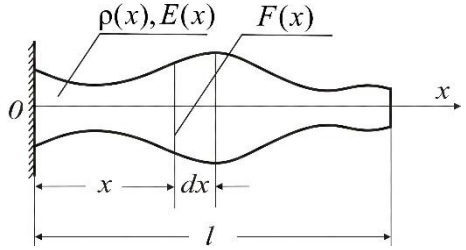

Figure 1. Rod design model on longitudinal vibrations

It is known [8, 12, 17], that differential equation of free longitudinal vibrations of rod, taking into account the resistance forces, generally looks as follows:

$$m(x)\frac{\partial^2 u}{\partial t^2} + p(x,t) = \frac{\partial}{\partial x}\left(E(x)F(x)\frac{\partial u}{\partial x}\right) + r(x,t) \qquad (1)$$

where *E(x)F(x)* - longitudinal stiffness at the point *x*; *E(x)* – rod material's modulus of elaticity; *m(x)=p(x)F(x)* – mass per unit length intensity at the point *x*; *p(x)* – rod material's density; *p(x,t)* – external resistance forces intensity; *r(x,t)* – inner resistance forces intensity; *u(x,t)* – unknown function – longitudinal displacement of rod cross-section with coordinate *x* at the time of *t*.

This equation is right for the model, which is not taking into account inertial forces, which appears because of transverse strains.

There are many hypotheses to take into account resistance forces. Let the external resistance forces are proportional to the rod mass and velocity [17]. Inner friction will be taken into account by Kelvin-Voigt hypothesis [12, 17], corresponding to which the inner resistance force is proportional to the first velocity of deformation. In this case, equation (1) takes the form:

$$m(x)\frac{\partial^2 u}{\partial t^2} + \alpha m(x)\frac{\partial u}{\partial t} = \frac{\partial}{\partial x}\left(E(x)F(x)\frac{\partial u}{\partial x}\right) + \\ + \beta\frac{\partial^2}{\partial t\partial x}\left(E(x)F(x)\frac{\partial u}{\partial x}\right) \qquad (2)$$

where α, β – factors of external and inner friction properly.

Applying the Fourier method, solution of equation (2) will be in form:

$$u(x,t) = v(x)T(t) \qquad (3)$$

where *v(x)* – peak value of longitudinal displacement, *T(t)* – unknown function of time. Expression for longitudinal force we will get by known equation [12].

$$N(x,t) = E(x)F(x)\left(\frac{\partial u}{\partial x} + \beta\frac{\partial^2 u}{\partial t\partial x}\right) = \\ = N(x)\left(T(t) + \beta\dot{T}(t)\right) \qquad (4)$$

where $N(x) = E(x)I(x)v'(x)$ – peak value of longitudinal force. Dividing variables in equations (2), we will get two independent equations:

$$\ddot{T}(t) + 2h\dot{T}(t) + \omega^2 T(t) = 0; \qquad (5)$$

$$(E(x)F(x)v'(x))' + \omega^2 m(x)v(x) = 0 \qquad (6)$$

where $2h = \alpha + \beta\omega^2$; ω^2 – Fourier method constant.

It is not difficult to write down general solution of equation (5). Expressed through parameters of initial conditions of movement $T(0), \dot{T}(0)$, it has form $T(t) = Ae^{-ht}\sin(\tilde{\omega}t + \delta)$, where

$$\tilde{\omega} = \sqrt{\omega^2 - h^2}\ ,\ A = \sqrt{T^2(0) + \left(\frac{\dot{T}(0) + hT(0)}{\tilde{\omega}}\right)^2}\ , \\ \delta = \operatorname{arctg}\left(\frac{T(0)\tilde{\omega}}{\dot{T}(0) + hT(0)}\right) \qquad (7)$$

This solutions indicates that free lateral vibrations of rod with taking into account resistance forces are taken place in time by damping harmonic rule with frequency $\tilde{\omega}$ and that introduced constant value ω represents frequency of free vibrations without taking into account resistances (case $\alpha = \beta = 0$).

It is important to express peak functions $v(x)$, $N(x)$ by dimensionless fundamental solutions. Because of this let us take for initial variable parameters expressions $F(x) = F_0\phi(x)$, $E(x) = E_0\psi_1(x)$, $\rho(x) = \rho_0\psi_2(x)$, where F_0, E_0, ρ_0 - constants, properly area of cross-section, modulus of elasticity and density of material in some point of rod; $\phi(x), \psi_1(x), \psi_2(x)$ - dimensionless functions. Then $E(x)F(x) = E_0F_0A(x)$, $m(x) = m_0B(x)$, where $m_0 = \rho_0F_0$; $A(x) = \phi(x)\psi_1(x)$, $B(x) = \phi(x)\psi_2(x)$ - dimensionless functions, which properly define rules of variation of stiffness and mass per unit length along the rod. This approach allows us to get analytical forms for vibrations frequency and operate only with dimensionless values at calculations.

Fundamental form of vibrations is defined as a solution of equation (6). General integral of this equation and peak function for longitudinal force, expressed through initial parameters, are formulated in [18]. Here we show them as:

$$\nu(x) = \nu(0)X_1(x) + N(0)\frac{l}{E_0F_0}X_2(x) \quad (8)$$

$$N(x) = \nu(0)\frac{E_0F_0}{l}\tilde{X}_1(x) + N(0)\tilde{X}_2(x) \quad (9)$$

where $X_n(x)(n=1,2)$ - fundamental functions of equation (6), which are defined by absolutely and uniform convergent serieses:

$$X_n(x) = \alpha_{n,0}(x) - K^2\alpha_{n,1}(x) + K^4\alpha_{n,2}(x) - \\ -K^6\alpha_{n,3}(x) + ... \quad (10)$$

$$K = \omega l\sqrt{\frac{\rho_0}{E_0}} \quad (11)$$

Let call functions $\alpha_{n,0}(x)\,(n=1,2)$ as *initial* and functions $\alpha_{n,k}(x)\,(n=1,2)\,(k=1,2,3,...)$ as *generating*. They define in following way:

$$\alpha_{1,0}(x) = 1,\ \alpha_{2,0}(x) = \frac{1}{l}\int_0^x \frac{1}{A(x)}dx \quad (12)$$

$$\alpha_{n,k}(x) = \frac{1}{l^2}\int_0^x \frac{1}{A(x)}\int_0^x B(x)\alpha_{n,k-1}(x)dxdx \quad (13)$$

$$(k=1,2,3,...)$$

$$\alpha_{n,k}(x) = \frac{1}{l^{2k}}\int_0^x \frac{1}{A(x)}\int_0^x B(x)... \\ ...\int_0^x \frac{1}{A(x)}\int_0^x B(x)\,\alpha_{n,0}(x)dxdx...dxdx \quad (14)$$

Here are two formulas for generating functions for clarity – recurrent and detailed. Number of integrals in recent equation without integrals, which could have initial function, is *2k*.

For fundamental functions in equations (9) it is valid equation:

$$\tilde{X}_n(x) = \tilde{\alpha}_{n,0}(x) - K^2\tilde{\alpha}_{n,1}(x) + K^4\tilde{\alpha}_{n,2}(x) - \\ -K^6\tilde{\alpha}_{n,3}(x) + ... \quad (15)$$

where

$$\tilde{\alpha}_{n,k}(x) = lA(x)\alpha'_{n,k}(x)\ (n=1,2)\ (k=0,1,2,...) \quad (16)$$

It is important that unknown parameter *K* and functions (12), (14), (16) are dimensionless [18]. Because of this fundamental functions (10), (15) are dimensionless too. As a result, dimensions of constant factors at dimensionless functions in right parts of equations (8), (9) are the same with dimensions of corresponding left parts.

Directly from equation (11) we get analytical form of free vibrations frequency without taking into account resistances:

$$\omega = \frac{K}{l}\sqrt{\frac{E_0}{\rho_0}} \quad (17)$$

where *k* – unknown dimensionless *vibration factor*. Due to this formula, the problem of determining of frequency is going to determining the vibration factor. Equations for peak vibrations of rod $\nu(x)$, $N(x)$ exactly depend on vibration factor. That is why frequency equations will be used for its determining. These equations will be found after realization of specified initial boundary conditions.

There are cases when initial and generating functions are calculated in explicit form and, as a result, fundamental solutions transforms into primitive or special functions. However, such cases are rare. Therefore, in terms of generality of results it is important to indicate an effective way of numerical implementation of the above formulas for initial and generating functions, which would be suitable for any continuous variable stiffness and random continuous variable mass per unit length.

It is known that one of the methods of numerical integration is based on replacing the integrand by its approximating polynomial. This idea is useful in our case, because it avoids multiple numerical integration, which is prescribed by formulas (12), (13), (14). This is especially important for ease of software implementation of the method.

$$\frac{1}{A(x)} = A_0 + A_1\left(\frac{x}{l}\right) + A_2\left(\frac{x}{l}\right)^2 + ... + A_s\left(\frac{x}{l}\right)^s \quad (18)$$

$$B(x) = B_0 + B_1\left(\frac{x}{l}\right) + B_2\left(\frac{x}{l}\right)^2 + ... + B_p\left(\frac{x}{l}\right)^p \quad (19)$$

Then we easily get from equations (12), (16) forms of initial functions by polynomials:

$$\alpha_{1,0}(x) = 1;\ \alpha_{2,0}(x) = \frac{1}{l}\int_0^x \frac{1}{A(x)}dx = \frac{x}{l}\sum_{j=0}^{s}\frac{A_j}{j+1}\left(\frac{x}{l}\right)^j;$$

$$\tilde{\alpha}_{1,0}(x) = 0;\ \tilde{\alpha}_{2,0}(x) = 1$$

It is more difficult to get generating functions. It is clear from equation (14) that at conditions (18), (18) generating functions could be expressed as polynomials. However, calculating of factors of these polynomials is complicated problem. Required formulas were get in work [18] and have the form:

$$\alpha_{n,k}(x) = \left(\frac{x}{l}\right)^{2k+n-1}\sum_{j=0}^{kp+(k+n-1)s} c_{k,j}^{(n)}\left(\frac{x}{l}\right)^j \quad (20)$$

$$\tilde{\alpha}_{n,k}(x) = \left(\frac{x}{l}\right)^{2k+n-2}\sum_{j=0}^{kp+(k+n-2)s} \frac{d_{k-1,j}^{(n)}}{2k+j+n-2}\left(\frac{x}{l}\right)^j \quad (21)$$

Coefficients of these polynomials are calculated by formulas:

$$c_{k,j}^{(n)} = \frac{e_{k-1,j}^{(n)}}{2k+j+n-1}\ (k=1,2,3,...) \\ (j=0,1,2,...,kp+(k-n+1)s) \quad (22)$$

$$e_{k-1,j}^{(n)} = \sum_{h=0}^{j} \frac{A_{j-h} d_{k-1,h}^{(n)}}{2k+h+n-2}; \quad d_{k-1,j}^{(n)} = \sum_{r=0}^{j} B_{j-r} c_{k-1,r}^{(n)}$$

at that $A_{j-h} = 0$, if $j-h > s$ and $d_{k-1,h}^{(n)} = 0$, if $h > kp + (k+n-2)s$; $B_{j-r} = 0$, if $j-r > p$ and $c_{k-1,r}^{(n)} = 0$, if $r > (k-1)p + (k+n-2)s$. Here $e_{k-1,j}^{(n)}$ is calculated by values of $d_{k-1,h}^{(n)}$, which are calculated in its turn by values of $c_{k-1,r}^{(n)}$. It means that formula (22) is recurrent ratio on which every next value of $c_{k,j}^{(n)}$ is calculated by previous values. Initial parameters are given by formulas:

$$c_{0,0}^{(1)} = 1; \quad c_{0,j}^{(2)} = \frac{A_j}{j+1} \ (j = 0,1,...,s) \tag{23}$$

Formula (22) can be written in detailed form:

$$C_{k,j}^{(n)} = \frac{1}{2k+j+n-1} \sum_{h=0}^{j} \left(\frac{A_{j-h}}{2k+h+n-2} \sum_{r=0}^{h} B_{h-r} \, c_{k-1,r}^{(n)} \right)$$
$$(k = 1,2,3,...) \ (j = 0,1,2,..., kp + (k-n+1)s). \tag{24}$$

Expressed in analytical form formulas for dynamics parameters with indication of its numerical way of realization allows to define free dynamic vibrations *y(x,t)* and dynamic inner forces *N(x,t)* for the rod with random continuous variable stiffness and random continuous variable mass per unit length at any possible boundary conditions.

2.2. Example

Let consider uniform rod with a wedge form with constant thickness *d* and heights of bases a, b $(0 \le a \le b)$. Let the minor base of wedge is in point *x=0* (free end), and major – in point *x = l* (fixed end) (Figure 2).

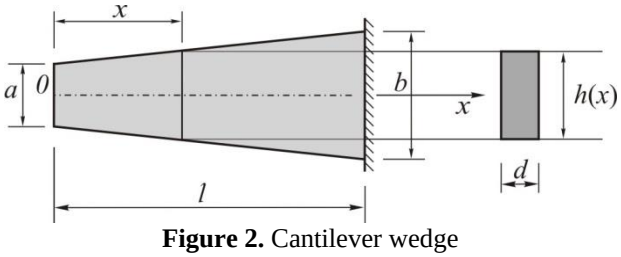

Figure 2. Cantilever wedge

Since the cross-section height in point *x* will be $h(x) = a + \frac{b-a}{l} x$, for the area of this cross-section we can write down $F(x) = db\left(\gamma + (1-\gamma)\frac{x}{l}\right)$, where $\gamma = \frac{a}{b}$ $(0 \le \gamma \le 1)$. Than, with a glance to accepted above designations, let $F_0 = bd; \ \phi(x) = \gamma + (1-\gamma)\frac{x}{l}$. Consequently $A(x) = B(x) = \gamma + (1-\gamma)\frac{x}{l}$.

It is obvious that at $\gamma = 0$ wedge will be gabled, at $0 < \gamma < 1$ it will be truncated wedge and at $\gamma = 1$ wedge degenerates into a rod with a constant cross-section.

This case corresponds to dynamic boundary conditions: $N(0,t) = 0; \ u(l,t) = 0$. Taking into account that they have to be performed for any time and using equations (3), (4), we get the equivalent boundary conditions in peak form: $N(0) = 0; \ \nu(l) = 0$.

Realizing boundary conditions by formula (7), we get the frequency equation $X_1(l) = 0$, or

$$\alpha_{1,0}(l) - \alpha_{1,1}(l)K^2 + \alpha_{1,2}(l)K^4 - \alpha_{1,3}(l)K^6 + \cdots = 0 \tag{25}$$

Left part of this equation is convergent series that is guaranteed by uniform convergence of series that defines fundamental functions. Its solutions can be found with any prescribed accuracy by the method of root comparison, which corresponds to different number of held series members.

For roots $K_j \ (j = 1,2,3,...)$ of equation (25) according to formula (16) frequencies of free vibrations without taking into account resistances will correspond:

$$\omega_j = \frac{K_j}{l}\sqrt{\frac{E}{\rho}} \ (j = 1,2,3,...) \tag{26}$$

For this frequencies will correspond frequencies with resistances taken into account: $\tilde{\omega}_j = \sqrt{\omega_j^2 - h_j^2}$, $h_j = \frac{\alpha + \beta\omega_j^2}{2}$ $(j = 1,2,3,...)$.

Free vibrations forms, corresponding to frequencies (26), on the base of (8) let formulate as $\nu_j(x) = \nu_j(0) V_j\left(\frac{x}{l}\right) \ (j = 1,2,3,...)$, where $V_j\left(\frac{x}{l}\right) = X_1(x, K_j) = \sum_{k=0}^{\infty} (-1)^k K_j^{2k} \alpha_{1,k}(x)$ - dimension-less function that defines the rule of general vibration form.

As can be seen a key role is played here by generating functions $\alpha_{1,k}(x) \ (k = 1,2,3,...)$. In particular, when the wedge is gabled, this functions can be calculated in explicit form:

$$\alpha_{1,0}(x) = 1, \ \alpha_{1,k}(x) = \frac{1}{l^2}\int_0^x \frac{1}{x}\int_0^x x\alpha_{k-1}(x)\,dx\,dx = \\ = \frac{1}{2^2 4^2 ... (2k)^2}\left(\frac{x}{l}\right)^{2k} \ (k = 1,2,3,...) \tag{27}$$

Then

$$X_1(x)=1-\frac{K^2}{2^2}\left(\frac{x}{l}\right)^2+\frac{K^4}{2^2 4^2}\left(\frac{x}{l}\right)^4- \\ -\frac{K^6}{2^2 4^2 6^2}\left(\frac{x}{l}\right)^6+\cdots=J_0\left(K\frac{x}{l}\right) \quad (28)$$

where J_0 is Bessel's function with zero index [19]. Frequency equation and the rule of general vibration form of rod will be expressed by Bessel's function:

$$J_0(K)=0;\ V_j\left(\frac{x}{l}\right)=J_0\left(K_j\frac{x}{l}\right)(j=1,2,3...) \quad (28)$$

Here we come to the well-known conlusion [12] that vibration factors of gabled cantilever wedge are zeros of Bessel's functions that are well-known. First three zeros of this function are shown in table 1.

When the rod has a form of truncated wedge, generating functions $\alpha_{1,k}(x)$ $(k=1,2,3,...)$ cannot be calculated in explicit form. For its software calculation quadrature formula (19) will be applied. It should only be noted that in this example function $B(x)$ is initially expressed by polinominal (19), where $p=1,\ B_0=\gamma,\ B_1=1-\gamma$. Therefore it is not required to build for it approximation.

There are results of calculation of first three vibration factors of truncated cantilever wedge for every value of parameter γ with increment of 0.1.

Table 1. Vibration factors of truncated cantilever wedge

	Parameter γ				
	0	0.1	0.2	0.3	0.4
K_1	2.4048	2.2085	2.0594	1.9500	1.8640
K_2	5.5201	5.3009	4.9873	4.8959	4.8399
K_3	8.6537	8.1179	8.0307	7.9719	7.9334

	Parameter γ					
	0.5	0.6	0.7	0.8	0.9	1
K_1	2.4048	2.2085	2.0594	1.9500	1.8640	$\frac{\pi}{2}$
K_2	5.5201	5.3009	4.9873	4.8959	4.8399	$\frac{3\pi}{2}$
K_3	8.6537	8.1179	8.0307	7.9719	7.9334	$\frac{5\pi}{2}$

Let stop at case $\gamma=0,5$. First three frequencies of free longitudinal vibrations of cantilever wedge without taking into account resistance corresponds to this case:

$$\omega_1=\frac{1,7940}{l}\sqrt{\frac{E}{\rho}};\ \omega_2=\frac{4,8021}{l}\sqrt{\frac{E}{\rho}}; \\ \omega_3=\frac{7,9089}{l}\sqrt{\frac{E}{\rho}} \quad (29)$$

Research of longitudinal vibrations of wedge occurs in [17]. There are calculated by B.G. Galerkin's method first two frequencies of free vibrations. In the terms of taken here designations, calculated there vibrations are:

$$\omega_1=\frac{1,794}{l}\sqrt{\frac{E}{\rho}};\ \omega_2=\frac{5,033}{l}\sqrt{\frac{E}{\rho}} \quad (30)$$

As can be seen, with the full coincidence of the first frequency, the relative error between the second is about 4.6%.

Graphs of rules of free vibrations forms, which corresponds to frequencies (24) are shown in figure 3.

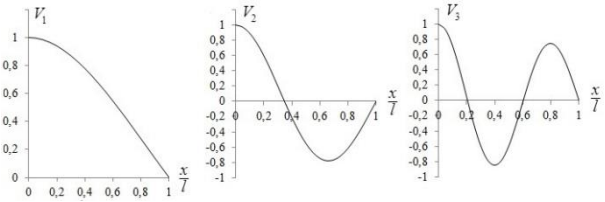

Figure 3. Graphs of rules of free vibrations form

Finally, the simplest situation arises when $\gamma=1$. Then:

$$\alpha_{1,k}(x)=\frac{1}{(2k)!}\left(\frac{x}{l}\right)^{2k},\quad X_1(x)=\cos K\frac{x}{l} \quad (31)$$

Hence we have frequency equation $\cos K=0$ and the rule for general forms of free vibrations of rod $V_j\left(\frac{x}{l}\right)=\cos K_j\frac{x}{l}$ $(j=1,2,3...)$.

3. CONCLUSION

The method of force integration, which can be used for calculation of systems with continuous variable parameters, was suggested. There are adduced all required formulas in analytical form for research of free lateral vibrations of rod with random continuous variable longitudinal stiffness and random continuous variable mass per unit length at any possible boundary conditions. Frequencies are calculated and formulas for main vibration forms of uniform cantilever wedge are found.

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POUZDANOST I PROCJENA TRENUTNOG STANJA UPORABIVOSTI KONSTRUKCIJE

STRUCTURAL RELIABILITY AND EVALUATION OF CURRENT STATE OF CONSTRUCTION

Matija Orešković, Vladimir Zadravec, Željko Kos, Evgenij V. Klimenko

Stručni članak

Sažetak: *Većina oštećenja u armiranobetonskim konstrukcijama dogodilo se kao rezultat opterećenja, tj preopterećenja. Ako je to povezano s faktorom trajnosti konstrukcije, onda moramo gledati vrijeme nastajanja štete, tj. vrijeme kada je postalo jasno da je konstrukcija počela popuštati. Granično stanje uporabljivosti odgovara stanjima iza kojih zahtjevi za korištenje konstrukcije ili konstrukcijskih elementa više nisu ispunjeni. Ovaj članak se bavi pouzdanosti konstrukcije i indeksom pouzdanosti kao najčešće korištenom veličinom za prikaz pouzdanosti konstrukcije. Opći postupci procjene stanja konstrukcije i njihove granice detaljno su opisane u članku.*

Ključne riječi: *indeks pouzdanosti, oštećenje konstrukcije, pouzdanost konstrukcije, postupci procjene*

Professional paper

Abstract: *Most of the causes of damage in reinforced concrete constructions happened as a result of the load, i.e. overload. If this is connected to the durability factor of the construction, then we need to look at the time of damage formation – that is the time when it became clear that the structure began to yield. Serviceability limit state correspond to states beyond which requirements for use of construction or construction element are no longer fulfilled. This article deals with the structure reliability and index of reliability as the most commonly used measure of the structure reliability. General assessment procedures for construction and its boundaries are described in detail.*

Ključne riječi: *structure damage, structure reliability, index of reliability, evaluation procedures*

1. INTRODUCTION

Various authors, technical committees and regulations have dealt with damage classification through history. As for the rules, Eurocode 2 and Derzhavni budiveljni normi Ukrajini (DBN) prescribe restrictions in the design area of structure (due to the temperature effect, creep and shrinkage of concrete, long-term compressive stress, maximum crack). Regulations in other European countries are written in a similar way.

The RILEM (International Union of Laboratories and Experts in Construction Materials, System and Structures) technical committee DCC-104 in 1991, after a three-year work brought out a state-of-the-art report on the classification of damage in concrete structures. In summary, it can be said that most of the damage to concrete structures originates due to the generally poor design (design phase of construction), poor technology and poor quality of construction materials (construction phase), overloading of the structure (exploitation phase, but also the design!) and from a variety of atmospheric and chemical influences. The actual classification can be illustrated by the following picture (Fig 1):

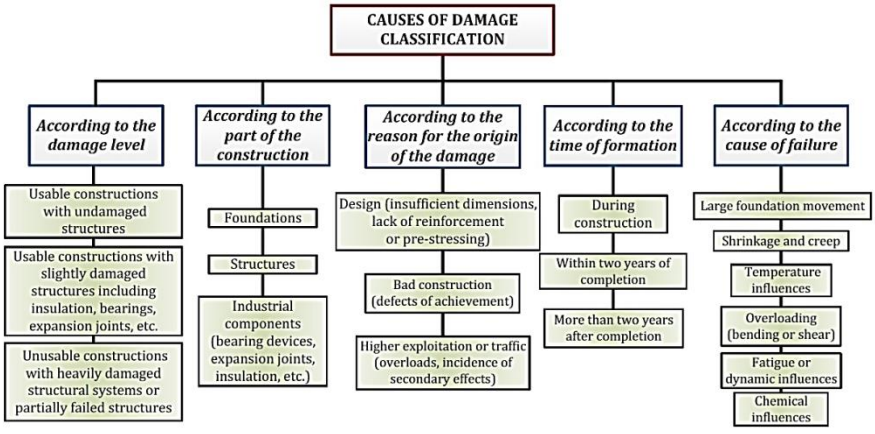

Fig 1 Classification of causes of damage on reinforced concrete structures

If we look at the cause of the damage, the most interesting thing is the appearance of cracks (a manifestation of damage) as a result of the load, i.e. overload. If this is connected to the durability factor of the construction, then we need to look at the time of damage formation – that is the time when it became clear that the structure began to yield (formation of cracks). Considering this, the formation of cracks can be divided due to: a) overloading without permanent deformation (short-term overloading in the elastic area of stress), b) overloading with permanent deformation (deformation over the elastic limit).

Calculation methods according to the limit states are based on the analysis of bearing capacity of materials. It is clear that the calculated bearing capacity is only theoretical state because it is insured with more safety factors. In fact, we can say that the theoretical strength of concrete is 55-65%.

2. CALCULATION OF THE EXISTING STRUCTURES

Serviceability limit state correspond to states beyond which requirements for use of construction or construction element are no longer fulfilled. They include structure retaining in the elastic range, the functionality of the structure or its parts, people comfort and external appearance of the structure. We differ reversible and irreversible serviceability limit states and three combinations of action for the usability calculation: characteristic, frequent and constant.

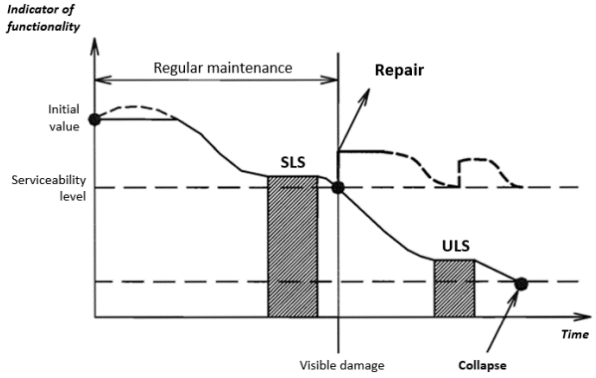

Fig 2 Possible behavior of the structure during the lifespan

The calculation model which is being implemented for calculation of existing structure must show appropriate behavior of the structure, resistance of its parts and load in accordance with the actual state of load on the existing structure.

2.1 Simple calculation methods

For lower-level assessment often is effectively calculating accordingly on basic conservative methods using simple calculation models taking into consideration safety of structure. Typical simple calculation methods are those conducted on the spatial framework and rod elements taking into consideration simplified distribution of load and linear elastic behavior of the material, resulting with equilibrium solution at the lower limit.

2.2 Complex calculation methods

When lower-level assessment has failed, more detailed calculation methods should be used. These include the finite element method and nonlinear methods (analysis of yield) which may result in higher bearing capacity. Specific modeling of time varying behavior material (shrinkage and creep of reinforced and prestressed concrete structures) and taking into account the interactions between the components of a material (adhesion, impact of embedded reinforcement) will reveal the hidden reserves of the structure and reduce the conservatism of simpler methods. When applying fully probabilistic assessment, stochastic finite elements can be used. The difference compared to conventional finite elements is that stochastic take into account of spatially interdependence of random variables. The method of stochastic finite element in contrast to the classical deterministic finite element method involves random changes in material and geometric properties of the model and random forces acting on it.

2.3 Adaptive calculation methods

In order to use within the evaluation of construction new information on its behavior (eg. due to long-term observation), calculation models need to be adjusted. By adapting the model it is possible to restore the structural variables (eg. properties of stiffness) by using measured data, such as changes in displacements, deformations, damage values (eg. the crack width).

2.4 Structure reliability

Approach to structural reliability assumes that the behavior and state of the structure is fully determined by a finite number of random variables and a finite number of connections between them. These variables are on the one hand the characteristics of the structure (geometry, resistance), on the other hand the characteristics of the observed actions on the structure. With relationships between these variables we can describe the failure of the individual parts or of entire construction.

If the P_f indicates the probability of construction failure, then the reliability can be seen as the probability that there will be no failure (chance of survival) and can be defined as the complement of P_f. The probability of failure can be generally expressed with the function of of behavior g for which applies that the observed structure will "survive" if g>0, or it will come to a construction failure if g≤0:

$$P_f(g \le 0) = \int_{g \le 0} \varphi(X) dX = \int_{g \le 0} \varphi(x_1, x_2, \dots, x_n) dx_1 dx_2 \dots dx_n \quad (1)$$

Here is φ(X) common function of probability density of the vector of all basic variables X. The calculation of

this equation is often a very complex task. There are two basic methods of calculation probability of failure:

The exact methods (level III) based on simulation techniques that are time-consuming calculations. A simple rule can be given in the form of:

$$N > C/P_f \quad (2)$$

where N is the required number of samples, and C is a constant related to the level of confidence (Eng. confidence level) and the type of function that is determined by. The default value of C can be 100 and higher.

Approximate methods (level II) use approximate methods for determining probability of failure that are fast and reliable. The best known are FORM - First Order Reliability Method) and SORM - Second Order Reliability Method.

Approximation of failure surface in calculation point can be linear (FORM approximation) or another approximate function of the second order (SORM approximation). In FORM method the probability of failure is approximately expressed by:

$P_f = \varphi(-\beta)$ φ→ distribution function of a standard normal variable

In SORM approach the failure surface is approximated with hyperbolic paraboloid passing through calculation point. In this case, the probability of failure is given by expression that takes into account the different individual curves in calculation point:

$$P_f = \varphi(-\beta)\prod_{i=1}^{n}(1 - k_i\beta)^{-1/2} \quad (3)$$

2.5 Index of reliability

The most commonly used measure of the structure reliability is the index of reliability.

$$\beta = -\varphi^{-1}(\mathrm{P_f}) \quad (4)$$

where $\varphi^{-1}(\mathrm{P_f})$ represents an inverse function of the standardized normal distribution probability of failure $\mathrm{P_f}$. The general view can be presented by taking into consideration two variables, R and E resistance and effect of action impact. In the base case the reliability of the structure function of behavior (reliability limit) g can be described with:

$$g = R - E \quad (5)$$

Assuming that the R and E mutually independent random variables with normal distribution with medium values μ_R and μ_E and with standard variations σ_R and σ_E, then g also has a normal distribution with a median value and standard variation:

$$\mu_g = \mu_R - \mu_E \quad (6)$$

$$\sigma_g = \sqrt{(\sigma_R^2 + \sigma_E^2} \quad (7)$$

Distribution of reliability limit is shown on Fig 3 where the probability of failure can also be seen ($P_f = probability(g \leq 0)$, and also the probability of survival $P_s = probability(g > 0)$.

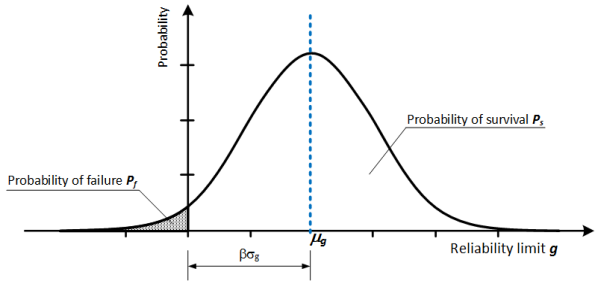

Fig 3 Distribution of reliability limit

Thus, the collapse of the structure corresponds to the event described with the inequality g <0. As g has a normal distribution, the probability of failure Pf can be determined by transforming g into standardized normal variable given by:

$$u = \frac{(g-\mu_g)}{\sigma_g} \quad (8)$$

For the critical value of function behavioral g = 0, standardized variable has a value of:

$$u = \frac{-\mu_g}{\sigma_g} \quad (9)$$

The probability Pf is then given with standardized normal function of distribution in critical point $u = -\mu_g/\sigma_g$,equal to the limit of reliability g = 0:

$$P_f = \varphi(-\mu_g/\sigma_g) \quad (10)$$

where φ represents standardized normal distribution function. Because there is connection between the probability of failure and index of reliability $P_f = \varphi(-\beta)$, in the observed base case of structure reliability, assuming a normal resistance distribution R and the effect action E, index of reliability is:

$$\beta = \frac{\mu_g}{\sigma_g} = \frac{\mu_R - \mu_E}{\sqrt{(\sigma_R^2 + \sigma_E^2}} \quad (11)$$

In this case the index of reliability represent the distance of reliability limit average value g from the start (zero), taking a standard variation σ_g from g as a unit measure. However this expression for the probability of failure and index of reliability is valid only by assuming normal distribution of both primary variables R and E. In the general case, when R and E have a non-normal distribution, the above expressions can be considered as first assessment, and the more accurate probability of failure can be determined by the expression:

$$P_f = \int_{-\infty}^{+\infty} \varphi_E(x)\varphi_R(x)dx \quad (12)$$

$\varphi_E(x) \rightarrow$ function of probability density of the action effect E

$\varphi_R(x) \rightarrow$ distribution function of resistance R

When failure probability is known, the index of reliability is determined from the expression:

$$\beta = -\varphi^{-1}(P_f) \quad (13)$$

The probability of structure failure, and therefore its reliability is time-variable. If the resistance of a structure reduces with time, with increasing the load, index of reliability over time will be reduced. Three possibilities of reliability change are shown in Fig 4.

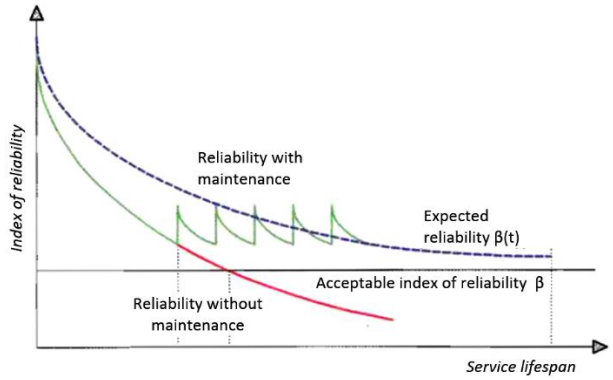

Fig 4 Possibilities of reliability change in construction lifespan due to structure maintance: The blue curve shows the expected behavior of the structure in its lifespan; red line shows the unacceptable behavior of the structure as the lower limit of acceptable behavior has been reached during construction usage; green line shows the behavior of the structure by taking adequate activities at specific time intervals which maintained the level of reliability.

3. EVALUATION PROCEDURES OF CURRENT STATE OF CONSTRUCTION

Evaluation of existing structures can be implemented through procedures of various sophistication and with different investment efforts. General assessment procedures can be divided into three categories:

1) Assessment based on measurements - methods in which the effects of actions are determined by direct measurements, not by construction calculations. As the measures of serviceability can be determined only by direct measurements, these are assessment methods exclusively of serviceability limit states.
2) Assessment based on models - methods in which the effects of actions are determined by calculation models. With this methods can be modeled and hence evaluate the ultimate limit state of construction as well as serviceability limit state. The methods consists of three steps: 1. collecting data on actions and resistance of structure; 2. calculation of effects on construction model; 3. evaluation of bearing capacity and usabillity (serviceability).
3) Informal assessment – methods based on experience and judgement of engineers that deals with evaluating. Structure condition is evaluated based on visual inspection. Therefore, these methods are more or less subjective and are applied only exceptionally.

The proposed assessment levels are not strict, and the boundaries between them are flexible (all shown through Table 1):

- Level 0: informal qualitative assessment - assessment based on the experience of engineers to visually assess the effects of the aging (cracks, flaking, chipping, corrosion), mainly used for preliminary evaluation of the structure.
- Level 1: determination of the action effect by measurements - evaluates the usage by comparing the measured and limit values given by regulations or determined individually.
- Level 2: assessment approach by partial factors based on a documentation review - evaluates the capacity and serviceability of existing structure on the simple calculation models by using data from main and detailed design and inspection documentation.
- Level 3: assessment approach by partial factors based on additional tests - evaluates the capacity and usability of existing structure in an improved and detailed calculation models by using data on the structure obtained from detailed non-destructive tests.
- Level 4: assessment of targeted reliability with modified partial coefficients - Values of partial coefficients are adjusted for a group of structures with similar structural behavior or actions. Targeted reliability is adopted, and assessment of capacity and usability is carried out taking into consideration values that are adjasted to a specificconstruction.
- Level 5: fully probabilistic assessment - structure reliability calculation is carried out directly (without partial factors) for what is necessary to know the statistical properties of all the basic variables. Uncertainties are modeled probabilisticly.

Table 1 The classes and levels of structure evaluation and adequate procedures

LEVELS OF EVALUATION		**EVALUATION PROCEDURE**		
OBJECTIVE OF EVALUATION	EVALUATION LEVEL			
INFORMAL ASSESSMENT		Assessment based on the experience of engineers to visually assess the effects of the aging (cracks, flaking, chipping, corrosion), mainly used for preliminary evaluation of the structure.		
Qualitative state assessment	**Level 0**			
EVALUATION BASED ON MEASUREMENTS		**Determination of the effects of actions**		**The process of proving**
Quantitative evaluation of usability	**Level 1**	Measuring the values of certain parameters under the applied load (actual or experimental)		Comparison of measured and limit values
EVALUATION BASED ON MODELS		**Collection of data**	**Calculation model**	**The process of proving**
Quantitative evaluation of the bearing capacity and usability	**Level 2**	From designs and regulations Construction examinations	Basic models Detailed models	Deterministic (exceptionally) Semi Probabilistic (parc. coefficient.)
	Level 3	Construction examinations (measurements) and material testing. Monitoring for system recognition Load monitoring The evidential load	Detailed models (FEM, nonlinear calculations) Adjusted models	Semi Probabilistic (parc. coefficient.)
	Level 4		Detailed models (MKE, nelinearni proračuni) Adjusted models	Semi Probabilistic (parc. coefficient.) Approximate probabilistic methods (FORM, SORM)
	Level 5	As for levels 3 and 4 + The statistical data properties	Simple adjusted models Stochastic models of finite elements	Approximate probabilistic methods (FORM, SORM) Simulation probabilistic methods (MCS)

4. CONCLUSION

There are different methods to assess the reliability, and to improve the prediction of lifetime and the management of civil engineering structures in an uncertain context. Main questions while designing construction are: How can the most likely failures and the most critical failure scenarios, which could optionally be the basis of risk analysis, be highlighted; How can uncertain data, describing the geotechnical characteristics of materials, be represented and used; what are the consequences of heterogeneity and variability for structural safety; How can the reliability or durability of a system be quantified; how can information gained over time be used to update reliability calculations; How can a policy of inspection and maintenance be optimized? In an engineering context, methods we use must allow us to analyze a system, its failure modes, and to model the failure scenarios in order to evaluate their criticality.

Maintenance optimization must be planned using reliability methods, including a presentation of the concepts of maintenance and lifecycle costs of a system. Cost models for the maintenance of components and systems must be defined in order to allow the selection of an optimal maintenance policy. Designers (engineers) should remain cautious: the result of any study are highly dependent on assumptions made and models used (whether physical, mechanical or probabilistic). Main question will always be: is the problem well-posed and the system being studied well defined, and analyzed by structural and functional approaches? An analysis of a system makes sense only for the problem being solved, especially in the context of a multicriteria analysis. There is not one single unique definition of components and their relationships.

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PRIMJENA NUMERIČKE I ANALITIČKE METODE GRANIČNIH ELEMENATA U ANALIZI REBRASTIH PLOČA

NUMERICAL AND ANALYTICAL BOUNDARY ELEMENT METHOD APPLICATION IN RIBBED SLAB ANALYSIS

Mykola Surianinov, Oleksandr Chuchmai, Oleksii Shyliaiev

Pregledni rad

Sažetak: *U članku je provedena analiza rebrastih ploča uz pomoć numeričke i analitičke metode graničnih elemenata. Naveden je detaljni redoslijed rješenja problema, te je riješen konkretni primjer.*

Ključne riječi: *glatke ploče, metoda graničnih elemenata, poprečne grede, rebraste ploče, savijanje*

Review article

Abstract: *Article is dedicated to analysis of ribbed slabs using the numerical and analytical boundary element method. Program realization of problem solution if performed. Test example of calculation is given.*

Keywords: *boundary element method, coffered ceilings, cross beams, deflection, smooth plate.*

1. INTRODUCTION

Ribbed slabs are widely applicable in many branches of industry: civil engineering, mechanical engineering, aviation, shipbuilding etc. It is an advanced type of ceiling in the civil engineering – coffered ceilings, which can be described as plate supported with system of crossed beam-ribs, which are located in the bottom. In this construction, concrete is removed from the tensile region of cross-section. There are retained only ribs in which tensile reinforcement is placed. As a result, the considerable material economy can be achieved beside ceilings with solid cross-section. On the other hand, overlapping bays can be increased significantly.

Classical methods of structural mechanics (work method or deflection method) and numerical methods are generally used for analysis of such systems. The most common method is the finite element method [1, 2]. Application of numerical and analytical boundary element method (NA BEM) is highly efficient [3-5].

2. MAIN SECTION

Let us look at the fragment of coffered ceiling as shown in the figure 1.

The main idea of proposed approach consists in following. Construction parts with ribs parallel to axis *ox* (call this direction lateral), are considered as a smooth plates with thickness $h_1 = h + h_{rib}$ and width $b = b_{rib}$, where h - plate thickness, h_{rib}, b_{rib} - rib cross-sections dimensions (which are not necessarilly the same).

For this modules (module is a unit of sampling in BEM) the theory of smooth plates analysis,

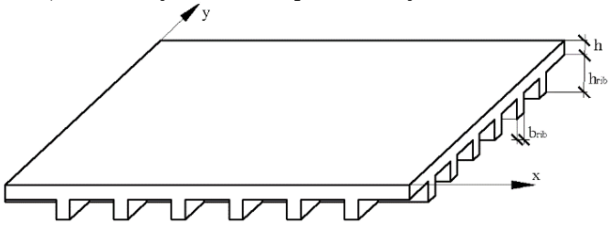


Figure 1. Fragment of coffered ceiling

stated in [3, 4], with according expression of fundamental functions, Green's function and load vector is valid. In the figure 2 such modules are indicated with even numbers. Other modules (odd numbers in the figure 2) are represented as plates supported with ribs in longitudinal direction, i.e. parallel to axis *oy*.

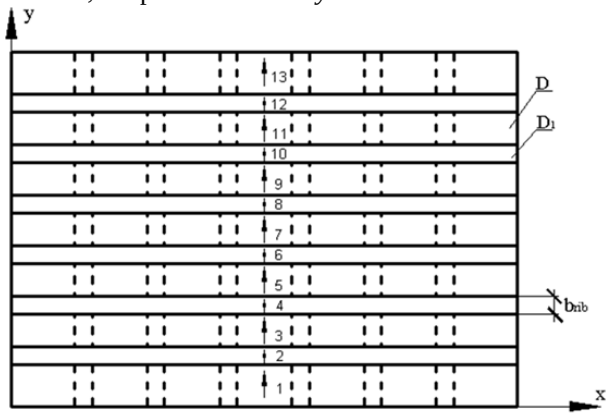


Figure 2. System discretization to one-dimensional modules

Let us take a closer look at NA BEM application to these modules.

Differential equation of plate bending flexure in this case becomes [6]

$$\frac{\partial^4 W}{\partial x^4} + 2\frac{\partial^4 W}{\partial x^2 \partial y^2} + \frac{\partial^4 W}{\partial y^4} = \frac{\bar{q}}{D}, \quad (1)$$

where $W = W(x,y)$ – plate deflection; $\bar{q} = \bar{q}(x,y)$ – free term of an equation, which takes into account not only external loads, but also presence of support ribs in longitudinal direction, as shown in figure 3.

We apply for (1) the Kantorovich-Vlasov method, i.e. deflection of plate median surface we will evaluate as:

$$W(x, y) = W_1(y)X_1(x) + \\ + W_2(y)X_2(x) + \ldots + W_k(y)X_k(x). \quad (2)$$

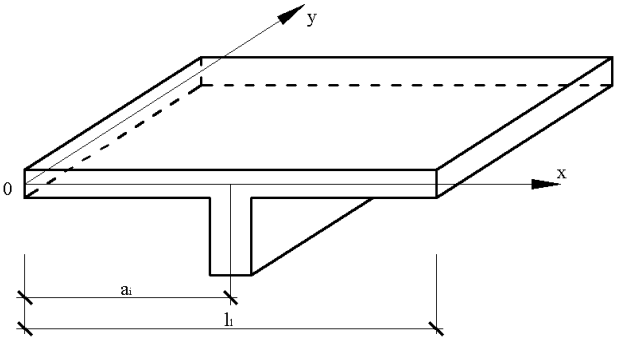


Figure 3. Plate with a rib in longitudinal direction

Truncate the series (2) to one term and take deflection variation only in *y* direction. It is equal to assume the design model as the plate with infinite number of degree of freedom in one direction and one degree of freedom in another direction. Then plate median surface point deflection will be:

$$W(x, y) = W(y)X(x). \quad (3)$$

The function of lateral distribution of deflections $X(x)$ should be selected so that it most accurately describes the shape of plate swept surface in the direction of axis *x*. Beam bending flexure curves, which have the same with plate conditions of support in the direction of axis *x*, fully satisfies this requirement.

There are two ways to select deflections function $X(x)$ – static and dynamic. In static method, the beam deflection is defined by applied static load.

In this case $X_1(x)$ will be:

$$X_1(x) = \left(\frac{x}{l_1} - 2\frac{x^3}{l_1^3} + \frac{x^4}{l_1^4}\right) + M(0)\left(8\frac{x}{l_1} - 12\frac{x^2}{l_1^2} + 4\frac{x^3}{l_1^3}\right) + \\ + M(l_1)\left(4\frac{x}{l_1} - 4\frac{x^3}{l_1^3}\right);$$

$$M(0) = M(l_1) = -\frac{l_1^2}{12}.$$

Applied load should be so that symmetric and skew symmetric forms of deflection curves sequentially alternates.

In dynamic method, beam natural mode shapes define its deflections.

In this case $X_1(x)$, for example, will be:

$$X_1(x) = \sin(\omega_1 x/l_1) - sh(\omega_1 x/l_1) - \\ - \alpha_*[\cos(\omega_1 x/l_1) - ch(\omega_1 x/l_1)];$$

$$\alpha_* = \frac{\sin\omega_1 - sh\omega_1}{\cos\omega_1 - ch\omega_1};\ \omega_1 = 4.73004075.$$

Load $\bar{q} = \bar{q}(x,y)$ has the most general view in the case that supporting ribs has both solid and thin-walled cross-section:

$$\bar{q}(x,y) = q(x,y) - \sum_{i=1}^{n} EI_x W^{IV}(y)X(a_i)\delta(x-a_i) - \\ - \sum_{i=1}^{n} \frac{GA}{k_1} W''(y)X(a_i)\delta(x-a_i) - \\ - \sum_{i=1}^{n} \left[EI_\omega W^{IV}(y)X'(a_i) - GI_K W''(y)X'(a_i)\right]\delta'(x-a_i), \quad (4)$$

where EI_x, EI_ω, EI_k – rib stiffness at flexure and torque;

k_1 – factor, which depends on cross-section shape;

a_i – coordinate of *i*-rib location.

$k_1 = 1.2$ for rectangle cross-section. Factor k_1 is defined by equation [7] in general case.

$$k_1 = \frac{A_v(z)}{B_x^2(z)} \int_A \frac{S_{EyA}^2}{Gb^2} dA,$$

where A – cross-section area; $A_v = \int_A G dA$;

$$B_x(z) = \int_A Ey^2 dA;\ S_{EyA} = \int_A Exy dA.$$

Delta function $\delta(x-a_i)$ and its derivative $\delta'(x-a_i)$ are used in (4) when rib is very narrow-width and can be considered as a line; in other case rib existence is considered by difference of Heaviside unit functions.

Let us return to the equation (3). We substitute it into (1) and into known from the plate flexure theory expressions of static parameters (bending moments and adjusted shear forces). Multiplying both sides of each expression by $X(x)$ and integrating in limits $[0; l_1]$, we will get Cauchy problem for one-dimensional model of rectangle plate, supported with longitudinal ribs, flexure:

$$W^{IV}(y) - 2r^2 W''(y) + s^4 W(y) = \frac{\bar{q}(y)}{D} \quad (5)$$

at initial conditions

$$DW(0);\ D\theta(0) = DW'(0); \\ M(0) = -D\bar{A}[W''(0) - \mu r^2 W(0)]; \quad (6) \\ Q(0) = -D\bar{A}[W'''(0) - (2-\mu)r^2 W'(0)],$$

where

$$r^2 = -\overline{B}/\overline{A};\ s^4 = C/\overline{A};$$
$$\overline{q}(y) = \int_0^{l_1} \overline{q}(x,y)X(x)dx/\overline{A}; \quad (7)$$

$$\overline{A} = A + \frac{1}{D}\sum_{i=1}^{n} EI_x X^2(a_i) + \frac{1}{D}\sum_{i=1}^{n} EI_\omega [X'(a_i)]^2; \quad (8)$$

$$\overline{B} = B + \frac{1}{2D}\sum_{i=1}^{n} EI_k [X'(a_i)]^2 + \frac{1}{2D}\sum_{i=1}^{n} \frac{GA}{k_1} X^2(a_i); \quad (9)$$

$$A = \int_0^{l_1} X^2(x)dx;\ B = \int_0^{l_1} X''(x)X(x)dx;$$
$$C = \int_0^{l_1} X^{IV}(x)X(x)dx. \quad (10)$$

Differential equation (5) by its structure is similar to the equation, that describes flexure of plates without rib supports, but form of expressions (7)-(9) argues that in (5) ribs parameters are taken into account. With reference to realization of boundary element method algorithm it means, that rib parameters will be taken into account in fundamental functions expressions.

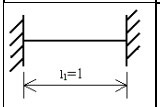
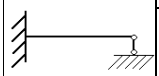
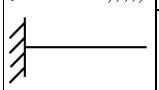
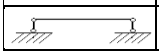
Kinematic and static parameters for supported plate will be in general the same as for the plate without ribs, but in numerical expression they will be different. Because deflection *W(y)*, contained in following equations, will differ from deflection of according „smooth" plate.

$$\theta_x(x,y) = W(y)X'(x);\ \theta_y(x,y) = W'(y)X(x); \quad (11)$$
$$M_x(x,y) = -D[W(y)X''(x) + \mu W''(y)X(x)]; \quad (12)$$
$$M_y(x,y) = -D[W''(y)X(x) + \mu W(y)X''(x)]; \quad (13)$$
$$H_x(x,y) = -H_y(x,y) = -D(1-\mu)W'(y)X'(x); \quad (14)$$
$$V_x(x,y) = -D[W_y(y)X'''(x) + W''(y)X'(x)]; \quad (15)$$

where $\theta_x(x,y)$, $\theta_y(x,y)$ – normals angles of deflection in direction of axes *x* and *y*; $M_x(x,y)$, $M_y(x,y)$ – bending moments; $H_x(x,y)$, $H_y(x,y)$ – torque moments; $V_x(x,y)$, $V_y(x,y)$ – shear forces.

Factors (7)-(10) values are calculated in program Scilab [8] and are shown in table 1 (in condition that stiffness rib dimensions are *b*x*h* = 0.1 x 0.1 m).

Table 1. Factors numerical values

Conditions of plate support	Factors		
	$\overline{A}$	$\overline{B}$	$\overline{C}$
	4,7510773e+00	-1,27447255e+01	518,5521
	3,9617707e+00	-1,05574402e+01	237,3516
	3,0717246e+00	3,49815534e+00	22,9401
	1,9218750e+00	-4,9348022e+00	48,7045

Cauchy problem solving (5)-(6) could be expressed accordingly to the algorithm of boundary element method

$$\begin{bmatrix} DW(y) \\ D\theta(y) \\ M(y) \\ Q(y) \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & -A_{13} & -A_{14} \\ A_{21} & A_{22} & -A_{23} & -A_{24} \\ -A_{31} & -A_{32} & A_{33} & A_{34} \\ -A_{41} & -A_{42} & A_{43} & A_{44} \end{bmatrix} \text{ x}$$

$$\text{x} \begin{bmatrix} DW(0) \\ D\theta(0) \\ D\theta(0) \\ Q(0) \end{bmatrix} + \int_0^y \begin{bmatrix} A_{14}(y-\xi) \\ A_{13}(y-\xi) \\ -A_{12}(y-\xi) \\ -A_{11}(y-\xi) \end{bmatrix} \overline{q}(\xi)d\xi \quad (16)$$

Thus at Kantorovich-Vlasov method application, solution of main differential equation is reducing to defining of deflection (4), where function *X(x)* is given and function *W(y)*is defining from (16) in the form:

$$DW(y) = A_{11}\cdot DW(0) + A_{12}\cdot D\theta(0) - A_{13}\cdot M(0) - A_{14}\cdot Q(0) + \int_0^y A_{14}(y-\xi)q(\xi)d\xi. \quad (17)$$

Solution of equation (5) depend on roots of according characteristics equation, which can be expressed as:

$$k_{1-4} = \pm\sqrt{r^2 \pm \sqrt{r^4 - s^4}}. \quad (18)$$

Fundamental function form is defining by *r* and *s* relation, which depend on boundary conditions on longitudinal edges of plate and stiffness ribs parameters. Herewith there should be six cases:

1. $|s| > |r|$, at that

$$k_{1-4} = \pm\alpha \pm i\beta,$$

where

$$\alpha = \sqrt{\frac{s^2 + r^2}{2}};\ \beta = \sqrt{\frac{s^2 - r^2}{2}}.$$

Deflection *W(y)* will be written in form:

$$W(y) = C_1\Phi_1 + C_2\Phi_2 + C_3\Phi_3 + C_4\Phi_4, \quad (19)$$

where Φ_1, Φ_2, Φ_3, Φ_4, - hyperbolic-trigonometric functions:

$$\left.\begin{aligned} \Phi_1 &= ch\alpha y \sin\beta y; \\ \Phi_2 &= ch\alpha y \cos\beta y; \\ \Phi_3 &= sh\alpha y \cos\beta y; \\ \Phi_4 &= sh\alpha y \sin\beta y. \end{aligned}\right\} \quad (20)$$

2. $s = r$, at that characteristic equation roots will be real and divisible:

$k_{1-4} = \pm\sqrt{r^2}$.

Deflection *W(y)* will be written in form (19) again:

$W(y) = C_1\Phi_1 + C_2\Phi_2 + C_3\Phi_3 + C_4\Phi_4,$

but now $\Phi_1 = ychry;\ \Phi_2 = chry;\ \Phi_3 = shry;$ $\Phi_4 = yshry.$

3. $|s| < |r|$, roots will be real and different:

$\lambda_1 = \sqrt{r^2 + \sqrt{r^4 - s^4}}, \quad \lambda_2 = \sqrt{r^2 - \sqrt{r^4 - s^4}}.$

Than integrated deflection:

$W(y) = C_1\Phi_1 + C_2\Phi_2 + C_3\Phi_3 + C_4\Phi_4,$

where

$\Phi_1 = sh\lambda_2 y;\ \Phi_2 = ch\lambda_1 y;\ \Phi_3 = sh\lambda_1 y;$
$\Phi_4 = ch\lambda_2 y.$

4. Roots of equation (18) are real and divisible:

$k_{1,2} = 0;\ k_{3,4} = \pm r_1;\ r_1 = -2\overline{B}/\overline{A}.$

In this case in expansion

$W(y) = C_1\Phi_1 + C_2\Phi_2 + C_3\Phi_3 + C_4\Phi_4$ we have

$\Phi_1 = shr_1 y;\ \Phi_2 = 1;\ \Phi_3 = y;\ \Phi_4 = chr_1 y.$

5. Roots of equation (18) are real and imaginary

$k_{1,2} = \pm i\beta;\ k_{3,4} = \pm\alpha.$

In this case

$\Phi_1 = \cos\beta y;\ \Phi_2 = \sin\beta y;\ \Phi_3 = ch\alpha y;\ \Phi_4 = sh\alpha y.$

6. Roots of equation (18) are imaginary

$k_{1,2} = \pm\alpha i;\ k_{3,4} = \pm\beta i;$

In this case:

$\Phi_1 = \cos\alpha y;\ \Phi_2 = \sin\alpha y;\ \Phi_3 = \cos\beta y;$
$\Phi_4 = \sin\beta y$

3. CONCLUSION

Thus full solution of the problem consists of six variants of roots of according characteristics equation; there are formulated six systems of fundamental orthonormalized functions (total number of 96) for them, Green's function is generated, six variants of load vector are formulated.

Program realization of developed algorithms is performed in software package Scilab. Ability of boundary conditions variation, rib number and their cross-section dimensions change, character of external load variation is foreseen.

Here on the figure 4 as a test example we show the calculation results of uniformly loaded on all area ribbed slab fragment with rigid restraint on all contour.

Deflection and bending moment at the center of construction are calculated. Calculation results are shown in the table 2, where values of deflection and bending moment at the center of plate calculated with finite element method in program ANSYS [8] are shown too.

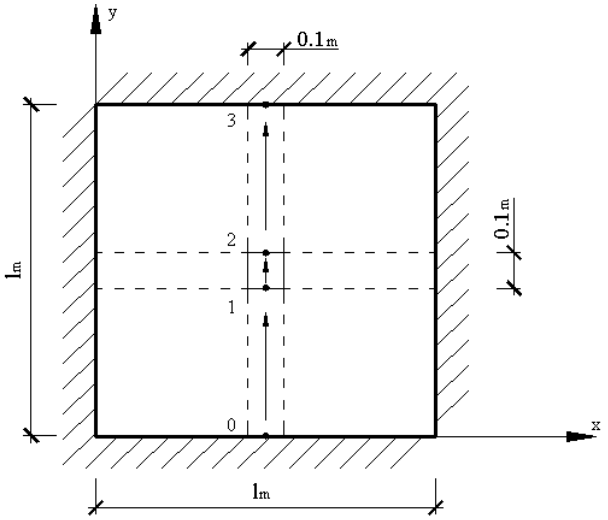


Figure 4. Test example

Table 2. Comparison of results, obtained by two methods

Value	NA BEM	FEM, ANSYS	Inaccuracy, %
Deflection, m	-0.1406e-06	-0.1357e-06	3.48
Bending moment, kNm	0.922e-02	0,884e-02	4.12

As we can see, boundary element method shows practically the same results with finite element method.

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VLASTITE DEFORMACIJE U STRUKTURI BETONA TIJEKOM NJENOG RAZVOJA

OWN DEFORMATIONS IN SELF-DEVELOPMENT OF CONCRETE STRUCTURE

Korobko O.A., Rogniuk E.V., Kotsiurubenko O.M., Kazmirchuk N.V.

Stručni članak

Sažetak: *U članku je izložena analiza organizacije strukture betona kao mreža interno povezanih procesa i fenomena na mikro i makro nivoima strukturne heterogenosti u pogledu deformacija različite prirode nastanka.*

Ključne riječi: *heterogenost, mikro i makro struktura, razvoj strukture betona, vlastite deformacije.*

Professional paper

Abstract: *The article presents an analysis of the organization of the concrete structure as a network of interrelated processes and phenomena on the micro- and macrolevels of structural heterogeneity in view of its deformations of a different nature.*

Keywords: *heterogeneity, micro- and macro structure, development of concrete structure, own deformations*

1. INTRODUCTION

Concrete is represented as a polystructural material [1, 2] with the characteristic levels of heterogeneity, each of which includes a set of own substructures with the unique set of elements. All components of the concrete are related to certain relationships and initiate the organization of each other through the positive and negative feedbacks. The implementation of the structural components interactions occurs not only on the individual levels, but also at the level of the concrete structure. This is because the concrete itself can create and manifest itself in the form of a hierarchy of heterogeneities. They are subsystems of concrete and systems for forming their substructures simultaneously [3]. Thus, all the processes of self-production structure of composed mixed material are combined into a single complex interdependent dynamic network of continuous cycles of birth, changes and additions [4]. It can be assumed that the kind of co-ordination of system material components should be executed by localized deformation and energy flows to ensure its required macro state responsible for the manifestation of the level of properties. In the initial period the most of active processes take place, accompanied by heat and the change in volume. The accepted model of concrete allows selecting the thermal and volume deformations as elements of the overall network of interactions, gradients which can have a significant impact on its structural design. On this basis, the task has been defined – to analyze the deformation phenomena involvement in the self-construction of concrete as a complex organized material and to identify the factors controlling their gradients.

2. THE IMPACT ON THE STRUCTURE OF ITS OWN DEFORMATIONS OF CONCRETE AS A COMPLEX ORGANIZED MATERIAL.

Article under certain assumptions and estimates, the microstructure was presented in the form of a multiphase heterogeneous highly concentrated coarse lyophobic system of freeze phase boundary [2], which allowed analyzing her structural organization based on unbalanced interparticle interactions. The processes at the level of binder particles are fundamental for the concrete structure formation as a complex dynamical system. This is dominated by the physical and mechanical processes that result in the formation of cluster structures (aggregates) of grain binders [5], and physico-chemical processes leading to the modification of their surface [6]. These processes and resulting effects at the micro level provokes the development of thermal effects and volume deformations, transmitted and perceived levels of other heterogeneity that react in response to them appropriate rearrangements of its structure.

The system with a fairly complex source composition spontaneously builds a path of self-initiation of physical and chemical, physical and physical-mechanical processes [7]. One of the main places in these processes takes thermal effects that arise as a result and is the cause of deepening self-organization phenomena. To identify the factors of self-motion process control system it is important to take into account not the cumulative effects of energy and its internal desire for order, which is realized through the ion gradients, temperature, concentration.

The analysis of the researches has shown [8, 9] that the first peak of heat release is associated with the formation of the dispersed system and is caused by reformation of the interface from the "solid - gaseous" in the state "solid - liquid". When asymmetric water molecules has been adsorbed on the surface of the solid particles of the dispersed phase the energy is released. The amount of this energy must be proportional to the surface area of the section and the surface tension at the interface (contact angle). Use of the average value is valid only in the case of similar size monomineral particles. Assuming the use of different-size particles, even the same nature, possible fluctuation of temperature change due to the change of the heat capacity, which depends on weight (volume) of the particles. Due to the different values of the surface area and size, the surface temperature of the particles, and particle volume of the dispersion medium will be different T1□T2□Tn. A temperature gradient caused by internal diffusion, flow around, sliding across the surface, runoff, exchange charges. Local perturbations in the dispersion are possible even if the composition of particles is mono-mineral one. Polymineral nature of the grain binder only increases the number of fluctuations. This is provoked with unequal thermal capacity of minerals, different orientation of individual minerals in the volume particle diffusion, and the difference in the coefficients of wetting (contact angles) that leads to the formation of local heat zones according to the number of mineral components.

Multifocal hydration mechanism is implemented in the multimineral and polydisperse systems that initiate the energy chaos. It is important that the phenomena that occur as a consequence of the defining processes may become dominant in the initiation of chemical phenomena with less chemically active ingredients. Furthermore, local changes in pH of the dispersion medium due to differences in the solubility of minerals, together with the local temperature gradients cause a local change in ion concentration, which leads to a localization process, and nucleation of the material composition and fluctuations in density.

Physical and chemical processes of the organization structure of the concrete at the level of binder particles are the source of origin of the volume deformations. Due multimineralityand polydispersity of the original composition of the binder caused uneven changes in local volumes of grains of different nature and size. Also, a disproportionate amount of the dispersion medium is changed. As a result, the particles and the liquid phase of the waves propagate deformations. Given the gradient thermal effects, volumetric deformation of the microstructure essentially determines the self-organization.

Introduction concrete as a polystructural material suggests that the microstructure forms part of a macrostructure which may be recognized as heterogeneity "matrix material - fillers". Groups of fillers and the matrix material concluded between them form structural cells, which differ in form determined by the way of packaging and relative orientation of the fillers. Also they differ in the size depended on the distance between the inclusions and the ratio of adhesive-cohesive binding forces at the interfaces between the matrix and fillers. [5] Macro organization is carried out by reacting the matrix with fillers and is accompanied by display of volume deformation gradients and forming phenomena at the interfaces between the two [2].

The distribution of the particle binder in clusters leads to formation an interconnected web of inter-cluster interfaces at the micro level. Simultaneously with this formation of the interface between the matrix material (microstructure) and fillers is occurred. Continuous volume changes of the structural units are responsible for the development of deformation processes at the interfaces between them, which leads to the localization and expression of deformation gradients in the microstructure of different volumes. This forms the initial wave, resulting in deformation gradient micro transferred to the level of the macrostructure. This will cause a spontaneous deformation of the interfaces between the matrix and the fillers, unique for each cell structure, which will affect the terms of interparticle and interfacial interactions going on in the microstructure, and will initiates a new deformation flow. Formation of return waves transition volume deformations from one level to another allows the influence the concrete structure heterogeneities on the organization of each other through mutual disturbances. It should be aware that each of the levels can only direct the structural transformation of other subsystems of the concrete, but not define them. Management of micro- and macrostructures structure formation is done by their own intra-potential; they can decide how and to what extent they respond to possible changes in their environment. Based on this, it seems reasonable to separate the driving forces (conditions) or that commits process (phenomenon) in the management factors and factors of nonspecific activation. And those and others are placed in the concrete in the molding products, but the first is responsible for the structural organization level, the components of which they are nationals, while the latter act as external influences, pushing design structures interacting levels on certain ways and forms of development.

Typical microstructure control factors include the quality and quantity of binder, by means of which aimed changes in structure formation processes are occured [2], thereby performing suggestive action on the formation of a macrostructure. It allows selecting the initial composition of the dispersed phase as a factor in the indirect (non-specific) activation of self-production structure of the macro-level. For the microstructure heterogeneity factors of indirectly influence parameters are structural cells, which at the same time, manifest themselves as intrinsic characteristics of macrostructure. They define the length and configuration of the external borders of the matrix material and the conditions for its adhesion to the surface of the filler.

The structure organization, both of separate levels of heterogeneity, and of the concrete, occurs under continuous action of generated streams of their own deformations. Deformation waves provoke self-generation and self-development at all levels of heterogeneity various sorts of flaws which as new elements automatically join in the organization of their structure, participating in manifestation and allocation of gradients of deformations. Thus there are prerequisites for emergence of such structural components of concrete as technological cracks and inner interfaces of partition

which in total with set tensions define heterogeneity of a material of a construction, and, so and safety of its operation.

3. CONCLUSION

Thus, we can conclude that the structure formation of concrete as a hierarchy of levels of homogeneities in structure is the result of interference of certain processes and phenomena connected with each other on the network principle. The net is defined as a special order of the structure organization of complex dynamic systems, in which they produce themselves by interrelated cycles of structural changes. All the network elements are involved in the origin and transformation of each other. This implies the dynamics of the highly ordered concrete structure through the coordination of joint activities of its structural components at different levels of irregularities. Deformations are also included as an element in the general network of recursive interactions. This suggests that deformations are generated by these interactions, but they also stimulate their manifestation. Thus external and internal factors can only initiate responses of material to the influence, but not operate them. This approach in the appointment of composition and technological modes of production of concrete products and structures will allow realize their potential more fully and provide reliable behavior under different operating conditions.

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OBLIKOVANJE I BUDUĆNOST KNJIŽNOG UVEZA U SVIJETU E-KNJIGE

BOOKBINDING DESIGN AND ITS FUTURE IN THE E-BOOK WORLD

Eva Dasović, Gorana Petković, Suzana Pasanec Preprotić

Pregledni rad

Sažetak: *Knjiga je intelektualno djelo većeg opsega čiji se materijalni oblik mijenjao u skladu s civilizacijskim razdobljima. S obzirom na način njezina pisanja i upotrebu određenih vrsta materijala za uvez, možemo reći da zaštitna funkcija knjige ima važniju ulogu od estetske. Njezina upotrebna vrijednost (klasa knjige) određuje se na temelju vrste uveza, dok izbor forme uveza ovisi o sadržaju i opsegu autorskog djela. Primjena digitalnih tehnologija izravno je pridonijela distribuciji digitalnih knjiga. Stoga izdavačke kuće distribuiraju svoja izdanja na digitalnim platformama svakim danom sve više. Postavljaju se pitanja kakav će utjecaj imati digitalno medijsko okruženje na tiskanu knjigu, koje vrste uveza će preferirati određene dobne skupine i kolika će zapravo biti potreba za ručnim odnosno nakladničkim uvezom knjiga u budućnosti. U radu su precizno definirani tehničko-tehnološki postupci projektiranja knjige isključivo u ručnom uvezu. Za potrebe ovog istraživanja promatrane su osnovne vrste uveza (tvrdi, meki, mehanički) knjige istog sadržaja, ali različite forme uveza (bešavna, šivana, mehanička).*

Ključne riječi: *vrsta uveza knjige, forma uveza knjige, format knjige, elektronička knjiga*

Review article

Abstract: *The book is intellectual work with relatively large number of pages, its material form was made different in accordance with a civilized periods. In view of book writing style and bookbinding materials are used, we notice that the protective function of the book is more important than aesthetic value. Book's use value (book classify) occurs in binding type, the choice between binding form depends on the book scope and volume. Digital technology has contributed in giving a share of digital books directly. For that reason, the publishing house supports digital platforms with continual increase. There are questions, in what way digital media environment will have a strong effect on the printed book, which binding types will prefer the people at different ages and what kind of publishing will require our society in the future. In the paper made up essence of craft bookbinding research project and the technical-technology procedures defined precisely. Purpose of that research was observed starting point of binding type (hardback, paperback, mechanical) and different binding forms (adhesive, thread, mechanical) with identical book content.*

Keywords: *book binding type, book binding form, book format, electronic book*

1. UVOD

Knjigoveštvo je završni dio grafičke proizvodnje i slijed radnih operacija treba biti strogo definiran. Kod projektiranja knjige slijed tehničko-tehnoloških operacija razlikuje se zbog specifičnosti vrste i forme uveza knjigoveškog proizvoda.[1,2]

Ručni i nakladnički uvez sastavni su dio knjigoveške proizvodnje. U radu su prikazane smjernice tehničko-tehnološkog oblikovanja knjige u ručnom uvezu. U obrtničkim knjigovežnicama ručni rad i knjižni uvez upotrebljavaju se za posebne prilike i izradu maketa u nakladničkoj proizvodnji knjiga.

Kupnja i uporaba knjige je uobičajena navika većine ljudi. Knjige skupljamo godinama, pohranjujemo ih na police, upotrebljavamo i razmjenjujemo ih tijekom cijelog života, što zapravo ukazuje na činjenicu da knjiga ima bezvremensko značenje. Od njezine prvobitne pojave do danas knjiga je doživjela znatne promjene u izradi papira, uporabi tehnike tiska, forme i vrste uveza, te u uporabi materijala za uvez i korice.

Zbog velike zastupljenosti elektroničke izdavačke djelatnosti, danas se postavlja pitanje kolika je stvarna potreba za tiskanom knjigom. Nove tehnologije desetljećima oplemenjuju grafičku proizvodnju, a u posljednje vrijeme značajne su promjene evidentne u grafičkoj pripremi. Uporabom pametnih telefona, pristup virtualnim bibliotekama moguće je ostvariti bez velikog napora, što dovodi u pitanje egzistenciju klasične izdavačke djelatnosti. Tradicija tiskanja knjige gubi na značaju, ali klasična knjiga uopće ne gubi na svojoj popularnosti i prodaji. Prodaja knjiga u klasičnom obliku veća je nego prodaja knjiga u digitalnom obliku zato što e-knjiga izravno pridonosi njezinoj materijalnoj vrijednosti. Klasična knjiga nudi posebno fizičko iskustvo, omogućuje čitateljima posebno zadovoljstvo listanja samo probranog sadržaja. Ne smije se izostaviti važnost grafičkog oblikovanja njezinog sadržaja i standardizacija ukupnih tehničko-tehnološki procesa koji izravno pridonose atraktivnosti knjige s aspekta prodaje.

Zbog brzih tehnoloških promjena i inovacija, generalno se mijenja shvaćanje pojma i izgleda knjige.

Elektroničko izdavaštvo je u eksperimentalnoj fazi razvoja i momentalno se rješavaju problemi utvrđivanja normi i protokola, što nije praksa klasičnog izdavaštva. Cilj ovog rada je istražiti navike, preferencije i stajališta ljubitelja knjige prema tiskanoj, odnosno elektroničkoj knjizi. Za potrebe istraživanja provedena je anketa, a koncept ankete temelji se na vizualnoj atraktivnosti knjige. Nastojalo se istražiti koliko su novca ispitanici spremni izdvojiti za određena izdanja knjiga te koje su njihove sklonosti s obzirom na vrstu i formu uveza. Knjige su ručno uvezane, a za različite vrste i forme uveza knjige upotrijebio se isti sadržaj. Na temelju rezultata istraživanja utvrđene su smjernice razvoja elektroničke izdavačke djelatnosti i njezin utjecaj na grafičku industriju.

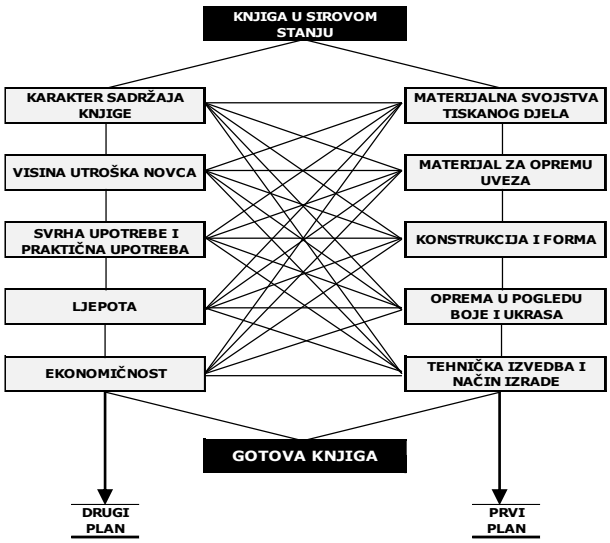
1.1. Odlike oblikovanja knjižnog uveza

Postoji više pristupa radu. Tradicionalan pristup oblikovanju uveza umara, što izravno uzrokuje obavljanje posla bez razmišljanja. Unošenjem u posao svaki pojedinac nastoji oblikovati uvez dajući mu odgovarajuću vanjsku formu i vodeći računa o samom sadržaju djela koje uvezuje. Stoga stručna znanja knjigoveže imaju značajnu ulogu pri komparaciji dvaju načina pristupa radu (tradicijski, inovativan).[3,4]

Oblikovanje uveza je umijeće pojedinca da izrazi sadržaj književnog djela. Dakle, oblikovanje treba biti podvrgnuto zahtjevima svrhe kojoj je namijenjena knjiga i njezinoj ljepoti. Nadalje, namjena i svrha knjige trebaju biti u međusobnoj vezi i služiti jedinstvenoj stvaralačkoj ideji. Za svako umjetničko oblikovanje potrebna je istinska mašta, a oblik gotovog djela treba već postojati u predodžbi. To je zapravo oblikovanje djela prema unaprijed, u mašti, stvorenom modelu, uzorku.[3-10] U knjigoveštvu takav proces rada može biti vrlo plodan jer se pojedinac može igrati materijalima, formama i vrstama uveza. Generalno takav pristup radu pridonosi stvaralaštvu i pronicljivosti, a svakako trebaju biti ostvareni sljedeći trostruki ciljevi oblikovanja knjige:

- knjižni uvez treba odražavati bitne sadržajne momente knjige i forma uveza treba biti srodna sadržaju,
- uvez treba biti u formi zadovoljenja oka i ruku, oka koje voli lijepu stvar i ruku koja voli „meki“ uvez,
- uvez treba biti ispravno napravljen, izdržljiv i prikladan za upotrebu.[11]

Osnovno pravilo nalaže da knjižni uvezi budu namijenjeni upotrebi. Karakteristike knjige najbolje će se zadovoljiti izborom vrste i forme uveza. Točke gledišta mogu se istraživati pojedinačno i/ili još detaljnije raščlanjivati (slika 1.). Povezane su sa svim drugim točkama i trebaju se s njima uskladiti, dakle točke trebaju biti u stvaralačkoj vezi. Konstrukcija i forma uveza odnose se na izgled knjižnog bloka i korica, te na način njihovog međusobnog povezivanja u cjelinu. Forma uveza se u svojoj cjelini sastoji od pojedinosti koje uvijek moraju biti podvrgnute cjelini, a forme se međusobno mogu razlikovati po važnosti (bešavni, šivani, mehanički uvez).



Slika 1. Smjernice oblikovanja knjižnog uveza[3]

1.2. Tehnička izvedba knjižnog uveza

Radni postupci i tehnike rada međusobno se razlikuju s obzirom na formu i vrstu uveza. Svaka faza tijekom rada i izrade postavlja ova pitanja:

- što treba učiniti
- kako ćemo predviđeni rad obaviti
- (ručno, strojno, linijski)
- čime ćemo radove napraviti (alati, strojevi)
- kada i u kakvoj vezi treba nešto učiniti
- nikad ne zaboraviti na pitanje – zašto?

Tehnička izrada povezana je sa sposobnostima pojedinca, upotrebljivošću sredstava za rad i uvjetima na radnome mjestu.[11] Temelj svega treba biti snaga oblikovanja i sposobnosti s ciljem da se knjižno djelo opremi prikladnim uvezom. Dakle, sve vrste i forme uveza traže poznavanje radnog postupka i ovladavanje uveznom tehnikom. Kvaliteta knjižnog uveza je postignuta samo ako je tehnika uveza ispunila svrhu knjige, kada je optimalan odnos svih dijelova i dodataka.

Tehnički uvjeti za pravilnu izradu knjige nisu mogući bez poznavanja materijala i alata. Za preradu materijala potrebni su prikladni tehnički postupci. Poznavanje svojstava papira od osobite je važnosti za vrijeme praktičnog rada. Nadalje, dobra organizacija posla može pridonijeti prikrivanju tehničkih nedostataka, što u konačnici ima pozitivan ishod na kvalitetu uveza.

Poznavanje materijala je nužno jer su oni podvrgnuti preradi više puta tijekom uveza. No ako su pojedincu svojstva materijala nepoznanica, knjižni uvez će doživjeti neuspjeh.[3],[18-22] Četiri osnovna pitanja za izbor materijala u knjižnom uvezu su:

- od kojih je sirovina izrađen materijal i kako
- u kojem obliku raditi s materijalom
- koja su svojstva i karakteristike materijala
- načini skladištenja, obrade i prerade materijala.

Papir, karton, ravna ljepenka, ljepila, konac, žica, gaza, vrpce, platna, kože, obojeni papiri za presvlačenje korica

i folije za otiskivanje, za potrebe knjižnog uveza, jednako su važni materijali. Osim toga, važno je znati koje tehničko-tehnološke uvjete treba zadovoljiti tijekom prerade materijala. Nadalje, sve informacije je dobro potkrijepiti i praktičnim iskustvom na temelju promatranja, uspoređivanja i promišljanja. Teorijska znanja o materijalima i praktična iskustva pojedinca trebaju pridonijeti radu bez smetnji. Dakle, oblikovanje knjižnog uveza treba se temeljiti na ispravnom odnosu i mjeri upotrijebljenih materijala.

Papir je najvažniji materijal. Svojstva papira tijekom prerade izravno utječu na kvalitetu uveza. Smjer toka vlakana u papiru treba biti paralelan s dužinom, pregibom knjige. Tada su najmanja naprezanja u hrptu knjige, pa je i stanje knjige nesmetano, a kad se knjiga zatvori, vraća se u svoju prijašnju formu. Suprotno, knjiga pruža otpor prema otvaranju, hrbat knjige je grebenasto iskrivljen, što u konačnici dovodi do uništenja forme uveza. Nadalje, debljina papira treba biti razmjerna debljini knjige, listovi otvorene knjige ne smiju imati tendenciju zatvaranja knjige. Format knjige i njezina debljina također trebaju biti u odgovarajućem odnosu. Jedinstvo mehanike uveza prepoznaje se u trenutku otvaranja, u sredini knjige, kada listovi obje polovice čine jednu naslagu koja najprije snažno raste, a zatim se u blagom padu spušta. Dakle, konstrukcija knjižnog uveza treba biti u funkciji gipkosti pregiba knjige jer je knjiga namijenjena čitanju.[23-26]

Uvez knjige treba biti trajan, a korice koje štite knjižni blok i upotrijebljeni materijali, s obzirom na kvalitetu, trebaju odgovarati postavljenom cilju. [12] Naravno, samo ispravnom konstrukcijom knjižnog uveza može se pridonijeti izdržljivosti (trajnosti) materijala. Kada knjiga dođe u ruke čitatelja, oblik knjige ne smije se odupirati ruci, a troškove uveza knjige treba planirati na ekonomski štedljiv način jer utrošak vremena i materijala treba odgovarati njezinoj stvarnoj potrebi.

1.3. Značajke elektroničke knjige

Digitalna izdanja obuhvaćaju sve publikacije koje su distribuirane digitalnim putem, a prije svega se misli na knjige, novine, trgovačke i potrošačke časopise, kao i na kataloge maloprodajnih tvrtki. Digitalizacija knjiga je proces pretvaranja fizičkih tiskanih knjiga u elektroničke knjige ili digitalne slike. Takav postupak zahtijeva mnogo manje vremena i truda nego metoda ponovnog tipkanja cijeloga teksta (prije nego što je skeniranje postalo izvedivo, ponovno tipkanje je obično bilo jedina opcija).[13]

Elektronička knjiga je digitalni ekvivalent tiskanoj knjizi (sl. 1.). Također, može biti interaktivna i sadržavati *online* časopise i digitalne knjige koje su napravljene kao audioknjige. E-knjige su tehnologija koja se rapidno razvija i mijenja. Neke se e-knjige proizvode simultano s proizvodnjom tiskanih knjiga, ali se u većini slučajeva kasnije stavljaju u prodaju. Često se e-knjige proizvode nakon što su knjige već tiskane, obično skeniranjem, a rjeđe pretipkavanjem.[14-15]

Jednostavno govoreći, e-knjiga je knjiga koju je moguće čitati na uređajima poput računala, tableta, pametnog telefona ili pak posebnih uređaja namijenjenih čitanju e-knjiga. Ona čitatelju najčešće donosi i dodatne mogućnosti koje u tiskanoj verziji knjige nisu dane. Primjerice, e-knjiga može sadržavati poveznice na vanjske sadržaje ili sadržaje unutar e-knjige, različite bilješke te audiodatoteke i videodatoteke.

Na zaslonu uređaja na kojem korisnik čita e-knjigu otvara se njezin sadržaj, a da bi to bilo moguće, potrebno je na uređaju instalirati aplikaciju za čitanje e-knjiga. Čitatelj može listati stranice te pretraživati sadržaj – tekst, poveznice, bilješke. Osim toga, i sam može unositi bilješke i/ili označavati dijelove teksta, a ovisno o dostupnim opcijama, svoje bilješke može dijeliti s drugim korisnicima. Bitno obilježje e-knjiga je mogućnost čitanja *offline*, odnosno nakon što je knjiga preuzeta na uređaj za čitanje, više nije potreban internet.

E-knjige se najčešće distribuiraju preko velikih distributera, odnosno e-knjižara.[14] Postoje velike globalne e-knjižare koje imaju vlastite platforme za distribuciju u obliku vlastitih e-čitača, tableta i aplikacija za sve danas dostupne hardverske platforme, ali postoji i velik broj lokalnih ili specijaliziranih e-knjižara koje se oslanjaju na neovisne e-čitače, tablete i pametne telefone.[15,16]

Formati e-knjiga su obično vezani za proizvođače hardvera i softvera za izradu i čitanje elektroničkog sadržaja. Postoji mnogo različitih vrsta formata e-knjiga s obzirom na različitu svrhu i kvalitetu pojedinih izdanja (.azw, .cbr, djvu, .epub, .pdf, .prc, .pdh, .jpeg, .html,…).

PDF je format koji je kreirala tvrtka Adobe Systems za potrebe tiska stolnog izdavaštva. Sadrži kompletan opis dokumenta koji smo snimili, a koji može uključivati grafiku, tekst i sliku. Često se upotrebljava kod digitalne distribucije magazina i luksuznih knjiga jer pruža najkvalitetniji prijelaz s papira zbog toga što se koristi izvornim tiskanim prijelomom. Podržavaju ga svi operativni sistemi. Elektroničke knjige mogu se distribuirati i kao niz slika ili po jedna slika za svaku stranicu, a glavni nedostatak toga je što korisnik ne može pretraživati tekst. Takvi se formati upotrebljavaju za stripove i knjige o umjetnosti. E-knjiga pred autore i izdavače stavlja velik izazov kad je riječ o zaštiti autorskog prava. Tu se prije svega radi o mogućnosti umnožavanja i neovlaštene distribucije digitalnog sadržaja, ali i o opcijama individualnog ili grupnog uređivanja teksta koje su dostupne korisniku, što neke e-knjige omogućuju, a čime se utječe na izvorni sadržaj. Zbog toga se na e-knjigama primjenjuje određena zaštita. DRM zaštita je tehnologija kojom se može onemogućiti kopiranje, ispisivanje i daljnja distribucija e-knjiga, pri čemu se može ograničiti broj preuzimanja i čitanje e-knjiga na određenom broju korisnikovih uređaja te definirati trajanje posudbe e-knjige. Različiti DRM sustavi različito reguliraju način zaštite autorskog prava, odnosno način i mogućnosti korištenja e-knjiga.[

2. EKSPERIMENTALNI DIO

Za potrebe ovog istraživanja projektirana je zbirka pjesama pod naslovom „Djedova poezija“ (autorsko djelo). Svi tehničko-tehnološki postupci oblikovanja knjigoveškog proizvoda (idejno rješenje – prijelom – tisak – uvez) definirani su za 3 vrste (tvrdi, meki, mehanički) i 3 forme uveza (bešavni, šivani, mehanički).[17] Knjige identičnog sadržaja ručno su uvezane. Četiri različita

uzorka knjiga istog formata (A5-stojeći) korištena su za potrebe anketiranja. Sistematizacija uzoraka knjiga provedena je prema navedenom:

TUK (tvrdi uvez/šivano koncem preko vezica)
MUK (meki uvez/bešavno)
KAT (meki kataloški uvez/bešavno+platnena traka)
MHU (mehanički uvez/spiralni)
ELK (elektronička knjiga).

Koncept ankete temelji se na osnovnim informacijama o ispitanicima: spol, starosna dob, zanimanje i razina obrazovanja. Te informacije izravno su potrebne u svrhu evaluacije rezultata istraživanja.

3.RASPRAVA REZULTATA

Anketa je provedena među članovima udruga ljubitelja knjiga, i to za različite dobne skupine. Sadržavala je ukupno 13 pitanja, od kojih su se četiri odnosila na osnovne informacije o ispitaniku, osam na osobno preferiranje vrste odnosno forme uveza, a jedno se pitanje odnosilo na njihovo subjektivno mišljenje o potrebama ručnog uveza knjige u budućnosti, te hoće li e-knjiga u potpunosti zamijeniti tiskanu knjigu. Zadnje postavljeno pitanje bilo je esejskog tipa.

Anketirali su se ispitanici koji nemaju apsolutno nikakva znanja iz područja grafičke struke. Pitanja su bila koncipirana kratko i jasno, a odnosila su se na njihove navike čitanja i preferencije. Za potrebe anketiranja ispitanicima je ponuđeno ukupno pet knjiga (4 tiskane + 1 elektronička). Predmet istraživanja bile su knjige istog sadržaja, ali različitih formi i vrsta uveza, te e-knjiga u PDF formatu na tabletu.

Anketi je pristupilo 239 ispitanika, 183 žene i 55 muškaraca. Gledajući dobne granice, 6,3% su osobe mlađe od 18 godina, 52,9% su osobe između 18 i 25 godina, 14,3% su osobe između 26 i 31 godinu, 10,5% su osoba između 32 i 38 godina, a 16% osoba je starije od 38 godina.

Ispitivana je posljednja završena razina obrazovanja i rezultati pokazuju da je 7,1% ispitanika završilo osnovnu školu, 54,2% ispitanika ima srednju stručnu spremu, 21,4% ispitanika ima višu stručnu spremu i 17,2% ispitanika je visoko obrazovano. Nadalje, 6,7% ispitanika su učenici srednjih škola, 45% ispitanika su studenti, 35,3% ispitanika su zaposlenici, a 13% ispitanika je nezaposleno.

Nakon uvodnih pitanja uslijedio je niz pitanja koja se odnose na navike čitanja ispitanika. Tako se 2,1% ispitanika izjasnilo da ne čita knjige, 14,3% ispitanika čita knjige rijetko, 23,9% ispitanika čita knjige ponekad, a 59,7% ispitanika čita knjige često. Nadalje, 89% ispitanika navodi zabavu kao svrhu čitanja tiskanih knjiga, 14,8% ispitanika čita knjige u poslovne svrhe, 64% ispitanika čita knjige u svrhu učenja i obrazovanja, te 3% ispitanika čita knjige iz nekih drugih osobnih razloga.

Rezultati ankete potvrđuju da 55% ispitanika čita elektroničke knjige. Potrebu za korištenjem elektroničke knjige 75,8% ispitanika navelo je kako svrhu čitanja iz zabave, 58,3% ispitanika u svrhu obrazovanja, 20,5% ispitanika u svrhu posla, dok 1,5% ispitanika čita elektroničke knjige u svrhu različitih osobnih potreba.

Tiskane se knjige čitaju češće (65,5%) te su ispitanici spremni više platiti za tiskano izdanje knjige (98,3%) nego za elektroničku verziju iste knjige.

Nadalje, rezultati ankete za četiri različita uzoraka knjiga potvrdili su kako 38,2% ispitanika preferira MUK i KAT, 61,3% ispitanika preferira TUK, a samo 0,4% ispitanika preferira MHU. Tvrdo uvezanu knjigu šivanu koncem ispitanici primarno preferiraju zbog estetske vrijednosti tvrdih korica, a sekundarno zbog kvalitete (čvrstoće) uveza knjižnog bloka. Stoga tiskana knjiga u ručnom uvezu ima estetsku i sentimentalnu vrijednost te je sastavni dio života pojedinca.

Za potrebe anketiranja postavljena su i dodatna pitanja o intenzitetu uporabe tiskanih knjiga i potrebama ručnog uveza u budućnosti. Rezultati ankete pokazali su kako 61,3% ispitanika smatra da elektroničke knjige nikada neće zamijeniti tiskane. S obzirom na to da studenti čine 50% populacije ispitanika, ne iznenađuju rezultati ankete. Studenti čitaju knjige iz zabave i radi obrazovanja. Iako je danas već dio literature dostupan na internetu, ispitanici preferiraju tiskane knjige, što izravno potvrđuje nedovoljnu zastupljenost elektroničkih knjiga u okruženju studentske populacije u Hrvatskoj. Nadalje, samo 2% ispitanika bi izdvojilo novac za elektroničke knjige. Smatraju da e-knjiga nema „čari“ tiskane knjige, osjet njezina posjedovanja eliminira osjetila mirisa i dodira. Iako je zastupljenost e-knjige na tržištu velika, ispitanici ipak preferiraju tiskanu verziju jer knjiga na njih djeluje opuštajuće dok je listaju i drže u rukama.

Iako su elektroničke knjige multifunkcionalne i imaju prednosti pred tiskanom knjigom, rezultati istraživanja su potvrdili kako nikada neće zamijeniti tiskane. Uvijek će postojati želja čovjeka za čarima listanja papira, za osjećajem dodira i mirisa papira, boje i materijala koji čine knjigu. Dakle, na temelju istraživanja se može zaključiti da će se povećati zastupljenost e-knjiga u svrhu obrazovanja, no, kao što televizija nije zamijenila kino niti radio, vidimo da mediji imaju tendenciju umnožavanja, a ne međusobnog istiskivanja. Vjerojatno će se kroz određeno vrijeme broj tiskanih knjiga znatno smanjiti u odnosu na e-knjige, ali nikada neće jedan oblik dokraja istisnuti drugi, niti će elektronička knjiga ikada zamijeniti tiskanu.

4. ZAKLJUČAK

U ručnom uvezu, planiranje i oblikovanje knjige treba se temeljiti na tehnološkim i estetskim načelima. Za potrebe ovog istraživanja razmatrane su tri osnovne vrste (meki, tvrdi, mehanički) i tri forme uveza knjige (bešavni, šivani koncem, spiralni-mehanički).

Posljednjih desetak godina elektroničke knjige polako zamjenjuju tiskane. Programski alati za obilježavanje sadržaja te iskustva zajedničkog umrežavanja i čitanja su samo jedna od mogućnosti razvoja digitalnog izdavaštva. E-knjiga ima svoje prednosti i nedostatke jer je ekonomski i ekološki prihvatljivija za uporabu. Globalno se smanjuje potrošnja papira i grafičkih boja, što izravno pridonosi očuvanju okoliša (ISO 14001). Njezini nedostaci su neuskladivost programskih rješenja i sučelja, otežano i usporeno čitanje teksta, moguće trajno gubljenje informacija i baterija, koja zahtijeva često punjenje.

Osobama koje preferiraju „mirisne knjige“, otisnute na papiru, napredak elektroničkih knjiga zvuči kao obilježje kraja jedne ere. No ipak postoji nešto u držanju klasične knjige u ruci i onom listanju stranica, što se nikako ne može usporediti s „pikselima“ na ekranu. Papir i tinta imaju trajnu vrijednost koju ljudi cijene, za razliku od „piksela“, koji su privremeni. Duhovna vrijednost tiskane knjige također se očituje u njezinoj izdržljivosti. Jedini njezini nedostaci su nemogućnost čitanja u mraku, kopiranje i visoka cijena.

Donedavno su informacije bile dostupne većim dijelom u tiskanom obliku, a danas su one javno dostupne zahvaljujući internetu. E-knjiga izravno onemogućuje da znanje postane talac izdavačke industrije, pa vrijednost znanja postaje javno dobro. Učenici i studenti, osobe koje čitanje, pisanje i učenje smatraju svojim životnim pozivom, najčešći su konzumenti elektroničke knjige.

Na temelju istraživanja može se zaključiti da e-knjiga, bez obzira na znatan porast uporabe, nikada neće zamijeniti klasičnu knjigu. Rezultati provedene ankete pokazuju da korisnici preferiraju knjigu za trajnu upotrebu kada je ona tvrdo uvezana i šivana koncem. Utvrđeno je kako elektronička knjiga nikada neće zamijeniti tiskanu. Štoviše, u ručnom uvezu knjiga dobiva na svojoj materijalnoj i estetskoj vrijednosti i postaje unikatno djelo autora.

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ANALITIČKI PRISTUP U ODREĐIVANJU GEOMETRIJSKOG PRIRASTA RTV KOD AM I FM RASTERSKE TEHNOLOGIJE

AN ANALYTICAL APPROACH FOR DETERMINING THE MECHANICAL DOT GAIN OF AM AND FM SCREEN TECHNOLOGY

Dean Valdec, Darijo Čerepinko, Mario Tomiša

Izvorni znanstveni članak

Sažetak: *FM rasterska tehnologija se razlikuje od konvencionalne AM tehnologije nepostojanjem linijature rastera i korištenjem mikro točkica za predstavljanje tonskih vrijednosti na slici. Geometrijski prirast RTV je promjena fizičke veličine rasterskog elementa koja se javlja za vrijeme procesa reprodukcije. Glavno pitanje ove studije bilo je definirati odnos između geometrijskog prirasta RTV kod AM i FM rasterske tehnologije. Pomoću dviju nezavisne analitičke metode temeljene na matematičkim jednadžbama definirane su prijelazne točke u %RTV kod kojih prirast RTV kod obje tehnologije ima jednaku vrijednost. Rezultati istraživanja su pokazali da se pomoću obje metode dobiju identične vrijednosti koje su važne prilikom odabira rasterskih tehnologija i definiranja osnovnih parametara rastriranja.*

Ključne riječi: *geometrijski prirast RTV, AM i FM rasterska tehnologija, promjer i opseg rasterskog elementa*

Original scientific paper

Abstract: *FM screening technology differs from conventional AM screening by the absence of screen ruling and the use of micro dots to represent the tonal values in an image. Mechanical dot gain is the change in geometrical dot size that occurs during the reproduction process. The major question of this study was to define the relationship between mechanical dot gain of AM and FM screening technology. Using two independent analytical methods, based on mathematical equations, the transition points of percentage dot area were defined where dot gain at both screening technology has the same value. The research results show that using both methods get identical values important for choosing a raster technology and defining basic parameters of screening.*

Key words: *mechanical dot gain, TVI - tone value increase, AM and FM screen technology, dot diameter, dot perimeter*

1. UVOD

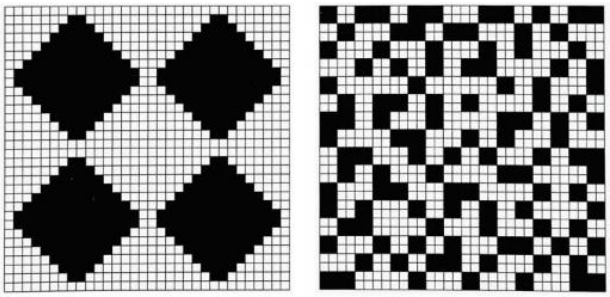
Kvaliteta i vjerodostojnost rasterske reprodukcije u suvremenoj grafičkoj tehnologiji vezana je, prije svega, uz dosljednu i ponovljivu reprodukciju rasterskih elemenata. Odabir rasterske tehnologije ovisi prvenstveno o tehnici tiska, bojilima i tiskovnim materijalima, a najzastupljenije su AM i FM rasterska tehnologija [1].

Za vrijeme proizvodnog procesa dolazi do promjene u veličini rasterskog elementa koja može rezultirati pomacima u tonu i obojenju. Postoje različiti faktori koji utječu na prijenos rastertonskih vrijednosti te mogu uzrokovati fizičku deformaciju rasterskog elementa, a jedan od načina kontrole je mjerenje prirasta RTV. Prirast RTV neizbježna je pojava koja se uvijek pojavljuje u tiskovnom procesu te se nastoji kompenzirati i standardizirati [2].

Prirast RTV (engl. Dot Gain, Tonal Value Increase) u tisku se nikada u potpunosti ne kompenzira jer će rezultirati presvijetlom reprodukcijom. Presvijetla reprodukcija ne odgovara percepciji ljudskog oka i ono očekuje da „vidi“ tamniju reprodukciju sa većim kontrastom. Prema tome, kontrolirani prirast RTV u skladu sa standardom je u potpunosti prihvatljiva pojava [3].

Određivanje prirasta RTV započinje izradom otisaka testnih karata kod različitih uvjeta tiska primjenom različitih rasterskih tehnologija. Otisci se analiziraju pomoću denzitometrijske metode, a rezultati mjerenja daju relevantne podatke o kvaliteti reprodukcije [4].

Primjena ove metode zahtjeva dosta napora, stoga je cilj ovog rada analitičkim pristupom definirati odnos između geometrijskog prirasta RTV kod AM i FM rasterske tehnologije (Slika 1).



Slika 1. AM i FM rasterski elementi kod 44% RTV [4]

1.1. AM tehnologija rastriranja

AM raster ili amplitudno modulirani raster (engl. Amplitude Modulated Screening) još je uvijek najraširenija metoda rastriranja [5]. Ova metoda postavlja fiksni broj rasterskih elemenata na pravokutnu mrežu. Mreža je definirana brojem linija po inču (lpi) ili po centimetru (lpcm) i određuje koje finoće će biti rasterski elementi. Veličina ili amplituda rasterskog elementa modulira se prema tonskim vrijednostima slike. Tamnije tonove stvaraju veći rasterski elementi, a u svjetlijim područjima rasterski elementi su manji. Kod visokih linijatura AM rastriranje u srednjim tonovima je besprijekorno. Međutim, u svijetlim i tamnim tonovima gube se sitni rasterski elementi, a to znači da se gube detalji na slici. Rezultat je smanjena kvaliteta reprodukcije sa vidljivim efektom „posterizacije". Kod linijatura rastera od 200 lpi i više, uzorak rasterskog elementa je nevidljiv za normalnog promatrača sa uobičajene udaljenosti za čitanje, a otisnuta slika poprima fotografsku kvalitetu. Ova metoda rastriranja je provjerena tijekom dugogodišnje primjene i primjenjuje se u skoro svim tehnikama tiska.

1.2. FM tehnologija rastriranja

FM raster ili frekventno modulirani raster (engl. Frequency Modulated Screening), također poznat kao stohastički raster, nadilazi mnoga ograničenja AM rastera. FM raster modulira broj ili učestalost rasterskog elementa, a ne njegovu veličinu. FM raster koristi mikro točke veličine od 10–60μm, odnosno tako male veličine koje su održive na tiskovnoj formi i u tisku. Umjesto postavljanja rasterskih elemenata na mrežu, FM raster nakuplja mikro točke ovisno o tonskoj vrijednosti slike. Iako se čini da je to nakupljanje nasumično, bez ikakvog reda, ove točke su pažljivo izračunate i postavljene. Efekt nakupljanja omogućava FM metodi reprodukciju najfinijih detalja, a otisnuta slika više nalikuje na fotografiju nego na rastersku reprodukciju [4].

Uzorak FM rastera je po izgledu vrlo sličan zrncima srebro halogenida u fotografskom filmu. Uzevši u obzir takav izgled i relativno malu veličinu rasterskog elementa rezultat je oštra slika sa puno detalja. Na taj se način iz slike visoke razlučivosti može izvući maksimalna korist.

2. ANALITIČKI PRISTUP U ODREĐIVANJU GEOMETRIJSKOG PRIRASTA RTV

Temeljem provedenih prijašnjih istraživanja, utvrđeno je da se prirast RTV kod AM rastriranja povećava s povećanjem linijature rastera i smanjenjem kvalitete papira [2]. Nadalje, eksperimentalnom analizom utvrđeno je da je prirast RTV kod FM rastera relativno veći u odnosu na AM raster. Međutim, u svijetlim područjima prirast RTV je veći kod AM rastera [6]. Razlog tome je što veličina rasterskih elemenata kod AM rastriranja linearno raste, a veličina rasterskih elemenata kod FM rastriranja je fiksna.

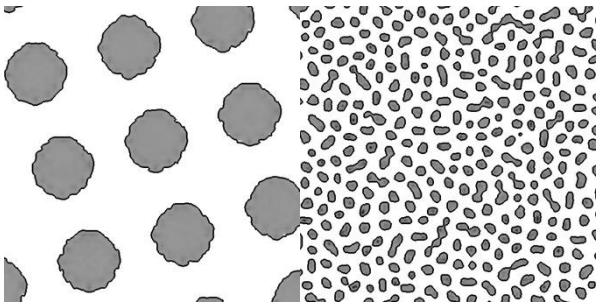
Cilj ove analize je odrediti ključne točke kod kojih geometrijski prirast RTV kod obje tehnologije ima jednake vrijednosti. Za potrebe analize definirana su dva osnovna parametra rastriranja: standardna izlazna razlučivost 2540 dpi i okrugli oblik rasterskog elementa (engl. Round dot). Analitičkim pristupom te primjenom i kombiniranjem vrijednosti dviju najvažnijih varijabli u procesu rastriranja (veličina FM rasterskih elemenata i vrijednosti linijature AM rastera) izračunate su vrijednosti pokrivenosti površine u postocima koje odgovaraju upravo tim ključnim točkama. Za potrebe analize definirano je osam najčešćih linijatura rastera (120, 133, 150, 175, 210, 240, 280 i 340 lpi) te četiri veličine FM rasterskog elementa za izlaznu razlučivost od 2540 dpi (20, 30, 40 i 50 μm).

Pomoću jednadžbi koje su izvedene na temelju geometrijskih modela moguće je odrediti dodirne točke koje matematički opisuju odnose veličina AM i FM rasterskih elemenata, a samim time i odnos prirasta RTV.

Postupak izračuna prijelaznih točaka može se izračunati pomoću dvije metode. Prva metoda se temelji na postavljanju odnosa opsega rasterskih elemenata FM i AM rasterske tehnologije, a drugi način se temelji na određivanju promjera rasterskog elementa kod AM rasterske tehnologije. Oba postupka će biti detaljno objašnjena i prikazana pomoću matematičkih jednadžbi.

2.1. Metoda 1: Usklađivanje prirasta RTV putem izračuna odnosa opsega FM i AM rastera

Temelj za analizu prirasta RTV pomoću ove metode je činjenica da se može odrediti postotak pokrivenosti površine (%RTV) kod kojeg je prirast RTV identičan za obje tehnologije rastriranja (AM i FM). Prirast RTV kod obje rasterske tehnologije ima jednaku vrijednost samo u slučaju kada je ukupan opseg rasterskih elemenata po jedinici površine jednak (slika 2).



Slika 2. Prikaz ukupnog opsega AM i FM rasterskih elemenata po jedinici površine kod 20% RTV

Slika 2 prikazuje opseg rasterskih elemenata po jedinici površine kod konvencionalnog AM rastera linijature 200 lpi (lijevo) i kod 20 mikronskog stohastičkog FM rastera (desno).

Ako je r_{FM} polumjer rasterskog elementa kod FM rastera, a n broj rasterskih elemenata po jedinici površine tada pokrivenost površine A_D iznosi:

$$A_D = {r_{FM}}^2 \pi n \quad (1)$$

Iz formule (1) slijedi:

$$n = \frac{A_D}{{r_{FM}}^2 \pi} \quad (2)$$

Ako se omjer broja rasterskih elemenata kod FM rastera (n) i broja rasterskih elemenata kod AM rastera (L^2) po jedinici površine prikaže kao parametar q tada se pomoću formule (2) dobije:

$$q = \frac{n}{L^2} = \frac{A_D}{L^2\, {r_{FM}}^2\, \pi} \tag{3}$$

Korištenjem formule (2) dobiva se da je opseg svih rasterskih elemenata po jedinici površine u FM rasteru jednak:

$$o_{FM} = 2r_{FM}\pi n = 2r_{FM}\,\pi \cdot \frac{A_D}{{r_{FM}}^2\,\pi} = \frac{2A_D}{r_{FM}} \tag{4}$$

Sukladno formuli za izračun pokrivenosti površine kod FM rastera (1) pokrivenost površine kod AM rastera iznosi:

$$A_D = {r_{AM}}^2 \pi L^2 \tag{5}$$

Iz formule (5) slijedi:

$${r_{AM}}^2 = \frac{A_D}{L^2\pi} \tag{6}$$

Nadalje, iz formule (6) slijedi:

$$r_{AM} = \frac{\sqrt{A_D}}{L\sqrt{\pi}} \tag{7}$$

Dakle, ubacivanjem formule za radijus AM rasterskog elementa (7) dobiva se opseg svih elemenata u AM rasteru:

$$o_{AM} = 2\, r_{AM}\, \pi L^2 = 2\pi L^2 \cdot \frac{\sqrt{A_D}}{L\sqrt{\pi}} = 2L\sqrt{\pi A_D} \tag{8}$$

Konačna formula za omjer opsega FM i AM rastera koja se primjenjuje u proračunu za potrebe analize dobije se pomoću formula (4) i (8):

$$\frac{O_{FM}}{O_{AM}} = \frac{\frac{2A_D}{r_{FM}}}{2L\sqrt{\pi A_D}} = \frac{\sqrt{A_D}}{r_{FM}\, L\sqrt{\pi}} \tag{9}$$

gdje je:
O_{FM} – opseg FM rasterskih elemenata na jediničnoj površini
O_{AM} – opseg AM rasterskih elemenata na jediničnoj površini
A_D – postotak pokrivenosti površine rasterskog elementa u postocima
r_{FM} – polumjer FM rasterskog elementa
L – linijatura rastera u l/mm

Za izračun omjera opsega FM i AM rastera koriste se prethodno određene vrijednosti linijature AM rastera (L) i radijusa FM rasterskog elementa (r_{FM}). U slučaju kada je omjer opsega FM i AM rastera jednak 1 znači da je opseg jednak, a samim time jednak je i geometrijski prirast RTV. Ako je omjer veći od 1, veći je opseg FM rasterskih elemenata, a time i geometrijski prirast RTV i obrnuto. Rezultati proračuna prikazani su u poglavlju 3.

Poveća li se radijus rasterskog elementa za Δr, površina tog rasterskog elementa poveća se za ΔP. Obzirom da je kod FM rastera n elemenata istog radijusa r_{FM}, ukupno povećanje površine iznosi:

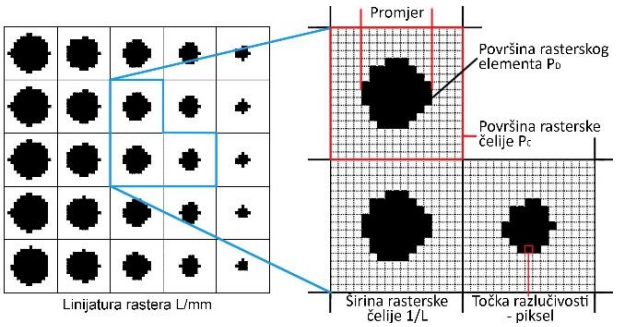
$$\begin{aligned}\textstyle\sum_{i=1}^{n} \Delta P_i &= n\Delta P = n[(r_{FM} + \Delta r)^2\pi - {r_{FM}}^2\pi] \\ &= n\pi[{r_{FM}}^2 + 2r_{FM}\cdot\Delta r + \Delta r^2 - {r_{FM}}^2] \\ &= n\pi[2r_{FM}\cdot\Delta r + \Delta r^2] \\ &= n\pi\Delta r[2r_{FM} + \Delta r]\end{aligned} \tag{10}$$

2.2. Metoda 2: Usklađivanje prirasta RTV pomoću izračuna promjera AM rasterskog elementa

Druga metoda temelji se na izračunu veličine AM rasterskog elementa i usklađivanju sa veličinom FM rasterskog elementa. Primjenom izvedene formule izračuna se promjer AM rasterskog elementa za pojedine RTV vrijednosti u svijetlim tonovima. Temeljem proračuna, veličine FM rasterskih elemenata u mikronima prikazuju se kao vrijednosti %RTV kod AM rastera što ujedno određuje ključnu točku gdje je geometrijski prirast RTV izjednačen.

2.2.1. Izvođenje formule za izračun promjera AM rasterskog elementa

Na slici 3 prikazana je struktura rasterske rešetke kod AM rastera koja će poslužiti kao temelj za izvođenje važnih formula koje se koriste za određivanje veličine rasterskog elementa i usklađivanje sa veličinom rasterskog elementa kod FM rastera.



Slika 3. Struktura rasterske rešetke kod AM rastera

Postupkom rastriranja najmanja veličina rasterskog elementa kod izlazne razlučivosti od 2540 dpi definirana je pojedinačnim pikselom što odgovara veličini od 10 mikrometra. Sljedeće veličine rasterskog elementa se formiraju sa 2, 3 i 4 piksela. Rasterski element sa 2x2 piksela (4 piksela kod 2540 dpi) odgovara veličini od 20 mikrometra. Nadalje, sljedeće veličine rasterskog elementa se formiraju sa 5, 6, 7 i 8 piksela. Rasterski element sa 3x3 piksela odgovara veličini od 30 mikrometra.

Promjer rasterskog elementa u mikrometrima izračunava se na temelju odnosa pokrivenosti površine rasterskog elementa P_D i površine rasterske ćelije P_C:

$$P_D = \frac{A_D}{100} * P_C \tag{11}$$

Pokrivenost površine rasterskog elementa P_D i površina rasterske čašice P_C određuje se iz formula:

$$P_D = \left(\frac{d}{2}\right)^2 * \pi \quad (12)$$

$$P_C = \left(\frac{1}{L}\right)^2 \quad (13)$$

gdje je:
d – promjer rasterskog elementa
A_D – postotak pokrivenosti površine u postocima
L – linijatura rastera definirana brojem linija po milimetru (l/mm)

Uvrštavanjem u početnu formulu (11) dobije se:

$$\left(\frac{d}{2}\right)^2 * \pi = \frac{A_D}{100} * \left(\frac{1}{L}\right)^2 \quad (14)$$

Nakon sređivanja dobije se konačna formula za promjer rasterskog elementa u milimetrima koja se množi sa 1000 da bi se dobila vrijednost u mikrometrima:

$$d = \sqrt{\frac{A_D}{25*\pi*L^2}} * 1000 \quad (15)$$

Formula se koristi kod izračuna promjera rasterskog elementa na originalu gdje nema utjecaja prirasta RTV, odnosno izračunava se teoretska veličina rasterskog elementa originala.

Za pretvaranje linijature rastera definirane u inčima (lpi) u linijaturu definiranu u milimetrima (l/mm) za izlaznu razlučivost od 2540 dpi koristi se sljedeća formula:

$$L = \frac{lpi}{25{,}4} \quad (16)$$

Vrijednosti promjera su izračunate pomoću kreirane formule (15) za standardnu izlaznu razlučivost od 2540 dpi i linijature rastera od 120–340 lpi u najsvjetlijim tonovima (od 1-10% RTV), a prikazane su u tablici 1.

Tablica 1. Teoretske vrijednosti promjera AM rasterskog elementa u mikronima

Linijatura rastera		Veličina rasterskog elementa (µm) za definirane vrijednosti %RTV						
LPI	L/mm	1%	2%	3%	4%	5%	7%	10%
120	4,724	24	34	41	48	53	63	76
133	5,236	22	30	37	43	48	57	68
150	5,905	19	27	33	38	43	51	60
175	6,889	16	23	28	33	37	43	52
210	8,268	14	19	24	27	31	36	43
240	9,449	12	17	21	24	27	32	38
280	11,024	10	14	18	20	23	27	32
340	13,386	8	12	15	17	19	22	27

Upravo su vrijednosti promjera kod definiranih rastertonskih vrijednosti ključne za usklađivanje sa veličinom FM rasterskih elemenata, posredno preko postotka pokrivenosti površine (%RTV). Istaknuto područje u tablici 1 (1% kod 340 lpi) je slučaj gdje je rasterski element manji od jednog piksela kod definirane razlučivosti (minimum je 10 mikrona) te stoga neće biti reproduciran temeljem navedene izlazne razlučivosti. Reprodukcija 1% RTV kod 340 lpi ipak je moguća primjenom veće izlazne razlučivosti prilikom rastriranja. Veličina jednog piksela kod 4000 dpi iznosi 6 mikrona, a kod 5800 dpi 4 mikrona [7].

Iz tablice 1 također je vidljivo da FM rasterski element od 20 µm nije ništa manji od rasterskog elementa 2% kod 210-linijskog AM rastera.

2.2.2. Usklađivanje veličine FM rasterskog elementa sa površinom pokrivenosti (%RTV)

Pokrivenost površine u postocima obzirom na promjer rasterskog elementa i linijaturu rastera iz tablice 1 može se izračunati korištenjem sljedeće formule, koja je izvedena iz formule za izračunavanje promjera (15):

$$A_D = (5 * d * L)^2 * \pi \quad (17)$$

gdje je:
A_D – postotak pokrivenosti površine u postocima
d – promjer rasterskog elementa u mm
L – linijatura rastera u l/mm

Rezultati proračuna dobiveni pomoću formule (17), odnosno RTV vrijednosti ključnih točaka kod kojih je prirast RTV jednak prikazani su u sljedećem poglavlju.

3. REZULTATI I DISKUSIJA

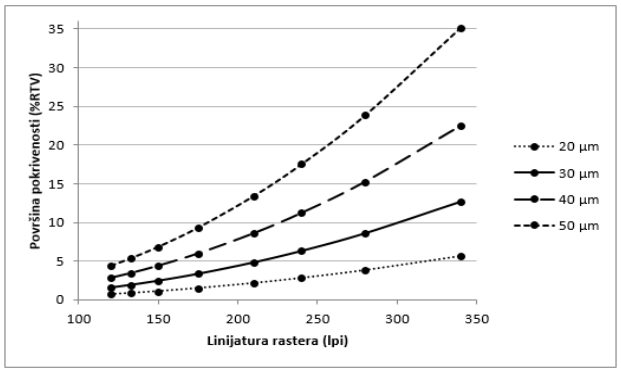
Za proračun su korištene konačne formule (9) i (17) iz obje opisane metode s ciljem određivanje postotka pokrivenosti površine kod kojeg je geometrijski prirast RTV jednaka vrijednost.

Tablica 2. Pokrivenost površine (%RTV) kod kojih je geometrijski prirast RTV kod FM i AM rastera jednak

Linijatura (L)		Pokrivenost površine A_D (%) za definirane veličine FM točaka u µm			
LPI	L/mm	20µm	30µm	40µm	50µm
120	4,724	0,7	1,6	2,8	4,4
133	5,236	0,9	1,9	3,4	5,4
150	5,906	1,1	2,5	4,4	6,8
175	6,890	1,5	3,4	6,0	9,3
210	8,268	2,1	4,8	8,6	13,4
240	9,449	2,8	6,3	11,2	17,5
280	11,024	3,8	8,6	15,3	23,8
340	13,386	5,6	12,7	22,5	35,2

Rezultati dobiveni primjenom obje formule potpuno su identični što potvrđuje vjerodostojnost istraživanja i primjenjivost opisanih metoda. Rezultati proračuna za omjer $\frac{O_{FM}}{O_{AM}} = 1$ prikazani su posredno preko postotka pokrivenosti površine, a nalaze se u tablici 2.

Prijelazna točka, mjesto sa jednakim geometrijskim prirastom RTV, prikazana kao postotak pokrivenosti površine kod određene linijature povećava se s porastom linijature rastera i sa povećanjem veličine FM rasterskog elementa kao što prikazuje slika 4, a na temelju podataka iz tablice 2. Ista veličina rasterskog elementa u mikronima prisutna je kod svih osam navedenih linijatura rastera, ali kod različitih RTV vrijednosti.



Slika 4. Promjena pokrivenosti površine utjecajem linijature rastera (lpi) te veličine FM rasterskih elemenata

4. ZAKLJUČAK

Geometrijski prirast RTV definiran je površinom kružnog vijenca P oko rasterskog elementa. Kružni vijenac prikazuje promjenu površine rasterskog elementa ΔP uslijed promjene radijusa rasterskog elementa Δr. To je u stvarnosti razlika između površine teoretske veličine rasterskog elementa na originalu i površine rasterskog elementa nakon reprodukcije u tisku. Širina kružnog vijenca Δr uvijek je ista kod strogo definiranih uvjeta tiska neovisno o veličini rasterskog elementa. Na ukupni prirast RTV utječe broj rasterskih elemenata na jedinici površine koji je direktno zavisan o ukupnom opsegu svih rasterskih elemenata. Kod AM rastera broj rasterskih elemenata definiran je linijaturom rastera (lpi), a kod FM rastera veličinom rasterskog elementa (µm).

Ovim istraživanjem je dokazano da je, kod određenih RTV vrijednosti u svijetlim tonovima, geometrijski prirast RTV kod AM i FM rasterske tehnologije jednake vrijednosti. Te RTV vrijednosti nazvane su prijelaznim točkama. Od te točke prema svijetlim tonovima geometrijski prirast RTV će biti veći kod AM rastera, a od te točke prema tamnijim tonovima geometrijski prirast RTV će biti veći kod FM rastera. Također je dokazano da je geometrijski prirast RTV funkcija direktno zavisna o ukupnom opsegu rasterskih elemenata po jedinici površine.

Pomoću definiranih analitičkih metoda ne može se odrediti ukupni prirast RTV jer on ovisi o vrsti i linijaturi rastera, vrsti tiskovne podloge, svojstvima bojila, uvjetima tiska i dr. Postupak za određivanje ukupnog prirasta u praksi zahtjeva dosta napora, vremena i novca.

Temeljem rezultata analitičkih metoda može se odrediti samo omjer prirasta RTV FM i AM rasterske tehnologije što je vrlo često jedan od kriterija odabira rasterskih tehnologija te definiranja osnovnih parametara rastriranja u praksi. To je posebno izraženo u današnje vrijeme kada se teži što većim linijaturama rastera i što manjim veličinama FM rastera primjenom većih izlaznih razlučivosti poput 4000 ili 5800 dpi.

Rezultati istraživanja primjenjivi su i kod odabira prijelazne točke kod hibridnih rastera koji kombiniraju spomenute FM i AM rastere. Prijelazna točka određuje mjesto gdje se dvije vrste rastera spajaju s ciljem dobivanja što mekšeg prijelaza iz jednog rastera u drugi.

Analiza pokrivenosti površine kod prijelaznih točaka iz tablice 2 i promjera rasterskog elementa iz tablice 1 ukazala je na zaključak da se kod RTV vrijednosti do 2% prednost može dati AM rasterskoj tehnologiji, a kod većih RTV vrijednosti prednost se može dati FM rasterskoj tehnologiji. Razlog je taj što se upravo reprodukcija 2% RTV u tisku smatra dobrom reprodukcijom.

Prema podacima iz tablice 2 može se zaključiti da što je rasterski element manji (veća linijatura rastera) veća je relativna geometrijska deformacija rasterskog elementa. To se može povezati sa ukupnim opsegom – ukupnom dužinom kontura rasterskih elemenata. Grubi raster ima manji broj rasterskih elemenata na jedinici površine od finih rastera (ukupna dužina kontura je manja), što znači da je i ukupni opseg manji pa je i prirast RTV manji.

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WPF i MVVM

WPF AND MVVM

Željko Knok, Mark Marčec

Stručni članak

Sažetak: *Današnje tržište softvera ima dosta razvijenu tehnologiju s kojom se bitno olakšava izrada i održavanje kompleksnih informacijskih sustava. Jedna od tih tehnologija je WPF (Windows Presentation Foundation) s primjenom MVVM (Model View ViewModel) obrasca. Ovaj rad se bavi analiziranjem MVVM obrasca u WPF-u uz opis značenje samog obrasca.*

Ključne riječi: *Model, View, ViewModel, Command, Converter, Binding, C#, XAML*

Professional paper

Abstract: *Today's software market has really advanced technology to benefit the process of designing and maintaining really complex information systems. One of the technologies is WPF (Windows Presentation Foundation) with the MVVM (Model View ViewModel) pattern. This work analyses the MVVM pattern in WPF and will describe the meaning of the pattern.*

Key words: *Model, View, ViewModel, Command, Converter, Binding, C#, XAML*

1. UVOD

Model View ViewModel je pattern ili obrazac koji omogućava odvajanje prezentacijskog dijela aplikacije (GUI-a) od implementacije same aplikacije. WPF tehnologija je od samog početka osmišljena sa ciljem da ide ruku pod rukom sa MVVM obrascem. Ovaj obrazac je podijeljen u tri dijela. Model, gdje se definiraju podaci i njihovi tipovi. View ili pogled definira izgled korisničkog sučelja programa i prikazuje konačan izgled podataka te ViewModel koji je posrednik Modela i View-a te je zadužen za prezentaciju podataka i za navigaciju kroz korisničko sučelje. Binder je XAML koji oslobađa programera da ne mora pisati logiku koja služi za sinkronizaciju Viewa i ViewModela. Ovakvim načinom rada se bitno olakšava održavanje aplikacije te dodavanje novih mogućnosti.

2. ELEMENT BINDING I CONVERTERS

U ovom djelu predstavljena je ideja MVVM arhitekture kroz neke praktične primjere. Prvi korak je Binding koji će biti podijeljen u dva dijela Element Binding i Data Binding.

2.1. Element Binding

Element binding povezuje podatke između dvije kontrole na korisničkom sučelju. Binding se definira u XAML-u. Jednostavan primjer Element Binding-a bi bio povezivanje metode za ispis vrijednosti u TextBox i slidera.

Ako bi se radilo na stari način bez povezivanja ili bindinga, dohvatio bi se event kada se promijeni vrijednost slajdera, pa bi promjenu se vrijednost konvertirala u niz znakova, da bi se onda taj niz znakova dodijelilo kao vrijednost svojstva tekst ili Text željenog TextBlock-a. Taj kod bi izgledao ovako [2]:

```
private void slider_ValueChanged(object sender, RoutedPropertyChangedEventArgs<double> e)
{
   lblSliderValue.Text = slider.Value.ToString();
}
```

Kod korisničkog sučelja sa mnogo kontrola ovakav kod može se nagomilati i smanjiti čitljivost koda koji je bitan za rad aplikacije. Primjenom bindig-a izbjegavamo gomilanje koda u „code-behind" datoteci (.xamlcs) nekog prozora. U XAML-u povezivanje gumba sa metodom za zatvaranje prozora izgleda kao na slijedećem primjeru.

```
<Button Command="{Binding CloseCommand}" Content="Zatvori" Style="{StaticResource ActionButton}"
ctrl:ControlExtensions.IsHighlighted="True"/>
```

2.1.1. TwoWay mod Binding-a

Dvije nove ključne riječi u XAML-u su Mode i UpdateSourceTrigger. Mode=TwoWay govori da meta bindinga može ažurirati izvor, dakle ovaj put je binding

obostran. Binding se vrši u suprotnom smjeru uz pomoć ConvertBack. Druga ključna riječ UpdateSourceTrigger=PropertyChanged govori da se poziva binding čim se promijeni tekst polja. UpdateSourceTrigger je enumeracija koja može primiti i neke druge vrijednosti.

2.1.2. Multibinding

Multibinding omogućava povezivanje jedne kontrole na više izvora. Za razliku od običnog Element binding-a, multibinding mora koristiti konverter. Konverteri kod multibindinga nasljeđuju IMultiValueConverter interface i imaju dvije metode Convert i ConvertBack.

2.2. Converters

Konverteri omogućavaju pretvaranje vrijednosti iz jednog oblika u drugi, tj. promjenu vrijednosti iz jednog tipa promjenjive u drugi tip, kao i oblikovanje vrijednosti.

Svaki konverter mora imati dvije metode koje se zovu Convert i ConvertBack. Convert metoda je trenutno zanimljiva jer je ona zadužena za pretvaranje vrijednost npr. nekog TextBoxa-a u niz znakova te vraćanje oblikovanog niza znakova. Druga metoda ConvertBack je zadužena za „TwoWay“ binding. O TwoWay bindingu će biti riječ kasnije. Obje metode primaju četiri parametra: vrijdenost ili value, željena tip varijable ili targetType, parametar ili parameter i kulturu ili culture. Value je vrijednost koju će proslijediti (u ovom slučaju) textbox. TargerType je tip promjenjiva varijabla u koju konvertira našu vrijednost u ovom slučaju je to niz znakova. Culture služi za određivanje „kulture“ u koju se konvertira vrijednost, ovaj parametar je značajan ako aplikacija podržava više jezika, jer se u jednim jezicima na primjer koristi decimalna točka, a u drugim decimalni zarez. U ovom primjeru će se koristiti samo prvi parametar.

```
public object Convert(object value, Type targetType, object parameter, CultureInfo culture)
    {
        int number = (int)value;
        return number.ToString(SettingsBll.InvoiceNumberFormat);
    }
    public object ConvertBack(object value, Type targetType, object parameter, CultureInfo culture)
    {
        throw new NotImplementedException();
    }
```

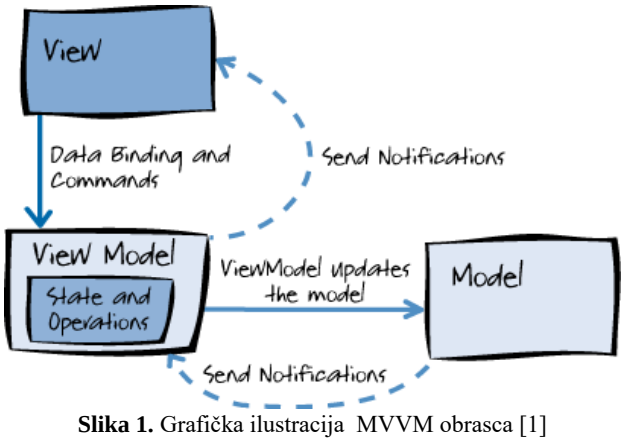
Konverter se primjenjuje uz pomoć StaticResource ključne reči i ključa resursa. Primjena konvertera se može vidjeti na slijedećem primjeru.

```
<Grid Margin="10" Name="grid1" Grid.Row="1"
        Visibility="{Binding Path=User.IsAdmin, Converter={StaticResource BoolToVis}}">
```

3. DATA BINDING

U prethodnom poglavlju je bio opisan Element Binding koji nije bio direktno vezan za Model View ViewModel pattern. Detaljnim pregledom koristeći Data Binding ulazi se u „dubinu“ MVVM obrasca koji ima centralno mjesto u arhitekturi MVVM aplikacija.

3.1. Model View ViewModel



Slika 1. Grafička ilustracija MVVM obrasca [1]

Kao što se vidi sa slike, MVVM aplikacije bi trebalo podijeliti u tri dijela:

- Model
- ViewModel i
- View

Pogled tj. view je jedan prozor ili češće UserControl. View se definira koristeći XAML kao što se definira bilo koji prozor. ViewModel sadrži model ili kolekciju modela, koji sadrže informacije za korisnika. Pokraj Modela, ViewModel može sadržati i komande (Commands) preko kojih korisnik vrši interakciju sa aplikacijom. Komande će biti objašnjene u slijedećem poglavlju. Svaki View je vezan za samo jedan ViewModel, dok recimo jedan prozor može sadržati više pogleda (Views). ViewModels i Views se definiraju u C# ili nekom drugom .NET jeziku.

Svaki Model i ViewModel trebaju se implementirati INotifyPropertyChanged interface iz System.ComponentModelnamespace-a. Implementacija ovog korisničkog sučelja se sastoji od samo jednog pristupa tipa PropertyChangedEventHandler (iz istog namespace-a) koji nosi naziv PropertyChanged. Prilikom promijene vrijednosti nekog svojstva potrebno je podići ovaj event da bi se obavijestio View da je došlo do promjene, da bi View (putem Data Binding-a) ažurirao kontrole sa novim podacima.

Svaka aplikacija koja prati MVVM obrazac bi trebala da ima tri direktorija, jedan za Views, jedan za ViewModels i jedan za Models:

- Model
- ViewModel i
- View

Svaki Model se treba nalaziti u Models direktoriju, ViewModel u ViewModels direktoriju kao i svaki View u Views direktoriju.

3.2. Data binding

Da bi View "znao" koji ViewModel da koristi za Data Binding potrebno je primjerak ContactsViewModel klase postaviti kao DataContext tog pogleda. DataContext je svojstvo koji ima svaka kontrola i svaki prozor. Sustavno svaki Data Binding se "veže" na ovo svojstvo.

4. KOMANDE I NAVIGACIJA

Komande su jedan od glavnih aspekata MVVM obrasca kada su u pitanju WPF aplikacije. Komande omogućuju interakciju korisnika sa aplikacijom. Povezivanje kontrola sa komandama se vrši najčešće Binding-om, ali često i putem resursa.

4.1. Komande

Svaka komanda (engl. Command) implementira ICommand interface iz System.Windows.Input namespace-a. Ovo sučelje objedinjuje dvije metode i jedan događaj:

- CanExecute
- Execute
- CanExecuteChanged

Metoda CanExecute provjerava da li se komanda može izvršiti, Execute je metoda koju poziva kontrola kada je potrebno izvršiti komandu, npr. Gumb prilikom klika. CanExecuteChanged je događaj koji bi se trebao aktivirati prilikom promijene "izvršivosti" komande. CanExecute metoda utiče na stanje kontrole. Ako se komanda ne može izvršiti, onda je npr. gumb za koju se veže komanda u stanju Disabled.

4.2. Navigacija

Navigacija sa stranicama je vrlo praktičan način navigacije u MVVM aplikacijama, kao što je to slučaj kod Windows 8 Metro aplikacija, Windows Phone te nekih Desktop aplikacija. Cilj je da se u glavnom prozoru prikazuju pogledi (Views) te "go back" gumb osim ako se ne prikazuje prva stranica. Navigacija se implementira koristeći komande. Da bi ViewModel-i znali kad dođe do navigacije na pogled ili se vrši navigacija sa pogleda dodaju se virtual metode u BaseViewModel koje će pozivati servis za navigaciju. Također glavni prozor treba imati panel koji će prikazivati trenutni pogled i gumb za navigaciju nazad ako je ona moguća. Ako nije moguće napraviti navigaciju na prethodnu stranicu, gumb "go back" treba sakriti. Pored ove dvije osobine BaseViewModel treba sadržavati i naslov pogleda koji se prikazuje. Naziv pogleda će se prikazati kao naslov prozora. Uzimajući u obzir navedene osobine dodaju se metode i svojstva u BaseViewModel klasu.

5. ZAKLJUČAK

Data Binding nam omogućava jednostavnu implementaciju bez pozadinskog koda, što povećava lakoću održavanja aplikacije kao i jasan put koji treba pratiti prilikom kreiranja CRUD aplikacija. Komandama je moguća interakcija sa aplikacijom i kreiranje novog kontakta. Navigacija se vrši koristeći ovaj servis, a koji se može koristi i u ostalim aplikacijama. WPF već imaju ugrađeni navigacijski servis sličan servisima koje koriste Windows Phone i Windows 8 aplikacije. Ovaj servis omogućava i navigaciju naprijed-nazad te prikaz aplikacije u Internet pretraživaču. Kompletna ideja MVVM obrasca je da razdvoji implementaciju korisničkog sučelja od poslovne logike u čemu je MVVM veoma uspješan. Prateći MVVM obrazac osigurava se konzistentan način implementacije aplikacija čime je olakšan način održavanja aplikacije i dodavanje novih mogućnosti.

5. LITERATURA

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OCJENA PRECIZNOG DIELEKTIČNOG MODELA I IZABRANIH PATENTA O OTKRIVANJU RAKA DOJKE POMOĆU MIKROVALOVA

ASSESMENT OF ACCURATE DIELECTRIC MODEL AND SELECTED PATENTS ON MICROWAVE BREAST CANCER DETECTION

Emine Avşar Aydin, Mustafa Berkan Biçer, Ali Akdağli

Izvorni znanstveni članak

Sažetak: *Ovaj rad govori o naprecima u otkrivanju i snimanju raka dojke pomoću mikrovalova u posljednjem desetljeću. Dan je uvod o raku dojke i metodama otkrivanja te detaljne informacije o snimanju pomoću mikrovalova i izabranim patentima. Raspravljene su prednosti i nedostaci prezentiranih patenata kao i trenutno stanje u detektiranju i snimanju raka dojke. Snimanje mikrovalovima kako bi se otkrio rak dojke metoda je od koje se mnogo očekuje, pošto se smatra kako postoje znatni ili primjetni kontrasti između malignih, benignih i normalnih tkiva kroz široki raspon frekvencija. Također, postoje mnogi dielektrični modeli, posebno se dvostruki Debye model koristio u definiranju dielektričnog odziva raznih bioloških tkiva. S druge strane, dvostruki Debye model nije precizan prilikom korištenja za ljudska tkiva, jer postoje ograničenja u saznanjima oko strukture, dinamike i makroskopskog ponašanja tkiva dojke. Neophodno je, ovisno o frekvenciji, izabrati ispravan dielektrični model u sustavima za detekciju.*

Ključne riječi: *benigna tkiva, debye model, dielektrični model, maligna tkiva, snimanje mikrovalovima,*

Original scientific paper

Abstract: *Advances in microwave breast cancer detection and imaging during last decade are reported in this review paper. An introduction to breast cancer and detection methods and detailed information about microwave imaging and selected patents are presented. The advantages and disadvantages of the presented patents and also state of breast cancer detection and imaging are discussed. Microwave imaging for breast tumor detection is considered to be promising, as it is believed that there is a significant or detectable contrast in malignant, benign and normal tissues over a broad frequency range. Also, there have been many dielectric models, especially the double Debye model has been used to define the dielectric response of different biological tissues. On the other hand, double Debye model is not accurate for human breast tissue because there are knowledge limitations about the structure, dynamics, and macroscopic behavior of breast tissue. It is vital that, according to frequency, accurate dielectric model should be chosen in detection systems.*

Keywords: *microwave imaging, malignant tissue, benign tissue, debye model, dielectric model*

1. INTRODUCTION

Breast cancer occurs in the breast. The breast tissue has a large area. It covers the area between the collarbone and armpit including the breastbone.

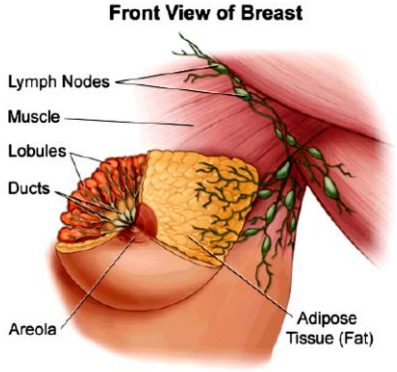

Figure 1. Internal structure of the breast[1]

The breast lies on the chest muscles. Each breast consists of glands, ducts and fatty tissue. A group of glands is said to be lobules. These groups can produce milk. Milk flows from the lobules through a network of ducts to the nipple. Spaces between the lobules and ducts are filled fatty tissue shown in Figure 1.

When there are mutations, or abnormal changes, in the genes responsible for regulating the growth of cells, cancer occurs. The genes are “control room”. It is known that during cell growth, all the cells in our body is refreshed and healthy cells take place instead of dying cells. But, cancer cells can turn on certain cells and kill others in a cell. Because of this, this case is an uncontrolled growth of breast cancer. Breast cancer usually occurs either in the cells of the lobules, or the ducts. However, every woman has her menstrual cycle due to the nature. In these cycles, breasts of women have different structures. At the same time, the structure of the breast tissue shows differences with age. For instance,

breast tissue of young women has glands and milk ducts, but breast tissue of old women has mostly fatty tissue.

According to the latest American Cancer Society Report, the most deaths of women in the US is due to breast cancer [2]. Although the breast cancer is the second most common cancer after lung cancer in the world, early diagnosis plays an important role to decrease the death rate. Many methods have been developed to detect the cancerous cells. For different frequencies of the microwaves, the malignant cells shows different electrical characteristics respect to the normal cells [3]. Due to this property of the breast tissue, the microwaves can be used for detecting of breast cancer.

Some important conditions of breast screening methods should be taken into consideration. These conditions are: comfort of the patients, producing high resolution images, cost and accuracy to detect malignant tumors [3].

The latest breast cancer detection technique is microwave imaging. There are many techniques to detect breast cancer. But these techniques, X-ray mammography, are inadequate for detection of the small group of malignant cells, are harmful because of their X-ray radiation [3, 4, 5, 6].

Microwave imaging makes a promise to be a safe and efficient breast cancer screening method. Previous studies show that microwave imaging is a cheaper and much safer technique than other modalities for breast cancer detection. Since the technique uses non-ionizing radiation, it is considered to be less harmful to patients [7].

Microwave breast imaging techniques consist of tomography and radar-based imaging. Communication of through breast is saved by microwave tomography. At the same time, an electrical property map of the region of interest is created. On the other hand, radar-based techniques focus on reflections from the breast in order to determine the location of meaning scatterers [3, 8].

In this paper, issues which are what is microwave imaging technique, and why are going on studies of breast cancer detection by using microwaves are focused on. In addition, there are many dielectric models. It is important to use accurately these models.

2. MICROWAVE IMAGING TECHNIQUE

Microwave imaging technique most widely has been studied for the detection of breast cancer. The main principle is based on the electrical properties; permittivity and conductivity, of malignant breast tumors tissue differ from those of the normal surrounding breast tissue. The breast is illuminated by the transmitting antennas and the signals scattered from the breast are collected by the receiving antennas. These signals have information about the tumor size, shape, location and electrical properties. Cancerous tissues have different dielectric permittivities and conductivities than healthy breast tissues. So, when an incident wave is sent, cancerous tissue scatters differently indicating their presence [9, 10].

3. SELECTED PATENTS ON MICROWAVE BREAST CANCER DETECTION

Several configurations of microwave breast cancer detection have been patented in recent years. Considering the deaths due to breast cancer, it has become a serious problem for all women. The current screening and imaging techniques such as X-ray mammography, ultrasound, and MRI are the key survival for all women. The accuracy of these techniques is only 73% in detecting breast cancer. In addition, the sensitivity and specificity of these techniques have still limitations. Because of this, researchers set out to find alternative techniques for the early detection of breast cancer. The present-day detection methods have still weaknesses. These weaknesses: 1) Each radiologist can read mammograms differently; 2) Specificity of mammography is low; 3) The result of the biopsy of the every lesion which was found by mammography is not malignant or the ratio of this only 20 to 35%; 4) X-ray radiations are known to cause damage to DNA of cells. Therefore, there is a need in the art of medical imaging for a complementary breast imaging tool. Microwave imaging for breast tumor detection is considered to be promising, as it is believed that there is a significant or detectable contrast in malignant, benign and normal tissues over a broad frequency range [9, 10, 11].

The patent named as "*Method for Detection of Tumors of the Breast"* introduces a new method for detection of tumors of the female breast [12]. This method comprises (i) coating the skin of that portion of the body which is to be evaluated for tumors with a heat sensitive color responsive chemical such as cholesterol (ii) heating that portion of the body so coated with penetrating radiation such as diathermy in either the microwave or radio wave frequency and (iii) scanning the color coated skin over that portion of the body so treated as to identify by color change that "hot spots" which indicate the location of possible tumors or lesions.

One of the objects of the present invention is to describe a new method of modified thermography which lacks undesirable side effects [12]. In addition, this invention is a very accurate diagnostic indicator of tumor sites. The other is to show a new color change technique for location of the potential or actual sites of breast tumors in females.

This method is based on different flow speed of blood at tumor tissue and normal tissue [12]. It is stated that the flow speed of the blood at normal tissue is 20 times faster than the tumor tissue. Hence, if the tissues are heated with a diathermy device, normal tissue dissipates its heat through the vascular system more rapidly than the tumor tissue and its heat stays constant during this process while tumor tissue's heat is increased.

The patent entitled as "*Microwave Detection System*" is employed for the detection of cancerous tumors and is particularly effective in the early detection of such tumors [13]. The system comprises a single unit a passive radiometer with an active microwave transmitter. In addition, this system is adapted for sensing subsurface temperatures. By using a solid state transmitter, heating of the subsurface tissue is localized. This localized heating enhances the tumor from a temperature differential standpoint due to vascular insufficiency associated with the thermal characteristics of tumors. This technique makes possible the early detection of cancer tumors. The advantage of this technique is that the level of radiation is

very small and well within safety standards since the applicator is uncoupled from the human body. The patent entitled as "*Microwave Endoscope Detection and Treatment System*" is adapted for use both as an applicator applied externally to the body and furthermore may be used endoscopically [14]. The endoscopic version may be used for the effective treatment and detection of some cancers.

In the patent named as "*Procedure and Apparatus for Noncontacting Measurement of Subcutaneous Temperature Distributions*" [15], a method and apparatus for noncontacting measurement and imaging of subcutaneous temperature distributions for the early detection of breast cancer are described. The system utilizing the method of the present is showed in Fig. (2).

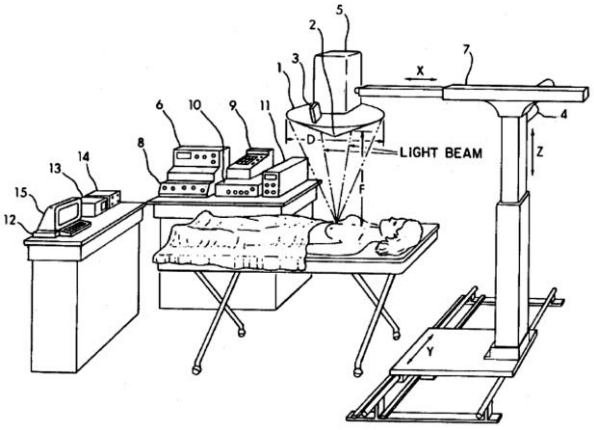

Figure 2. Schema of the system utilizing the method of the present invention[15]

With an elliptical reflector **1** into the receiving horn **2** of the receiving system **5** which is connected with the horn through a bent waveguide or coaxial line, the thermal radiation emitted is brought to a focus in the microwave frequency range of 8 to 36 GHz by a subcutaneous mamma carcinoma [15].

Two focusing light sources **3** are used at the subcutaneous object to indicate the temperature depth measurement with light spacing on the skin [15]. This make it possible to adjust the reflector height over the subcutaneous object focus. The reflected image is used for automatic adjustment of the scanner height. An infrared or photo – detectors is placed on the receiving horn and the height adjusting motor **4**. With automatic movement of the arm **7** which is supporting the reflector 1 and the radiometer 5, a fast scanning in X-Y direction is performed. Scanning speed, line length and spacing are stored at the controller **8.** The temperature output of the instrument **6** is connected to a strip chart or XY recorder.

It was the purpose of this invention to present a method for contactless subcutaneous temperature measurement giving a higher temperature sensitivity to gether with good spatial resolution which allows detection of deeper lying temperature changes of a small order [15]. This measurement is necessary for reliable early detection of tumors and arthritis. The method also permits shorter imaging times so as to reduce or even completely eliminate the influence of slight temperature changes and body movements during the measurement.

The patent named as "*Medical Diagnostic Microwave Scanning Apparatus"* introduces microwave apparatus for diagnosis of cancer of the breast [16]. This apparatus comprises of the main three parts: a microwave transmitter, a microwave antenna and a microwave receiver. While the microwave transmitter and the microwave antenna are used for directing a microwave signal to the breast under examination, the microwave receiver having amplitude and phase shift detectors is used for receiving of reflected microwave signals. To process the amplitude and phase information, a processor is connected to the receiver. Therefore, the amplitude and phase information can be detected and located cancer in the breast. In order to eliminate any air gap in the transmission path, a matching plate having a dielectric constant substantially the same as normal breast tissue is located between and in engagement with the breast and antenna. It is possible with a display unit to create a microwave image of cancer growth. A microwave scanner for diagnosing cancer of the breast which has a signal processing system is showed in Fig. (3).

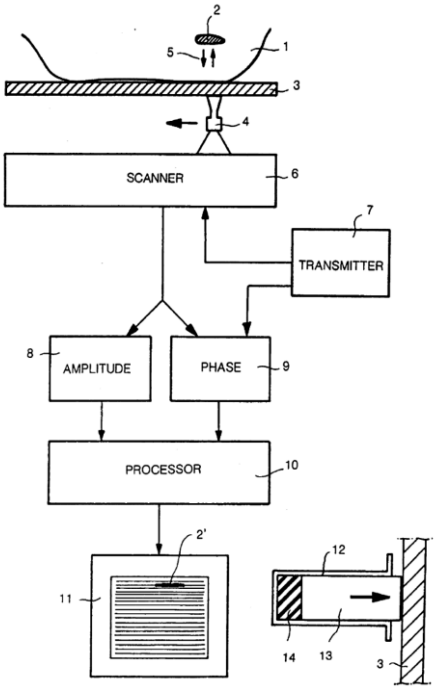

Figure 3. Schema of a Microwave Scanner for Diagnostic Cancer of the Breast which has a Signal Processing System[16]

In the patent named as "*Temperature Measuring Microwave Radiometer Apparatus"* [17], fourth improvement is mentioned in temperature-measuring radiometric equipment. In the first improvement, a microwave radiometer is used to measure the temperature of a specimen. By employing microwave noise power derived from a reference noise source in an amount that corresponds to a temperature higher than that of the specimen, radiometer sensitivity is increased. In the second improvement, a microwave radiometer is used to measure the temperature of patient's body tissue. Emissivity error is reduced by employing open-loop means comprising a microwave circulator for applying microwave noise power generated by at least one resistor thermostatically heated to a temperature in the

neighborhood of the temperature of a patient's body tissue back to the body tissue.

In the third improvement, system is suitable for use with a standard external applicator as well as for use in an applicator insertable into a natural opening of a patient's body. In addition, cancerous lesions are detected and located. In order to measure the temperature difference between two points of a patient's body tissue or other type of specimen, a microwave radiometer employs two displaced microwave antennas. By combining radiometric equipment with mammographic equipment, fourth improvement has a superior capability for detecting and locating a breast cancer lesion.

The patent named as "*Non-Invasive System for Breast Cancer Detection"* introduces a system for detecting an incipient tumor in living tissue such as that of a human breast in accordance with difference in relative dielectric characteristics. [18]. Non-ionizing electromagnetic input wave of preselected frequency is produced by a generator. This frequency is higher than three gigahertz. The living tissue is illuminated by input wave. The illumination location is moved over a portion of the living tissue in a predetermined scanning pattern. There are scattered return signals and differences in relative dielectric characteristics. This is indicative of the presence of a tumor in the scanned living tissue. Schema of Non-Invasive System for Breast Cancer Detection is showed in Fig. (4). In the patent named as "*Microwave Antenna for Cancer Detection System*" [19], in order to irradiate the living tissue and to collect backscatter or other scatter returns, a composite Maltese Cross or bow-tie antenna construction employed is used.

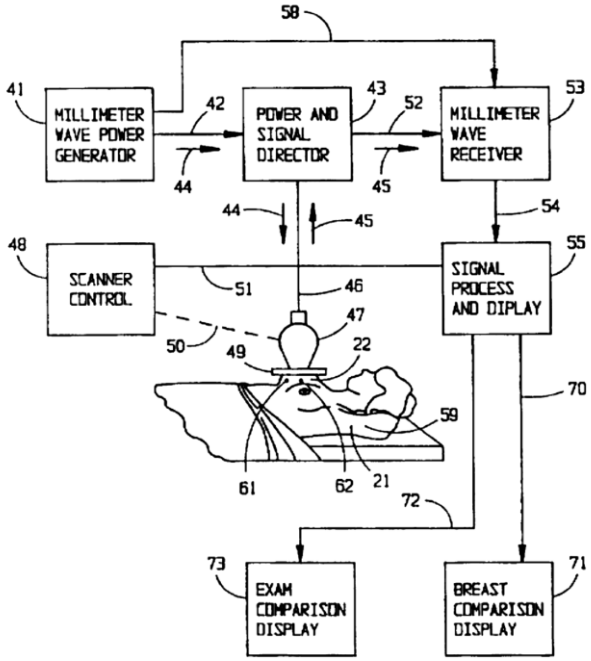

Figure 4. Schema of Non-Invasive System for Breast Cancer Detection[18]

There are eight important features of this invention [18]:

1) The selection of a band of operating frequencies. (Optimum operation is at frequencies in the range of three to ninety gigahertz.)
2) A wide aperture scanning system is used.
3) Techniques that aid in separating the desired scattered returns from a tumor from those originating either directly from the impinging wave form or from spurious reflections from scatterers of no interest.
4) In order to develop a synthetic time domain response, a stepped frequency technique is used.
5) Confocal techniques are used.
6) The combined use of the confocal method with the stepped frequency synthetic time domain method, especially for detecting anomalies at depth.
7) It provides convenience to conduct screening.
8) It can provide non-hazardous screening functions.

The patent named as "*Microwave Detection Tumors, Particularly Breast Tumors"* introduces a probe having a working end arranged to contact tissue [20]. There is at least one rectangular waveguide each waveguide having an aperture at the working end of the probe. The waveguides are used to create antennas tuned to receive microwave radiation emitted by the tissue opposite the working end of the probe. In order to detect the temperature of tissue opposite that waveguide, each waveguide is coupled electrically and mechanically to a dedicated radiometer in the probe. Conductive casings are used to insulate thermal distribution of the radiometers. A fragmentary perspective view of microwave detection apparatus is showed in Fig. (5).

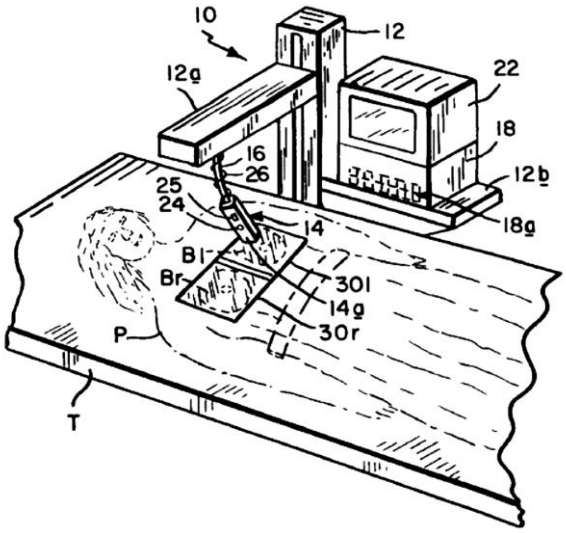

Figure 5. A Fragmentary Perspective View of Microwave Detection Apparatus[20]

An obvious advantage of this invention is that an apparatus makes temperature comparisons at corresponding locations on a patient's two breasts [20]. In addition, it produces an apparatus which can screen for breast tumors in a minimum amount of time. Thus, the breast can be examined in a shorter time than a standard mammography examination with this apparatus.

In another patent "*Electrical Impedance Method and Apparatus for Detecting and Diagnosing Diseases*" [21], a method and apparatus for screening, sensing, or diagnosing disease are defined. The aim of this method is to utilize a plurality of electrical impedance data measurements in organized patterns from two

anatomically homologous body regions. After subsets of data are processed and analyzed, the matrices and their derivatives are correlated by their characteristics to normal or disease states. Electrical Impedance Measurement System is showed in Fig. (6).

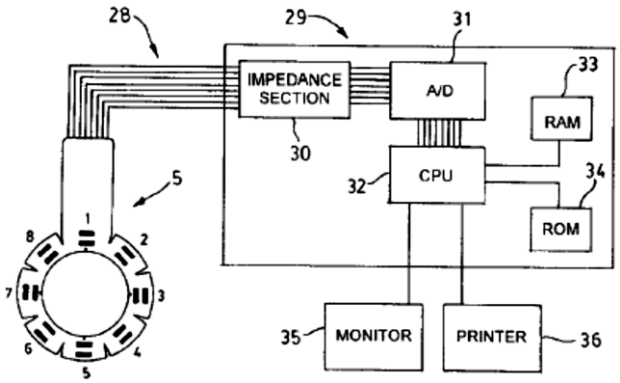

Figure 6. Schema of Electrical Impedance Measurement System[21]

The patent named as "*Microwave Discrimination between Malignant and Benign Breast Tumors"* describes improvements and applications that will characterize the differences between malignant and benign tumors [22]. In order to illuminate a discrete volume within the living tissue of the living organism and to develop scattered power returns from discrete volume, a non-ionizing input wave is applied to a field excitation antenna within a wide band frequency range. A portion of the scattered power returns are collected by a receiving antenna and then applied to signal processor. A separated signal is improved to identify the vascularization associated with one or more malignant tumors.

In another patent "*Multi-Frequency Microwave Induced Thermoacoustic Imaging of Biological Tissues*" [23], the steps of radiating a tissue region with a plurality of microwave radiation pulses are mentioned. Perspective view of a Thermoacoustic Scanning System is showed in Fig. (7). When the microwave pulses which include at plurality of different polarizations swept across a range of microwave frequencies, a plurality of thermoacoustic signals are emitted from the irradiated tissue region. By using the plurality of thermoacoustic signals, one image of the tissue region occurs. The tissue region means breast tissue. The respective images are combined to form an overall image of the breast after a plurality of images from fractional portions of the breast is taken. It is claimed that the frequency range is at least 1 GHz.

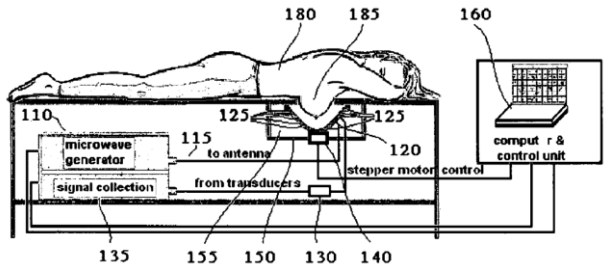

Figure 7. Perspective view of a Thermoacoustic Scanning System[23]

The patent entitled as "*Tissue Sensing Adaptive Radar Imaging for Breast Tumor Detection*" uses microwave backscattering to detect tumours [24]. There have been several approaches about microwave breast imaging such as tomography and radar-based methods. While a map of the electrical properties in the breast using measurements of energy transmitted through the breast is reconstructed in tomography, scattering objects (tumors) using measurements of energy reflected from the breast are detected strongly in radar-based method. In this invention, a radar-based approach is used.

By scanning the focal point through the volume of interest and observing areas of strong reflection, both presence (or absence) of tumor can be detected and localization of tumor is found. Perspective View of the Antenna Locations Used in a Tumor Detecting Scan is showed in Fig. (8).

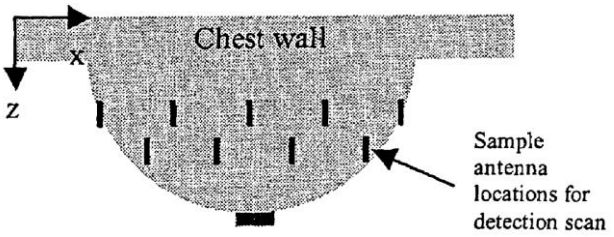

Figure 8. Perspective View of the Antenna Locations Used in a Tumor Detecting Scan[24]

In another patent "*Apparatus and Method for Diagnosing Breast Cancer Including Examination Table*" [25], a microwave breast cancer imaging method including examination table are mentioned. Scanning is both comfortable and reliable through this examination table. Perspective view of an examination table of the invention in use is showed in Fig. (9). In addition, the examination table includes a support system and an orientation system. As shown in Fig. (9), the breast can remain in a fixed position to allow for scanning. The breast with all layers is scanned. In order to develop a microwave response that is indicative of the presence of a lesion, microwave power is scanned upward through the scan plate. The visual imprint of the breast is recorded at the end of scanning. There may be spurious leakage of microwave power. Therefore, microwave-absorbing materials are used to suppress these leakages.

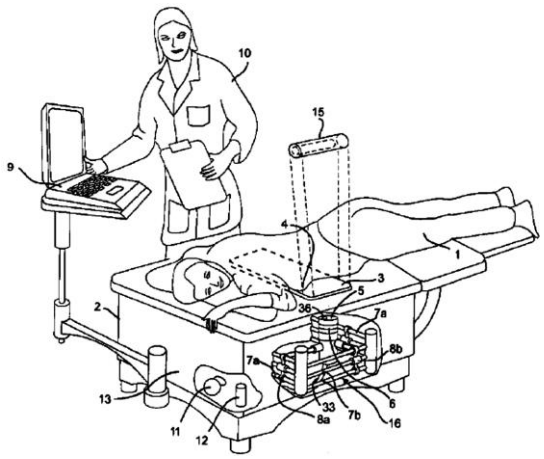

Figure 9. Perspective View of an Examination Table[25]

In the recent patent called "*Microwave Imaging Breast Phantom, Method for Testing Reliability of Breast Cancer Diagnostic Apparatus Using the Phantom, and Breast Cancer Diagnostic Apparatus Including the Phantom*" [26], a breast cancer diagnostic apparatus is tested. This invention includes both a simulated breast tissue phantom and a simulated cancer tissue phantom. A Cross-Sectional View of a Phantom is showed in Fig. (10). The simulated breast tissue and the simulated cancer tissue are created by using a solvent. It is assumed that the simulated cancer tissue phantom is in the simulated breast tissue phantom. Then, the simulated cancer tissue and the simulated breast tissue are separated from each other. In a detailed example, while the simulated breast tissue phantom can have relative permittivity of about 6 to 14 and conductivity of about 0.8 to 1.8 S/m in a frequency of 3 GHz, the simulated cancer tissue phantom can have relative permittivity of about 50 to 60 and conductivity of about 1 to 4 S/m in a frequency of 3 GHz to 1.3 GHz. A breast cancer diagnostic apparatus can include a microwave imaging breast phantom.

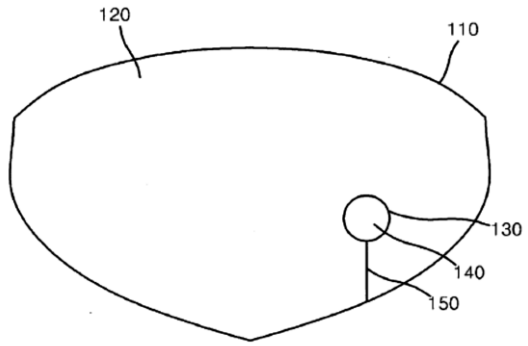

Figure 10. A Cross Sectional View of a Phantom[26]

4. DIELECTRIC MODELS

There have been many dielectric models, especially the double Debye model has been used to define the dielectric response of different biological tissues at terahertz (THz) frequencies. On the other hand, double Debye model is not accurate for human breast tissue. Because there are knowledge limitations about the structure, dynamics, and macroscopic behavior of breast tissue. Because of this, a new dielectric model is proposed in THz regime [27]. By the way, breast cancer detection is better done by this new model. While this new model is used/or suitable in high frequencies, Cole-Cole model has been used in low frequencies. There is an important question that is there a different model in the intermediate frequencies. Therefore, it is vital that according to frequency accurate dielectric model should be chosen in detection systems. In Fig. (11), Cole-Cole model is drawn in high frequencies and it is shown that this model is not suitable in high frequencies. In the same way, new dielectric model is drawn in low frequencies and is not suitable in low frequencies in Fig. (12).

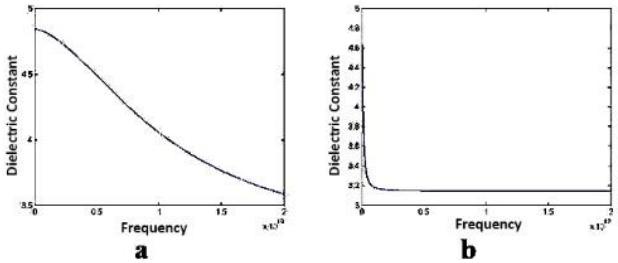

Figure 11. Graphics of Cole-Cole both **(a)** in the 0-20 GHz frequency range and **(b)** in the 0-2 THz frequency range

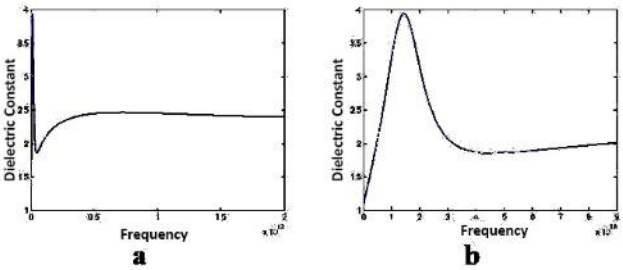

Figure 12. Graphics of New dielectric model both **(a)** in the 0-20 GHz frequency range and **(b)** in the 0-2 THz frequency range

5. CONCLUSION

Some noticeable patents on breast cancer imaging and detection that registered in last decade is presented in this study. Breast cancer imaging is an attractive topic and researchers are studying on it to develop new algorithms, methods and prototypes. In future, to image, detect and diagnose the smaller breast tumors with high performance and high resolution, it is expected that more studies for this purpose should be done. Besides, as seen that it is important to select the correct dielectric model according to the frequency.

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ANALIZA UČINKOVITOSTI VISOKOG OBRAZOVANJA U REPUBLICI HRVATSKOJ

EFFICIENCY ANALYSIS OF HIGHER EDUCATION IN CROATIA

Dunja Horvat Novak, Anica Hunjet

Pregledni rad

Sažetak: *Kvalitetna organizacija sustava obrazovanja sve je veći faktor u ostvarivanju kontinuiranog napredovanja gospodarstva. Upravo zbog toga je važno mjeriti kvalitetu obrazovanja kroz brojne pokazatelje učinkovitosti. Jedan od pokazatelja kvalitete visokog obrazovanja je i praćenje kretanja broja upisanih i završenih studenata na visokim učilištima koji jasno prikazuje povećava li se ili smanjuje broj studenata koji upisuju odnosno završavaju studije. U posljednjih nekoliko godina Hrvatska sve više ulaže u povećanje kvalitete visokog obrazovanja, djelomično kroz primjenu Bolonjskog procesa, a djelomično kroz interne analize samih ustanova visokog obrazovanja. Ulaganje u kvalitetu rezultiralo je pozitivnim stopama završavanja studija no unatoč tome, Hrvatska i dalje zaostaje za Europom prema udjelu visokoobrazovanih. Analiza učinkovitosti visokog obrazovanja pokazuje da Hrvatska kontinuirano povećava svoj udio visokoobrazovanih no da bi se dosegao prosjek Europske Unije, daljnji napori u poboljšanju obrazovne slike Republike Hrvatske i dalje predstavljaju nužnost.*

Ključne riječi: *učinkovitost, visoko obrazovanje, kvaliteta, pokazatelji učinkovitosti, gospodarski rast*

Review article

Abstract: *Quality organization of the education system is a growing factor in achieving continuous economic progress. Therefore it is important to measure quality of education through a number of indicators of effectiveness. One of the indicators of quality of higher education is also to monitor changes in the number of enrolled and graduated students at higher education institutions that clearly shows whether the number of students who enroll and complete their studies increases or decreases. In a last few years Croatia is investing in increasing quality of higher education, partly through implementation of Bologna process, and partly through internal analysis of institutions of higher education. Investing in quality resulted with positive completion rate but despite that, Croatia is still behind Europe according to the share of highly educated. Efficiency analysis of higher education shows that Croatia is continuously increasing its share of highly educated but in order to reach the average of European Union, further efforts in improving educational image still represent a necessity.*

Key words: *efficiency, higher education, quality, indicators of effectiveness, economic growth*

1. UVOD

U posljednjih nekoliko godina znanje postaje sve važniji resurs gospodarskog razvoja. Republika Hrvatska suočena je s izazovima svjetskog gospodarstva prema kojima, između ostalog, mora ispuniti određene zahtjeve u oblikovanju obrazovnog sustava. Osiguranje jamstva kvalitete obrazovnog sustava jedan je od zahtjeva koje Republika Hrvatska mora ispuniti. Kako stupanj obrazovanja stanovništva utječe na napredak gospodarstva, za Republiku Hrvatsku iznimno je važno povećati udio visokoobrazovanih. Posljednjih godina udio visokoobrazovanog stanovništva Republike Hrvatske raste no u usporedbi s Europom Hrvatska i dalje zaostaje. Da bi se udio visokoobrazovanih povećao potrebno je ulagati u kvalitetu obrazovanja te kontinuirano provoditi vanjska i unutarnja vrednovanja visokih učilišta. Na taj način utjecalo bi se na povećanje svijesti o važnosti obrazovanja što bi u konačnici rezultiralo povećanjem udjela visokoobrazovanih.

2. VISOKO OBRAZOVANJE U REPUBLICI HRVATSKOJ

Zakonom o znanstvenoj djelatnosti i visokom obrazovanju, pročišćeni tekst, („Narodne novine“ broj 123/03, 198/03, 105/04, 174/04, 2/07 - OUSRH, 46/07, 45/09, 63/11, 94/13, 139/13 i 101/14 - O i RUSRH) uređuju se sustavi znanstvene djelatnosti i visokog obrazovanja, a predstavljaju djelatnosti posebnog interesa za Republiku Hrvatsku i sastavni su dio međunarodnog, europskog, znanstvenog, umjetničkog i obrazovnog prostora. Visoko obrazovanje u Republici Hrvatskoj temelji se na akademskim slobodama, akademskoj samoupravi i autonomiji sveučilišta u skladu s Ustavom, međunarodnim ugovorima i Zakonom. Najviše stručno tijelo koje brine za razvitak i kvalitetu cjelokupne znanstvene djelatnosti i sustava znanosti, visokog obrazovanja i tehnološkog razvoja u Republici Hrvatskoj je Nacionalno vijeće za znanost, visoko obrazovanje i tehnološki razvoj.

Djelatnost visokog obrazovanja obavljaju visoka učilišta u što spadaju sveučilišta, te fakulteti i umjetnička akademija u sastavu sveučilišta, veleučilišta i visoke škole. Visoka učilišta obavljaju svoju djelatnost kao javnu službu, a osnivaju se kao ustanove. Ona mogu biti javna i privatna. Javna visoka učilišta su ona koja osniva Republika Hrvatska, a privatna učilišta osnivaju se odlukom osnivača na način propisan odredbama Zakona o znanstvenoj djelatnosti i visokom obrazovanju koji se odnose na osnivanje ustanova. Studijski programi usklađeni su od 2005. godine sa zahtjevima Bolonjskog procesa radi stvaranja Europskog sustava visokog obrazovanja.

Upis na studije obavlja se na temelju javnog natječaja koji objavljuju visoka učilišta koji provode studij najmanje šest mjeseci prije početka nastave. Visoka učilišta utvrđuju postupak odabira pristupnika na upis na način koji jamči ravnopravnost svih pristupnika bez obzira na rasu, boju kože, spol, jezik, vjeru, političko uvjerenje, nacionalno ili socijalno podrijetlo, imovinu, rođenje, društveni položaj, invalidnost, seksualnu orijentaciju i dob. Visoka učilišta utvrđuju kriterije na temelju kojih se obavlja klasifikacija i odabir kandidata za upis. Kriteriji za upis su uspjeh u prethodnom školovanju, vrsta završenog školovanja, uspjeh na klasifikacijskom ili drugom ispitu te posebna znanja, vještine ili sposobnosti. Visoka učilišta utvrđuju koji su srednjoškolski programi odgovarajući preduvjet za upis pojedinog preddiplomskog sveučilišnog, integriranog preddiplomskog i diplomskog sveučilišnog studija ili stručnog studija. Diplomski sveučilišni studij ili specijalistički diplomski stručni studij može upisati osoba koja je završila odgovarajući preddiplomski studij, pri čemu visoka učilišta propisuju koji se studiji smatraju odgovarajućim za upis pojedinog diplomskog studija. Osobe koje su završile preddiplomski stručni studij mogu upisati diplomski sveučilišni studij u skladu s općim aktom sveučilišta koje provodi taj studij. Odabir za upis može se uvjetovati polaganjem ispita kompetencija tijekom razredbenog postupka i/ili razlikovnih ispita na početku studijskog programa u statusu redovitog ili izvanrednog studenta. Poslijediplomski studij može upisati osoba koja je završila odgovarajući diplomski studij, a sveučilište može propisati i druge uvjete za upis poslijediplomskog studija.

3. STUDIJI NA VISOKIM UČILIŠTIMA

Visoko obrazovanje na visokim učilištima provodi se kroz sveučilišne i stručne studije koji se usklađuju s onima u europskom obrazovnom prostoru uz uvažavanje pozitivnih iskustava drugih visokoškolskih sustava. Sveučilišni i stručni studiji moraju biti u skladu s europskim sustavom za stjecanje i prijenos bodova (ECTS) po kojem se jednom godinom studija u pravilu stječe 60 ECTS bodova u punom nastavnom opterećenju. ECTS bodovi dodjeljuju se studijskim obvezama studenata na temelju prosječno ukupno utrošenog rada koji student mora uložiti kako bi stekao predviđene ishode učenja u sklopu te obaveze. Jedan ECTS bod u pravilu predstavlja 30 sati ukupnog prosječnog studentskog rada uloženog za stjecanje ishoda učenja.

3.1. Sveučilišni studiji

Sveučilišni studij osposobljava studente za obavljanje poslova u znanosti, umjetnosti i visokom obrazovanju, u poslovnom svijetu, javnom sektoru i društvu, te za razvoj i primjenu znanstvenih, umjetničkih i stručnih dostignuća.

Sveučilišno obrazovanje obuhvaća preddiplomski sveučilišni studij, diplomski sveučilišni studij i poslijediplomski studij. Osim ovih studija sveučilište može izvoditi i integrirani preddiplomski i diplomski sveučilišni studij. Preddiplomski sveučilišni studiji ustrojavaju se i izvode na sveučilištu, a diplomski i poslijediplomski studiji mogu se izvoditi i u suradnji sa znanstvenim institutima. Završetkom navedenih studija stječe se najmanje 300 ECTS bodova. Preddiplomski sveučilišni studij u pravilu traje tri do četiri godine. Završetkom ovog studija stječe se180 do 240 ECTS bodova. Preddiplomski studij osposobljava studente za diplomski studij te im daje mogućnost zapošljavanja na određenim stručnim poslovima. Završetkom preddiplomskog sveučilišnog studija stječe se akademski naziv prvostupnik / prvostupnica (baccalaureus / baccalaurea) uz naznaku struke.

Integrirani preddiplomski i diplomski sveučilišni studij traje pet do šest godina, a njegovim se završetkom stječe 300 ECTS bodova. Završetkom ovog studija stječe se akademski naziv magistar/magistra uz naznaku struke. U tehničkim znanostima završetkom ovog studija stječe se akademski naziv magistar inženjer, a u medicini, stomatologiji i veterini stječe se akademski naziv doktor uz naznaku struke.

Diplomski sveučilišni studij traje jednu do dvije godine, čijim se završetkom stječe 60 do 120 ECTS bodova. Diplomski studij može trajati i dulje uz odobrenje Nacionalnog vijeća za znanost, visoko obrazovanje i tehnološki razvoj. Ukupan broj bodova koji se stječu na preddiplomskom i diplomskom sveučilišnom studiju iznosi najmanje 300 ECTS bodova. Završetkom diplomskog sveučilišnog studija stječu se akademski nazivi ovisno o sveučilišnom programu. Završetkom sveučilišnog medicinskog programa stječe se naziv doktor (dr.) struke, a završetkom ostalih sveučilišnih programa magistar (mag.) struke u skladu sa Zakonom o akademskim i stručnim nazivima i akademskom stupnju, pročišćeni tekst („Narodne novine“ broj 107/07 i 118/12). Kratica akademskih naziva stavlja se iza imena i prezimena osobe.

Poslijediplomski studiji podrazumijevaju poslijediplomske sveučilišne studije i poslijediplomske specijalističke studije. Poslijediplomski sveučilišni odnosno doktorski studij može se upisati po završetku diplomskog sveučilišnog studija i traje najmanje tri godine. Ispunjenjem svih propisanih uvjeta i javnom obranom doktorske disertacije u znanstvenim područjima stječe se akademski stupanj doktora znanosti (dr.sc.), a ispunjenjem svih propisanih uvjeta u umjetničkom području stječe se akademski stupanj doktora umjetnosti (dr.art.). Kratica akademskog stupnja stavlja se ispred imena i prezimena osobe.

Poslijediplomski specijalistički studiji traju od jedne do dvije godine. Završetkom ovog studija stječe se akademski naziv specijalist određenog područja (spec.) u skladu sa Zakonom o akademskim i stručnim nazivima i

akademskom stupnju. Naziv specijalist odnosno njegova kratica dodaje se akademskom nazivu koji je osoba stekla na sveučilišnom diplomskom studiju ovisno o sveučilišnom programu. Završetkom poslijediplomskog specijalističkog studija stječe se 60 do 120 ECTS bodova. Sveučilište općim aktom može odrediti i stjecanje ECTS bodova na poslijediplomskom sveučilišnom studiju.

3.2. Stručni studiji

Stručni studiji provode se na visokim školama i veleučilištima, a iznimno se mogu provoditi i na sveučilištima uz suglasnost Nacionalnog vijeća u skladu sa Zakonom o znanstvenoj djelatnosti i visokom obrazovanju. Stručno obrazovanje obuhvaća kratke stručne studije, preddiplomske stručne studije i specijalističke diplomske stručne studije. Svaka razina stručnog studija završava stjecanjem određenog stručnog naziva.

Kratki stručni studiji traju od dvije do dvije i pol godine čijim se završetkom stječe 120 do 150 ECTS bodova. Završetkom ovog studija stječe se stručni naziv pristupnik/pristupnica uz naznaku struke u skladu sa Zakonom o akademskim i stručnim nazivima i akademskom stupnju.

Preddiplomski stručni studije traje u pravilu tri godine, a iznimno može trajati i četiri godine uz odobrenje Nacionalnog vijeća u slučajevima kad je to sukladno s međunarodno prihvaćenim standardima. Završetkom ovog studija stječe se 180 do 240 ECTS bodova te stručni naziv stručni/a prvostupnik/prvostupnica (baccalaureus/baccalaurea) uz naznaku struke u skladu s posebnom zakonom. Kratica stručnog naziva stavlja se iza imena i prezimena osobe.

Specijalistički diplomski stručni studij traje jednu ili dvije godine a njegovim se završetkom stječe 60 ili 120 ECTS bodova. Završetkom ovog studija stječe se stručni naziv stručni/a specijalist/ica određene struke u skladu s posebnim zakonom.

Stručni studiji pružaju studentima primjerenu razinu znanja i vještina koje omogućavaju obavljanje stručnih zanimanja i osposobljava ih za neposredno uključivanje u radni proces. Ukupan broj bodova koji se stječe na preddiplomskom i specijalističkom diplomskom stručnom studiju iznosi najmanje 300 ECTS bodova.

4. UČINKOVITOST VISOKOG OBRAZOVANJA U REPUBLICI HRVATSKOJ

Učinkovitost obrazovanja može se definirati kao izlazni rezultat posebnog pregleda ili analize koji se mjeri razinom postignuća posebnih ciljeva obrazovanja odnosno razinom na kojoj je visoko učilište ispunilo posebne ciljeve. Drugim riječima učinkovitost obrazovanja je izlazni rezultat koji mjeri razinu kvalitete određenog visokog učilišta. Učinkovitost ili efektivnost razlikuje se od efikasnosti po tome što efikasnost mjeri veličinu izlaznog rezultata odnosno korištenih inputa. Mjerenje uspjeha studijskog programa ili visokog učilišta provodi se putem različitih procedura koje obuhvaćaju nadzor, opažanje i obilazak učilišta. Da bi se dobilo primarno mjerilo uspjeha potrebno je prikupiti bitne pokazatelje, informacije i dokaze koji najbolje oslikavaju učinkovitost ustanove s obzirom na učenje studenata i akademsko postignuće. Mjerenje učinkovitosti obrazovanja stvara dodanu vrijednost kroz proces osiguravanja kvalitete i akreditacijski postupak te pridonosi razvoju kulture dokaza na visokom učilištu.

Pokazatelji uspješnosti predstavljaju niz statističkih parametara na temelju kojih se mjeri razina izvedbe visokog učilišta ili studijskog programa u određenoj kvalitativnoj dimenziji. Oni predstavljaju kvalitativna i kvantitativna mjerenja outputa odnosno kratkoročna mjerenja rezultata i mjerenja ishoda odnosno dugoročna mjerenja ishoda i učinaka sustava ili programa. Pomoću pokazatelja uspješnosti ustanova određuje referentnu vrijednost svoje izvedbe odnosno provodi usporedbu visokih učilišta.

Kvaliteta visokog obrazovanja može se definirati u širem i u užem smislu. U širem smislu kvaliteta predstavlja usklađenost visokog obrazovanja sa zahtjevima i potrebama korisnika, ciljevima, normama i standardima. U užem smislu kvaliteta podrazumijeva usklađenost procesa i rezultata pripreme visokoobrazovnih stručnjaka sa potrebama, ciljevima, normama i standardima države, poslodavca i društva u cjelini. Kvaliteta visokog obrazovanja rezultat je utjecaja velikog broja zahtjeva koji se nameću a podrazumijevaju zahtjeve korisnika visokog obrazovanja, zahtjeve Bolonjskog procesa i međunarodnih normi, zahtjeve sustava upravljanja kvalitetom i zahtjeve standarda rada visokoobrazovne institucije.

U posljednjem desetljeću sustav visokog obrazovanja u procesu je reforme. Godine 2001. potpisana je Bolonjska deklaracija i u skladu s time donesen je Plan razvoja sustava odgoja i obrazovanja od 2005.-2010. godine koji je definirao ciljeve i prioritete u visokom obrazovanju. Osnovni ciljevi bili su do kraja 2006. godine uspostaviti sustav jamstva kvalitete u visokoobrazovnom sustavu Republike Hrvatske i do 2010. godine smanjiti stopu odustajanja i trajanje studija, dok su glavni prioriteti bili poboljšati kvalitetu i učinkovitost odgoja i obrazovanja. Prvi korak u reformi učinjen je 2005. godine usklađivanjem preddiplomskih, diplomskih i stručnih studija s bolonjskim načelima a u razdoblju od 2005.-2009. godine restrukturirani su i poslijediplomski studiji.

Temelj Bolonjskog sustava jest sustav osiguranja kvalitete koji omogućuje stalno praćenje i poboljšavanje kvalitete programa studija kroz akademsku godinu. Sustav osiguranja kvalitete osnovni je preduvjet za unificiranje kvalitete studija na razini cijele Europe. Bez ovog sustava, diplome i programi u Hrvatskoj ne mogu se uspoređivati s diplomama i programima u Europskoj Uniji.

4.1. Osiguranje kvalitete u visokom obrazovanju

U cilju povećanja kvalitete u visokom obrazovanju, Europsko udruženje za osiguravanje kvalitete u visokom obrazovanju izradilo je Standarde i smjernice za osiguranje kvalitete u europskom prostoru visokog obrazovanja na zahtjev Bolonjske konferencije iz Berlina (2003.), s ciljem da se kvaliteta akademskih programa razvija i poboljšava za studente i ostale korisnike visokog

obrazovanja. Standardi i smjernice za osiguranje kvalitete u europskom prostoru visokog obrazovanja dijele se na:
- Europske standarde i smjernice za unutarnje osiguravanje kvalitete u ustanovama visokog obrazovanja,
- Europske standarde i smjernice za vanjsko osiguravanje kvalitete u ustanovama visokog obrazovanja,
- Europske standarde i smjernice za agencije za vanjsko osiguravanje kvalitete.

Unutarnje osiguravanje kvalitete odnosi se na procese kojima sama visokoobrazovna institucija jamči da se standardi i kvaliteta obrazovanja koje ona nudi održavaju i unapređuju. Rezultati dobiveni unutarnjim vrednovanjem najčešće su prvi dokumenti koji se razmatraju prilikom vanjskog vrednovanja. Vanjsko osiguranje kvalitete odnosi se na procese kojima nezavisna institucija jamči da se standardi i kvaliteta obrazovanja koje visoko učilište nudi održavaju i unapređuju. Vanjsko osiguravanje kvalitete razlikuje se od sustava do sustava, a može uključivati:
- različite vrste institucijskog djelovanja,
- vrednovanje predmeta ili programa,
- akreditaciju na razini predmeta, programa ili učilišta i
- njihove kombinacije.

Potpisivanjem Bolonjske deklaracije Republika Hrvatska je preuzela obvezu provoditi Standarde i smjernice za osiguranje kvalitete u visokom obrazovanju što znači da visoka učilišta trebaju provoditi postupke unutarnjeg osiguranja kvalitete a periodično se mora provoditi i vanjsko vrednovanje institucija. Vrednovanje visokih učilišta provodi Agencija za znanost i visoko obrazovanje. Kod vrednovanja visokih učilišta uzimaju se u obzir opći dokumenti/programi potrebni za utvrđivanje znanstvenog nastavnog rada na visokom učilištu te kvantitativni i kvalitativni elementi koji obilježavaju rad visokih učilišta.

Unutarnje vrednovanje ocjenjuje učinkovitost i uspješnost pojedinih ustrojnih jedinica u održavanju akademske kvalitete i standarda. Tijekom postupka unutarnjeg vrednovanja potrebno je provesti samoanalizu u kojoj će se utvrditi prikladnost sadržaja i učinkovitost studijskih programa u smislu postizanja očekivanih ishoda, te ispitati učinkovitost ocjenjivanja studenata radi mjerenja ostvarenja očekivanih ishoda studijskog programa. Osim toga potrebno je ispitati i učinkovitost nastave i učenja te se prema tome procjenjuju:
- vrste i prikladnost primijenjenih nastavnih metoda,
- način na koji se potiče sudjelovanje studenata na nastavi,
- kvaliteta nastavnog materijala,
- strategije razvoja nastavnika radi unapređenja kvalitete nastave,
- učinkovitost timske nastave i
- opterećenje studenata.

Unutarnje vrednovanje podrazumijeva i provođenje studentskih anketa kojima se ispituje mišljenje studenata o nastavnim programima i radu pojedinih nastavnika. Primarna svrha tih anketa jest unapređenje kvalitete nastave i analiza rezultata usmjerena prema isticanju dobrih primjera.

4.2. Pokazatelji uspješnosti visokog obrazovanja

Uloga procesa osiguranja i unapređenja kvalitete nastavnog procesa, studijskih programa, ali i svih ostalih procesa koji se odvijaju na visokim učilištima postaje sve značajnija u prostoru visokog obrazovanja. Inzistiranje na kvaliteti nastavnog procesa, utvrđivanju mehanizama osiguranja kvalitete i mjerilima za mjerenje kvalitete, neizostavni su elementi vrjednovanja institucija visokog obrazovanja.

Pokazatelji kvalitete su empirijske informacije koje daju sliku o tome na koji način ustanova realizira svoje ciljeve i osigurava kvalitetu obrazovnog procesa. Mogući parametri na temelju kojih s definiraju pokazatelji kvalitete su:
- ukupan broj upisanih studenata,
- broj studenata na prvoj godini,
- broj studenata koji su diplomirali,
- prosječna duljina studiranja,
- prosječna ocjena studiranja,
- odustajanje studenata,
- broj zaposlenih u znanstveno-nastavnim zvanjima,
- ukupne nastavne obveze studenata.

Pokazatelji kvalitete obrazovanja i uvjeta studiranja definiraju se različitim kombinacijama navedenih parametara kao što su:
- omjer broja diplomiranih i ukupan broj studenata,
- omjer broja upisanih na prvu godinu i broja diplomiranih studenata,
- omjer ukupnog broja studenta i broja zaposlenika itd.

Visoka učilišta usmjerena su k ostvarenju višestrukih ciljeva pa prema tome provode i različite aktivnosti. Za identificiranje i provedbu velikog broja pokazatelja uspješnosti potrebno je obuhvatiti cjelokupno područje djelatnosti. Najčešće korišteni pokazatelji uspješnosti uključuju:
- broj prijavljenih studenata s obzirom na upisne kvote,
- bodove stečene u razredbenom postupku koji su potrebni za upis,
- radno opterećenje znanstveno-nastavnog osoblja,
- stope zapošljavanja diplomiranih studenata,
- ugovore i raspoloživa sredstva za provedbu istraživanja,
- broj objavljenih članaka i studija,
- omjer studenata i znanstveno-nastavnog osoblja,
- prihode i rashode učilišta,
- opremu i namještaj učilišta i odjela.

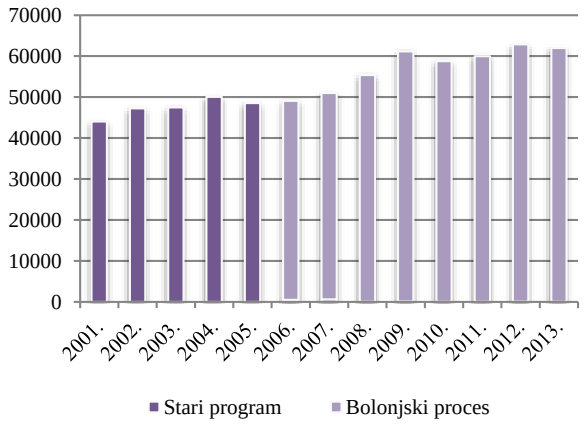
Pokazatelji uspješnosti obuhvaćaju različite aktivnosti ustanove, a kvaliteta se može vidjeti kroz ocjenu studijskih programa i modula te ocjenjivanje kvalitete učesnika obrazovnog procesa što uključuje nastavnike, studente i fakultet u cjelini. Prema tome može se zaključiti da je kvaliteta visokog obrazovanja složen pojam za čiji su nastanak, održavanje i razvoj zaslužni mnogi elementi poput države, nastavnika, studenata, poslodavaca i zaposlenih u visokoobrazovnim institucijama.

5. ANALIZA POKAZATELJA USPJEŠNOSTI VISOKOG OBRAZOVANJA REPUBLIKE HRVATSKE

Početkom 21. stoljeća visoko obrazovanje Republike Hrvatske prolazi kroz proces omasovljavanja. Podaci Državnog zavoda za statistiku o broju upisanih studenata na visoka učilišta pokazuju kako Hrvatska u posljednjih desetak godina bilježi porast broja studenata koji upisuju studij što upućuje na to da su stanovnici Hrvatske prepoznali važnost visokog obrazovanja.

Kretanje broja visokoobrazovanih ne ovisi samo o kretanju broja upisanih na visoka učilišta. Ovdje treba uzeti u obzir i mnoge druge čimbenike kao što su stope završavanja studija i stope odustajanja od studija, koeficijenti diplomskog i poslijediplomskog upisa i sl. Prema tome, broj visokoobrazovanih, između ostalog, ovisi i o kvaliteti obrazovanja koja se prati pomoću pokazatelja učinkovitosti.

5.1. Kretanje broja upisanih studenata na visoka učilišta

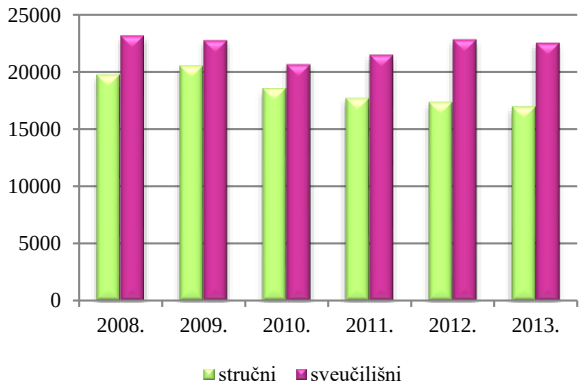


Grafikon 1. Studenti upisani na 1. godinu visokih učilišta od 2001. do 2013. godine

Grafikon 1. prikazuje ukupan broj studenata upisanih na 1. godinu studija na visokim učilištima s udjelom onih koji su upisivali studij po starom programu i onih koji su upisivali studij po programu Bolonjskog procesa. Na grafikonu je vidljivo da se broj studenata koji upisuju studije povećava, no rast nije kontinuiran, već postoje oscilacije broja upisanih studenta iz godine u godinu. Broj upisanih studenata raste u svim godinama navedenog razdoblja osim u 2005., 2010. i 2013. godini gdje je zabilježen lagani pad broja upisanih. Na grafikonu je vidljivo da se uvođenjem Bolonjskog sustava obrazovanja broj upisanih studenata na visoka učilišta povećao u odnosu na broj upisanih prije uvođenja Bolonje. Velik porast broja upisanih studenata na visoka učilišta mogao bi rezultirati naglim povećanjem broja visokoobrazovanih osoba u narednih nekoliko godina.

5.2. Kretanje broja upisanih studenata na preddiplomske stručne i preddiplomske sveučilišne studije

Broj studenata koji su upisali 1. godinu preddiplomskih stručnih i preddiplomskih sveučilišnih studija po programu Bolonjskog procesa ne prati trend rasta ukupno upisanih studenata na visoka učilišta.



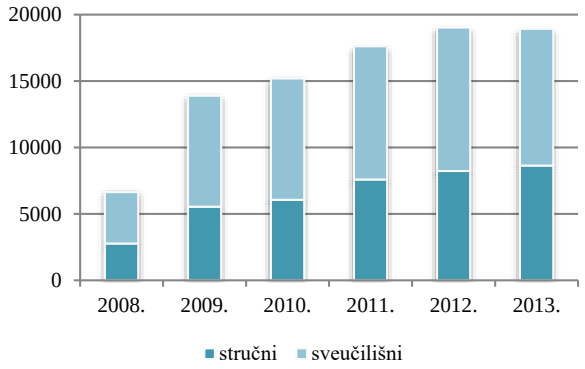
Grafikon 2. Studenti upisani na 1. godinu preddiplomskih studija od 2008. do 2013. godine

Na grafikonu 2. vidljivo je da veći broj studenata upisuje sveučilišne studije u odnosu na stručne studije. Broj studenata koji upisuju stručne studije u razdoblju od 2008. pa do 2013. godine kontinuirano se smanjuje uz iznimku 2009. godine gdje je broj upisanih studenata u porastu u odnosu na 2008. godinu. Broj studenata koji upisuju sveučilišne studije bilježi pad od 2008. do 2010. godine. U 2011. godini zabilježen je porast broja upisanih u odnosu na 2010. godinu koji se nastavlja i u 2012. godini no u 2013., broj upisanih studenata lagano pada.

Prema ovim podacima može se zaključiti da studenti upisani na 1. godinu preddiplomskih stručnih i sveučilišnih studija ne prate kretanje ukupno upisanih studenata na 1. godinu visokih učilišta. Kako se broj ukupno upisanih studenata na visoka učilišta povećava, a broj upisanih na preddiplomske studije smanjuje može se zaključiti da su za ukupno povećanje broja upisanih studenata na visoka učilišta zaslužni studenti koji upisuju diplomske stručne i sveučilišne studije i studenti integriranog preddiplomskog i diplomskog studija.

5.3. Kretanje broja završenih/diplomiranih studenata na preddiplomskim stručnim i preddiplomskim sveučilišnim studijima

Jedan od važnijih pokazatelja kvalitete obrazovanja jest praćenje broja završenih/diplomiranih studenata na preddiplomskim studijima u posljednjih nekoliko godina. Ovaj pokazatelj ujedno govori i o tome za koliko se povećava broj visokoobrazovanog stanovništva.



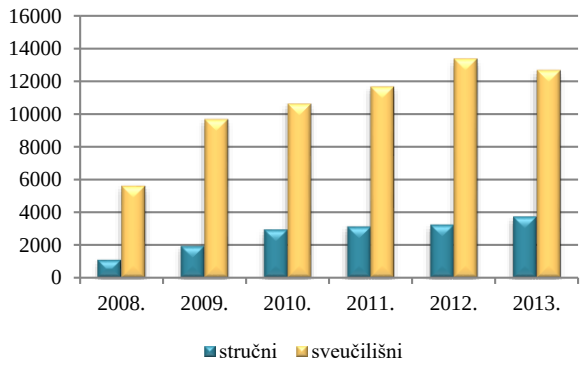
Grafikon 3. Studenti koji su završili/diplomirali na preddiplomskim studijima od 2008. do 2013. godine

Na grafikonu 3. vidi se da je veći broj studenata završio/diplomirao na sveučilišnim studijima što je i logično iz razloga jer više studenata upisuje sveučilišne studije. Iz grafikona je vidljivo da se omjer završenih studenata stručnog studija ravnomjerno povećava s omjerom diplomiranih studenata sveučilišnog studija u svim godinama navedenog razdoblja.

Kako se broj upisanih studenata na preddiplomske studije smanjuje, a broj završenih/diplomiranih studenata povećava, može se zaključiti da je iz godine u godinu sve veći postotak studenata koji upisuju studije ispunio svoje obaveze prema studiju i uspješno završio studij. Svako povećanje broja završenih/diplomiranih studenata u odnosu na prethodnu godinu znači i povećanje postotka visokoobrazovanog stanovništva što je dobar pokazatelj kvalitete obrazovanja.

5.4. Kretanje broja upisanih studenata na stručne specijalističke diplomske studije i sveučilišne diplomske studije

Broj studenata koji upisuje diplomske studije mnogo je manji od broja studenata koji upisuje preddiplomske studije. Iako se ova skupina studenata već smatra visokoobrazovanima, kvaliteta obrazovanja može se vidjeti i kroz praćenje broja upisanih studenata na diplomske studije. Kretanje broja upisanih studenata na diplomske studije govori o tome povećava li se ili smanjuje interes studenata za daljnjim nastavkom obrazovanja.

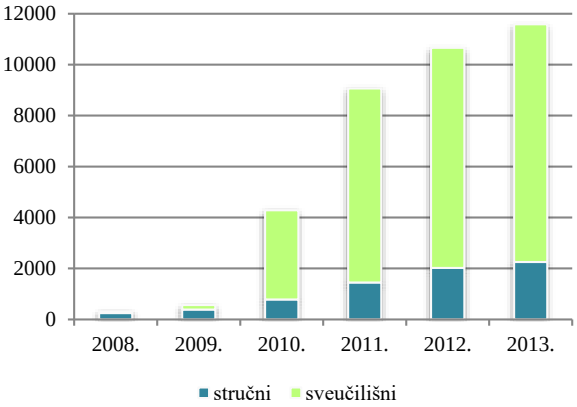


Grafikon 4. Studenti upisani na 1. godinu diplomskih studija od 2008. do 2013. godine

Iz grafikona 4. vidljivo je da znatno veći broj studenata upisuje sveučilišne diplomske studije u odnosu na stručne specijalističke diplomske studije. U 2008. godini zabilježen je znatno niži broj upisanih studenata na oba diplomska studija, iz razloga što je to godina u kojoj su diplomski studij mogli upisati samo oni studenti koji su redovnom roku završili preddiplomski studij po Bolonjskom procesu.

Kako se broj upisanih studenata na preddiplomske studije smanjuje a broj ukupno upisanih studenata na visoka učilišta raste, ovi podaci govore kako su upravo studenti upisani na diplomske studije zaslužni za povećanje broja ukupno upisanih na visoka učilišta.

5.5. Kretanje broja završenih/diplomiranih studenata na stručnim specijalističkim diplomskim studijima i sveučilišnim diplomskim studijima



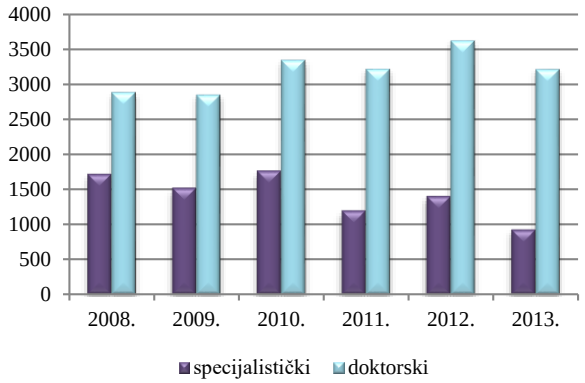
Grafikon 5. Studenti koji su završili/diplomirali na diplomskim studijima od 2008. do 2013. godine

Na grafikonu 5. prikazan je omjer studenata koji su završili stručni specijalistički diplomski studij i studenata koji su diplomirali na sveučilišnom diplomskom studiju od 2008. do 2013. godine.

Važno je uzeti u obzir kako su studenti u redovitom procesu studiranja upisivali diplomski studij tek 2008. godine u sustavu 3+2, odnosno 2009. godine u sustavu 4+1. Stoga se kao prvi redoviti diplomanti u Bolonjskom procesu mogu uzimati u obzir tek diplomanti u 2010. godini. Moguće je pretpostaviti kako su diplomanti u prethodnim godinama studenti koji su prijevremeno završavali studije te studenti koji su se u procesu studiranja prebacivali na višim godinama studiranja iz starog programa na novi.

Uzimajući to u obzir dolazi se do zaključka kako broj diplomanata kontinuirano raste na obje vrste studija, ali isto tako da je daleko veći broj studenata koji završavaju sveučilišni diplomski studij, nego studenata koji završavaju stručni specijalistički studij. Vjerojatan izvor takvog omjera je u daleko većem broju studenata koji upisuju sveučilišni diplomski studij.

5.6. Kretanje broja upisanih studenata na poslijediplomske specijalističke sveučilišne studije i doktorske studije



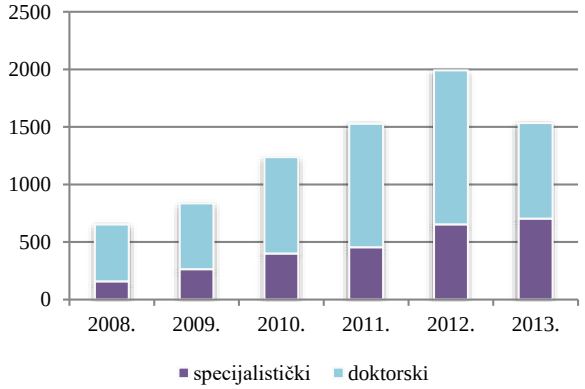
Grafikon 6. Studenti upisani na 1. godinu poslijediplomskih studija od 2008. do 2013. godine

Analizom grafikona 6. koji prikazuje kretanje broja studenata koji upisuju poslijediplomske specijalističke i doktorske studije može se doći do zaključka kako postoje negativna kretanja upisivanja na specijalističke studije. Vidljivo je da broj studenata dugoročno kontinuirano pada. Manji pozitivni pomaci dogodili su se 2010. godine te 2012. godine, ali nisu održani.

Gledajući kretanje upisa na doktorske studije vidljiv je kontinuirani blagi porast broja upisanih studenata, uz veća povećanja u 2010. i 2012. godini, što zapravo odgovara pozitivnim kretanjima upisa na poslijediplomske specijalističke studije te je moguće zaključiti kako je u tim godinama generalno povećanje interesa za poslijediplomske studije.

Uzroci takvih kretanja nisu poznati, moguće je samo pretpostaviti kako interes za poslijediplomskim specijalističkim studijem kontinuirano pada i važno je što ranije djelovati kako bi se taj negativan trend zaustavio i potaknuo veći interes studenata za tim studijem.

5.7. Kretanje broja diplomiranih studenata na poslijediplomskim specijalističkim sveučilišnim studijima i doktorskim studijima



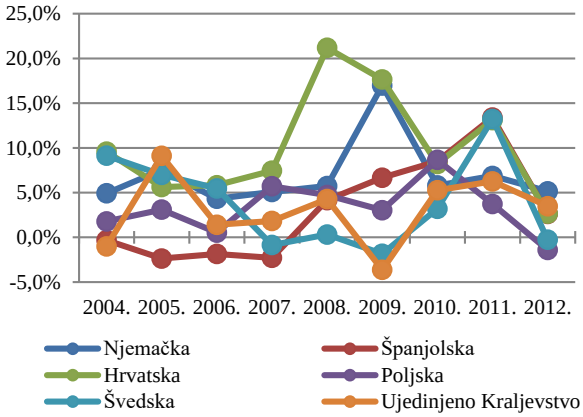
Grafikon 7.Studenti diplomirali na poslijediplomskim studijima od 2008. do 2013. godine

Analizirajući grafikon 12. vidljivo je kako se kroz 6 promatranih godina omjer broja studenata koji su diplomirali na poslijediplomskim specijalističkim studijima i doktorskim studijima približava omjeru 1:1, s time da postoji kontinuirani porast broja studenata koji završavaju oba studija, uz iznimku 2013. godine, koja bilježi pad broja studenata na doktorskim studijima nakon velikog povećanja u 2012. godini.

Ako trend kontinuiranog povećanja broja studenata koji završavaju poslijediplomske specijalističke studije promatramo u kombinaciji s evidentiranim padom broja studenata koji upisuju te studije, može se zaključiti kako je kvaliteta tih studija porasla, odnosno kako ih upisuju iznimno motivirani studenti koji većim dijelom i završavaju studije. Ista kombinacija može se primijeniti i za doktorske studije, gdje je dugoročno vidljiv i porast broja studenata koji upisuju i porast broja studenata koji završavaju doktorske studije, što je također iznimno pozitivan trend i upućuje na poboljšanje kvalitete izvođenja doktorskih studija.

6. UDIO VISOKOOBRAZOVANOG STANOVNIŠTVA U USPOREDBI S ZEMLJAMA EUROPSKE UNIJE

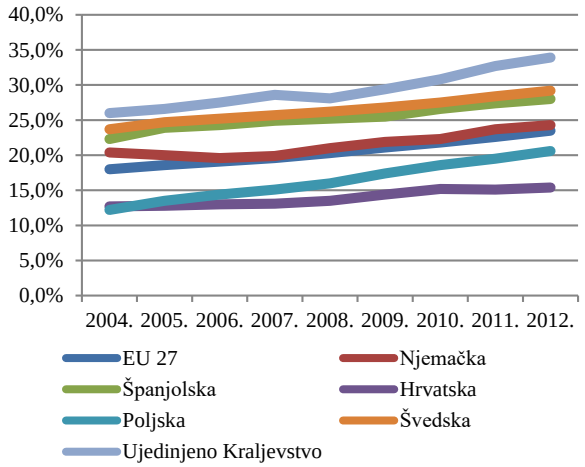
Nužnost za Republiku Hrvatsku jest povećanje postotka visokoobrazovanih. Iako se od uvođenja Bolonjskog sustava broj diplomiranih studenata u Hrvatskoj povećava udio visokoobrazovanih u odnosu na međunarodna kretanja i dalje je nizak.



Grafikon 8. Usporedba stope završavanja studija na visokim učilištima u Republici Hrvatskoj s zemljama Europske Unije od 2004. do 2012. godine

Na grafikonu 8. vidljivo je kako Hrvatska od 2006. godine pa nadalje premašuje Njemačku, Švedsku, Španjolsku, Poljsku i Ujedinjeno Kraljevstvo prema stopama završavanja studija. Uspoređujući Hrvatsku s ostalim zemljama može se zaključiti da Hrvatska ne zaostaje prema stopi završavanja studija, već naprotiv, Hrvatska bilježi najveće stope završavanja studija u navedenom razdoblju. Povećanje stopa završavanja studija za Hrvatsku znače da se ulaže u kvalitetu obrazovanja što će na kraju rezultirati povećanjem broja visokoobrazovanih.

Iako se broj diplomiranih studenata u Hrvatskoj povećava iz godine u godinu, Hrvatska još uvijek dosta zaostaje u postotku visokoobrazovanih u odnosu na prosjek Europske Unije. Ako usporedimo postotak visokoobrazovanih u Hrvatskoj i Europskoj Uniji, vidimo da Hrvatska i dalje treba kontinuirano raditi na povećanju kvalitete svoga obrazovanja kako bismo kroz narednih desetak godina dostigli prosjek Europske Unije.



Grafikon 9. Udio visokoobrazovanog stanovništva u Republici Hrvatskoj i zemljama Europske Unije od 2004. do 2012. godine

Na grafikonu 14. jasno je vidljivo kako Hrvatska najlošije stoji prema udjelu visokoobrazovanih od svih navedenih zemalja. Gledajući prosjek zemalja Europske Unije, samo su Poljska i Hrvatska ispod prosjeka EU 27, dok su Španjolska, Njemačka, Švedska i Ujedinjeno Kraljevstvo prestigle taj prosjek.

Republika Hrvatska znatno zaostaje prema udjelu visokoobrazovanih za prosjekom zemalja Europske Unije. U 2012. godini udio visokoobrazovanih iznosio je 15,4%. U odnosu na 2004. godinu, Hrvatska je povećala svoj udio visokoobrazovanih za 2,7%, što znači da prosjek zemalja Europske Unije više raste nego što raste udio u Hrvatskoj. Prema tome, može se zaključiti da iako Hrvatska konstantno povećava broj visokoobrazovanih, još uvijek zaostajemo u povećanju udjela visokoobrazovanih u odnosu na međunarodna kretanja.

7. ZAKLJUČAK

Kako je obrazovanje jedan od pokretača gospodarskog razvoja, svjesnost o važnosti obrazovanja na prostoru Republike Hrvatske sve više raste. Broj studenata koji upisuju visoka učilišta kontinuirano raste u posljednjih petnaestak godina što je dobar pokazatelj kvalitete obrazovanja. No, unatoč povećanju broja upisanih studenata na visoka učilišta, Hrvatska i dalje zaostaje po udjelu visokoobrazovanih za Europskom Unijom. Prema podacima provedene analize Republika Hrvatska kontinuirano povećava svoj udio visokoobrazovanih no ne dovoljnom brzinom koja bi mogla pratiti brzinu povećanja udjela u zemljama Europske Unije. U razdoblju od 2004. pa do 2012. godine Hrvatska je povećala svoj udio visokoobrazovanih za 2.7%, no udio visokoobrazovanih u zemljama EU 27 porastao je za 5.5%. Ovaj podatak upućuje na to da iako svijest o važnosti obrazovanja u Hrvatskoj raste, još uvijek nije na dovoljno visokoj razini koja bi rezultirala jednakim povećanjem udjela visokoobrazovanih kao što je to slučaj u Europi.

Problem visokog obrazovanja Republike Hrvatske upravo je svijest stanovništva o važnosti obrazovanja koja postoji, no samo među populacijom koja se već odlučila na studiranje i onom koja je završila prvu razinu studija i želi nastaviti obrazovanje na višim razinama. Taj dio populacije već se smatra visokoobrazovanima pa njihov nastavak studija ne utječe na povećanje stope visokoobrazovanih. Problem je u onom djelu stanovništva koji imaju završeno sekundarno obrazovanje te se nakon završetka školovanja umjesto studiranja odlučuju za izlazak na tržište rada. Taj dio populacije ima nedovoljno razvijenu svijest o važnosti obrazovanja te bi posebne napore trebalo uložiti kako bi se utjecalo na povećanje svijesti o važnosti obrazovanja kod ove skupine stanovnika što bi za posljedicu imalo povećanje udjela visokoobrazovanih.

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POBOLJŠANJE USTROJA I UČINKOVITOSTI RADA STUDENTSKE SLUŽBE NA PRIMJERU SVEUČILIŠTA SJEVER, SVEUČILIŠNOG CENTRA VARAŽDIN

IMPROVEMENT OF THE STRUCTURE AND EFFICACY ON THE EXAMPLE OF UNIVERSITY NORTHS STUDENT OFFICE, UNIVERSITY CENTER VARAŽDIN

Sandra Cvetko, Anica Hunjet, Živko Kondić

Pregledni članak

Sažetak: *Rad predstavlja segment istraživanja koje je provedeno s ciljem boljeg ustroja i efikasnosti rada studentske službe na Sveučilištu Sjever. Nakon uočavanja i definiranja problema za ovo istraživanje pristupilo se prikupljanju podataka i informacija, kako bi se došlo do spoznaje o trenutnom stanju. Prikupljeni podaci iz različitih izvora (arhiva studentske službe, dokumenti Sveučilišta Sjever, mišljenja nastavnika, asistenata i vanjskih suradnika) su analizirani, odnosno provedeno je proučavanje utvrđenog stanja kako bi se došlo do prijedloga za ostvarenje cilja koji je postavljen pred ovo istraživanje. Pri tome su korišteni različiti alati i metode kako bi se uočila optimalna varijanta rješenja prema prethodno definiranim kriterijima i mjerilima. Na kraju se ukratko opisuju zaključci za poboljšanje ustroja, efikasnosti i učinkovitosti rada studentske službe. Ne daju se rješenje u vidu konačnog oblikovanja i putokaza za bolji rad već se otvara mogućnost za daljnji rad na ovome projektu.*

Ključne riječi: *ustroj, efikasnost, studentska služba, reorganizacija*

Review article

Abstract: *This paper contains a segment of a research conducted with the goal of better structure and efficacy of University Norths student office. After perceiving and defining the problem, the data and information was gathered to perceive the current situation. The data collected from various sources (student office archives, University Norths documents, opinions of the teaching staff, teaching assistants and part-time lecturers) was analysed, respectively the existing situation was analysed so that a proposition to reach the goal set for this research could be made. To achieve this, different tools and methods where used to spot the optimal variant of the solution according to before defined criteria and benchmarks. At the end the conclusions are briefly addressed for the improvement of the structure, efficacy and effectiveness of the student office. The solutions are not given as a final way of organization and pointers for a better functioning, but the option for further work on this project is opened.*

Key words: *structure, efficacy, student office, reorganization*

1. UVOD

Organizacija je skupina ljudi koja svojim naporom omogućuje ostvarenje nekog zajedničkog cilja. Bilo koja organizacija (proizvodna ili uslužna) ne može se zamisliti i poslovati te opstati na tržištu ukoliko ne vodi računa o pravilnom, pravovremenom i kvalitetnom odabiru organizacijske strukture, ali i održavanju i unapređenju iste [3].

Sukladno rečenom i u organizaciji Sveučilišta Sjever uočavaju se različiti problemi koji sputavaju njegovu učinkovitost. Studentska služba kao jedna od organizacijskih cjelina doprinosi njegovom radu i vrlo je bitna za ukupno zadovoljstvo svih dionika.

Dugogodišnjim radom u studentskoj službi te prethodnim spoznajama, uočilo se da efikasnost poslova koje obavlja studentske službe nisu na očekivanoj i zahtijevanoj razini, odnosno da je moguće preustrojem i nekim poboljšanjima podići njenu efikasnost.

S tom idejom se krenulo u ovo istraživanje gdje su definirani ciljevi i hipoteze.

2. ISTRAŽIVAČKE HIPOTEZE I CILJEVI

U radu su definirane jedna nulta i dvije pomoćne hipoteze:

H_0- Potrebna je reorganizacija studentske službe Sveučilišta Sjever kako bi njenu efektivnost i učinkovitost podigli na višu razinu;

H_1- Preustrojem studentske službe Sveučilišta Sjever povećalo bi se zadovoljstvo studenata, nastavnika, odnosno svih dionika.

H_2- Preustrojem studentske službe povećala bi se kvaliteta usluge i ubrzali bi se svi procesi rada.

Opći cilj istraživanja je potvrđivanje ili odbacivanje definiranih hipoteza, a pojedinačni ciljevi su definirani kroz:

- definiranje prijedloga za poboljšanje ustroja studentske službe,
- uočavanje najbitnijih faktora koji djeluju na njezinu efikasnost,
- utvrđivanje svih ključnih resursa za efikasno funkcioniranje, te
- prepoznavanje boljeg ustroja i organizacije rada (ljudi, prostor, vrijeme, financije i dr.).

3. TRENUTNI USTROJ STUDENTSKE SLUŽBE SVEUČILIŠTA SJEVER

Sveučilište Sjever kroz svoja dva sveučilišna centra u Koprivnici i Varaždinu provodi sveučilišne i stručne studije. Kao što je prikazano na slici 1. studentska služba je organizirana kroz tri organizacijske jedinice [4]:

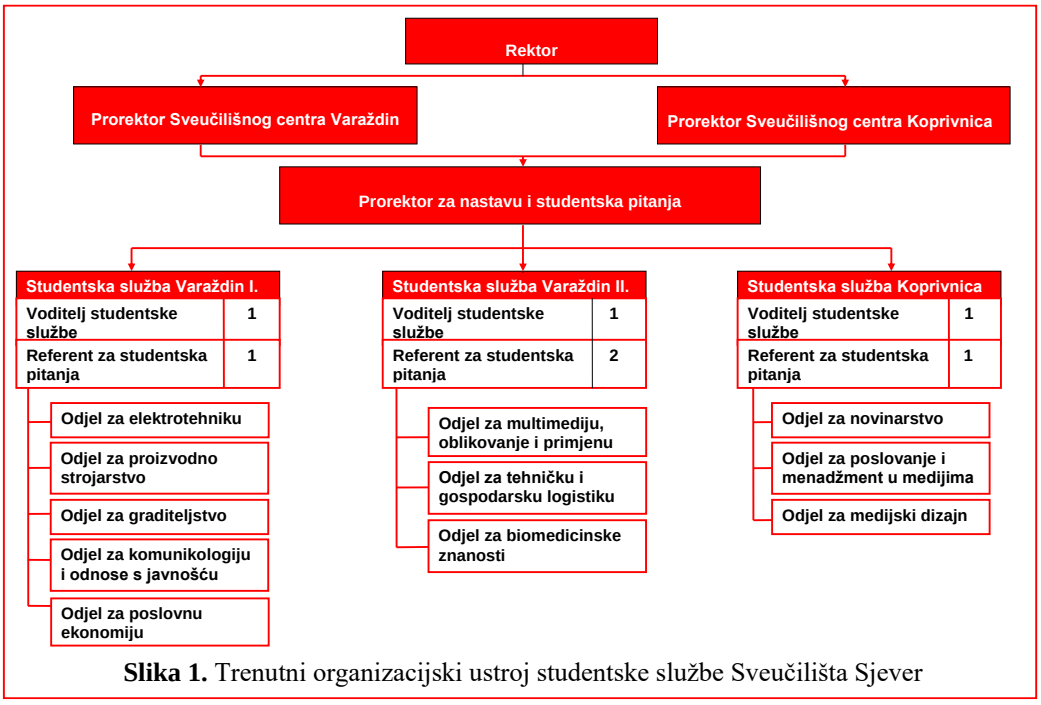
1. Studentska služba Sveučilišnog centra Koprivnica:

- za dva preddiplomska sveučilišna studija:
  - Novinarstvo
  - Medijski dizajn
- i jedan preddiplomski stručni studij
  - Poslovanje i menadžment u medijima

2. Studentska služba Sveučilišnog centra Varaždin:

Studentska služba I
- za preddiplomske stručne studije:
  - Elektrotehnika
  - Proizvodno strojarstvo
  - Graditeljstvo
- za diplomske sveučilišne studije:
  - Poslovna ekonomija
  - Komunikologija i odnosi s javnošću

Studentska služba II
- za preddiplomske stručne studije:



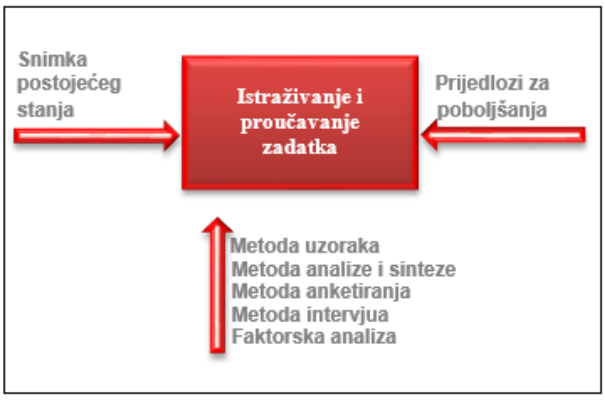
Slika 1. Trenutni organizacijski ustroj studentske službe Sveučilišta Sjever

4. ISTRAŽIVANJE I PROUČAVANJE TRENUTNOG STANJA

Jedna od korištenih metoda u ovom istraživanju bila je metoda ankete (slika 2) koja se temelji na znanstveno odabranom uzorku i to u najrazličitijim situacijama [2].

Za tu potrebu posebno su oblikovani anketni listići vodeći računa o njegovoj koncepciji, populaciji, uzorku, oblikovanju pitanja, načinu prikupljanja i obradi podataka.

Istraživanje je provedeno u dva dijela i to kroz anketiranje i analizu odgovora od strane nastavnika i asistenata te anketiranje i analizu odgovora od strane studenata.



Slika 2. Neke od korištenih metoda u istraživanju

4.1. Rezultati i analiza nastavničke ankete

Anketirano je 56 nastavnika koji predaju na Sveučilištu Sjever, odnosno u Sveučilišnom centru Varaždin. Sudjelovanje je bilo dragovoljno i anonimno, a nastavnici su usmenim putem, prije popunjavanja ankete bili obaviješteni o cilju i značaju istraživanja.

Od ukupnog uzorka, odnosno od 56 nastavnika upitnik je pravilno i potpuno ispunilo njih 50 što je bilo zadovoljavajuće za daljnje istraživanje i rad.

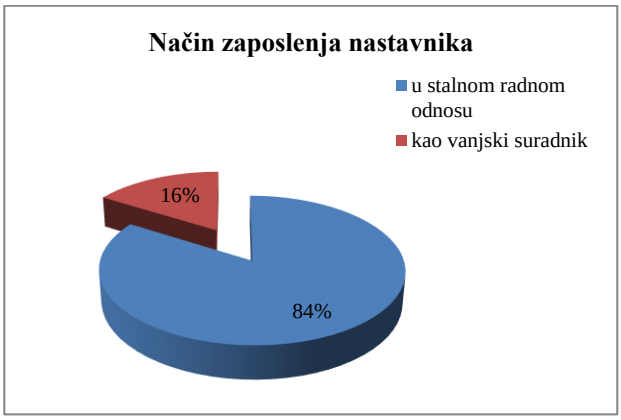
Za dobivanje podataka korišten je polustrukturiran anketni upitnik od četiri dijela. Prvi dio upitnika odnosi se na opće podatke vezane uz komunikaciju sa studentskom službom koji su prikazani s rezultatima u tablici 1.

Tablica 1. Anketa i sumirani odgovori nastavnika i asistenata za ocjenu njihovog zadovoljstva radom studentske službe

Zaposleni ste na Sveučilištu Sjever:	u stalnom radnom odnosu	47	83,93%
	kao vanjski suradnik	9	16,07%
Na koji način najčešće kontaktirate studentsku službu:	osobnim dolaskom	29	51,79%
	e-mailom	8	14,29%
	telefonom	4	7,14%
	kombinirani odgovori	14	25,00%
	nije odgovoreno na pitanje	1	1,78%
U studentsku službu dolazite:	jedanput tjedno	23	41,07%
	više puta tjedno	17	30,36%
	jedanput mjesečno	16	28,57%
Vrijeme zadržavanja u studentskoj službi:	do 5 minuta	35	62,50%
	od 5 - 15 minuta	19	33,93%
	više od 15 minuta	2	3,57%
Odgovaralo bi vam da studentska služba radi:	od 9:00 - 13:00 sati	14	25,00%
	od 12:00 - 16:00 sati	13	23,21%
	od 13:00 - 17:00 sati	14	25,00%
	od 16:00 - 20:00 sati	1	1,79%
Vaši prijedlozi za rad ukoliko Vam ponuđeni termini ne odgovaraju:	cijeli dan	5	8,93%
	jutarnji termin (do 16:00)	2	3,57%
	popodnevni termin (do 20:00)	4	7,14%
	nije odgovoreno na pitanje	3	5,36%

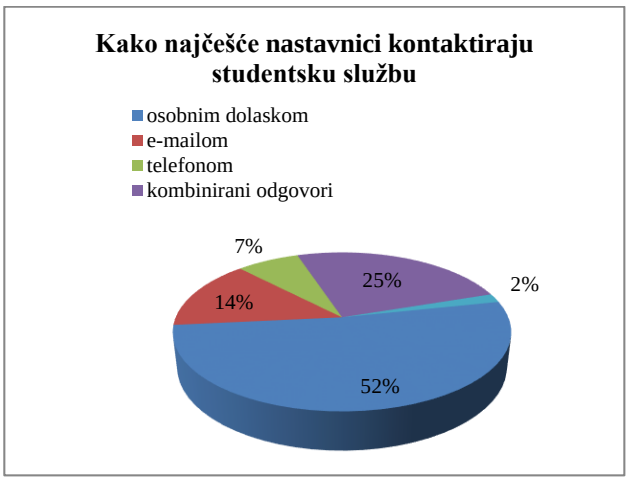
Među ponuđenim odgovorima nastavnici su odabrali odgovor na pitanja: kako su zaposleni na Sveučilištu Sjever, na koji način najčešće kontaktiraju studentsku službu, koliko često dolaze u studentsku službu, vrijeme zadržavanja u studentskoj službi i u koje vrijeme bi im odgovaralo da studentska služba radi.

Iz odgovora na pitanje o načinu zaposlenja vidljivo je da od anketiranih nastavnika njih 83,93% je u stalnom radnom odnosu a 16% su vanjski suradnici (slika 2).



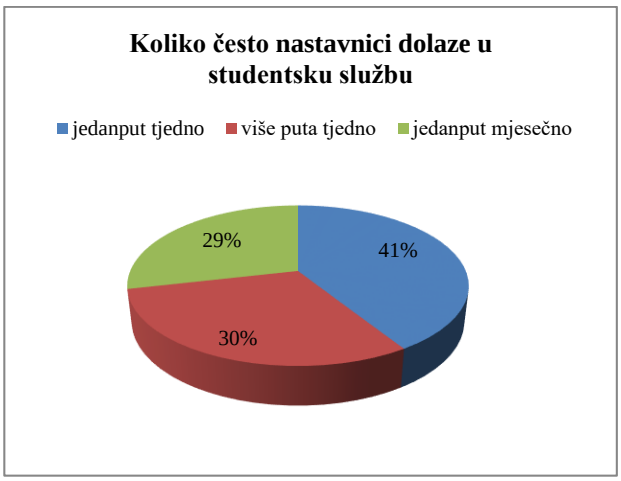
Slika 2. Oblik zaposlenja nastavnika koji komuniciraju sa studentskom službom

Na pitanje kako najčešće komuniciraju sa studentskom službom njih 52% je odgovorilo da je to osobni kontakt (slika 3).



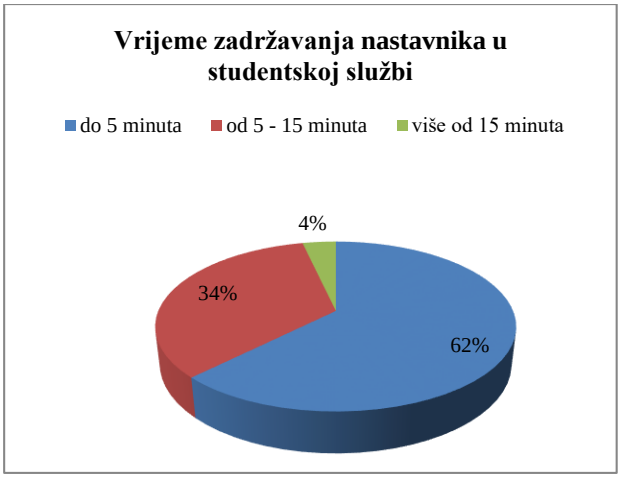
Slika 3. Način komunikacije nastavnika sa studentskom službom

Kroz anketiranje se željelo doći do podatka koliko puta nastavnici dolaze u prostore studentske službe. U tom smislu su im ponuđeni i odgovori. Iz analize odgovora teško je bilo razlučiti koja je to periodičnost. Slika 4 prikazuje odgovore.



Slika 4. Prikaz intenziteta dolaska nastavnika u studentsku službu

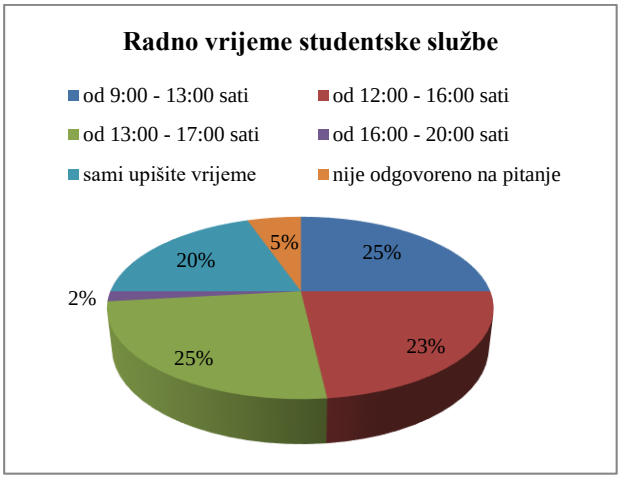
Nakon pitanja o periodičnosti dolaska u studentsku službu cilj je bio utvrditi okvirno vrijeme zadržavanja nastavnika u studentskoj službi. Iz odgovora je vidljivo da je to najčešće vrijeme do 5 minuta.



Slika 5. Vrijeme zadržavanja nastavnika u studentskoj službi

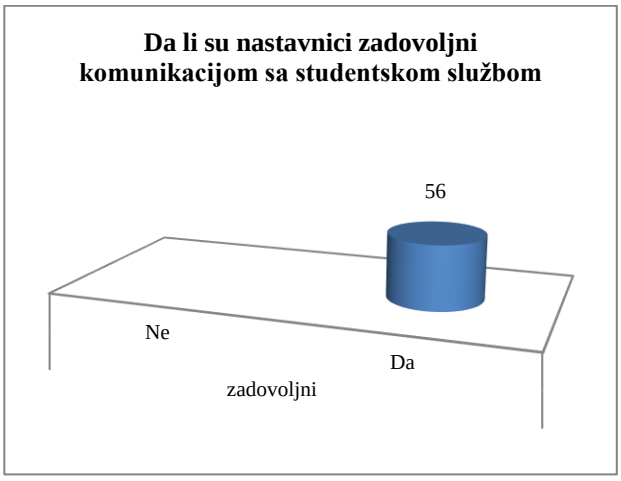
Na pitanje vezano uz razloge dolaska u studentsku službu nastavnicu su ponudili sljedeće odgovore:
- printanje ispitnih lista,
- potpisivanja prijavnica i
- podizanje ili vraćanje završnih radova studenata.

Jedno od pitanja nastavnicima odnosilo se na radno vrijeme studentske službe. Odgovore prikazuje slika 6.

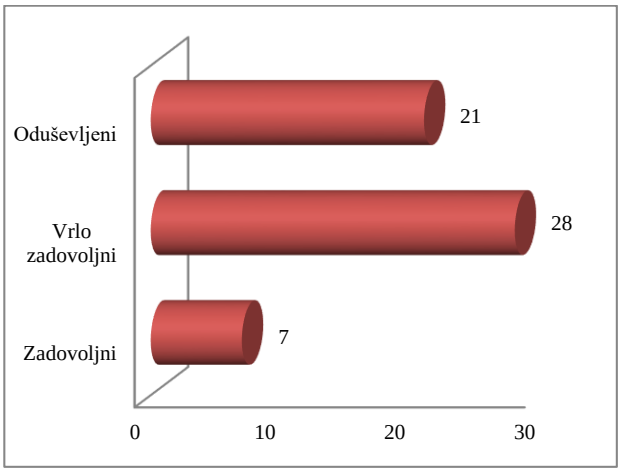


Slika 6. Prijedlog radnog vremena studentske službe koje bi odgovaralo nastavnicima

Drugi dio upitnika odnosio se na zadovoljstvo nastavnika komunikacijom sa studentskom službom. Ukoliko su nastavnici zadovoljni mogli su se izraziti kroz stupanj toga zadovoljstva putem Likertove skale kroz tri tvrdnje: oduševljeni, vrlo zadovoljni i zadovoljni. Ukoliko nisu zadovoljni komunikacijom svoje odgovore su posebno navodili. Slika 7 i 8 prikazuju odgovore. Interesantno je da su svi anketirani (100%) odgovorili da su zadovoljni s komunikacijom.



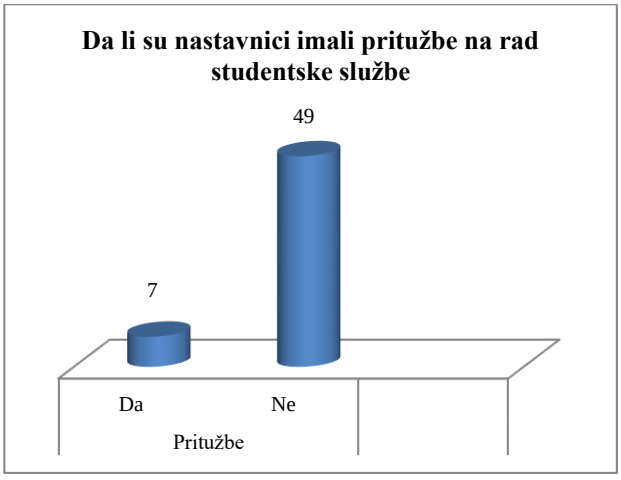
Slika 7. Prikaz odgovora na pitanje o zadovoljstvu nastavnika komunikacijom sa studentskom službom



Slika 8. Prikaz stupanj zadovoljstva nastavnika sa studentskom službom

Veći dio nastavnika, kao što je vidljivo iz slike 9, nije imalo pritužbe na usluge studentske službe.

Nastavnici koji su imali pritužbe žalili su se na sporost obrade dokumenata oko završnih radova studenata.



Slika 9. Prikaz pritužbi nastavnika na usluge studentske službe

Treći dio upitnika odnosi se na prikupljanje faktora na efikasnost rada studentske službe i to prema mišljenju nastavnika. Prikupljeni faktori su obrađeni faktorskom analizom kako bi se došlo do onih dominantnih. Saznanja o utjecajnim faktorima poslužila su za planiranje i predlaganje reorganizacije rada u studentskoj službi, a posebno pri kreiranju njenog ustroja, temelja, zadataka i dr. Analiza nije predmet obrade ovoga članaka.

Četvrti dio upitnika bio je otvoren za prijedloge i sugestije za unapređenje rada, kvalitete i efikasnosti usluga studentske službe.

1. Što biste istaknuli kao DOBRO u radu studentske službe?

Od 56 anketiranih nastavnika 47 (83,93%) nastavnika uglavnom je kao dobro u studentskoj službi komentiralo osoblje studentske službe kao:
- stručno,
- ljubazno,
- komunikativno,
- organizirano i
- ažurno.

2. Što biste istaknuli kao LOŠE u radu studentske službe?

Ono što smatraju loše u studentskoj službi komentiralo je 34 (60,71%) nastavnika. Puno zamjerki je bilo na:
- preopterećenost djelatnika studentske službe,
- neadekvatan prostor,
- preveliki broj studenata po djelatniku studentske službe,
- i organizaciju.

3. Navedite barem dva prijedloga ili sugestije za poboljšanje rada studentske službe?

Neki od najčešće navedenih prijedloga za poboljšanje rada studentske službe su:
- adekvatniji prostori,
- poboljšanje organizacije,
- zapošljavanje novih djelatnika,
- reorganiziranje radnog vremena i
- reorganizaciju studentske službe.

4.2. Rezultati i analiza studentske ankete

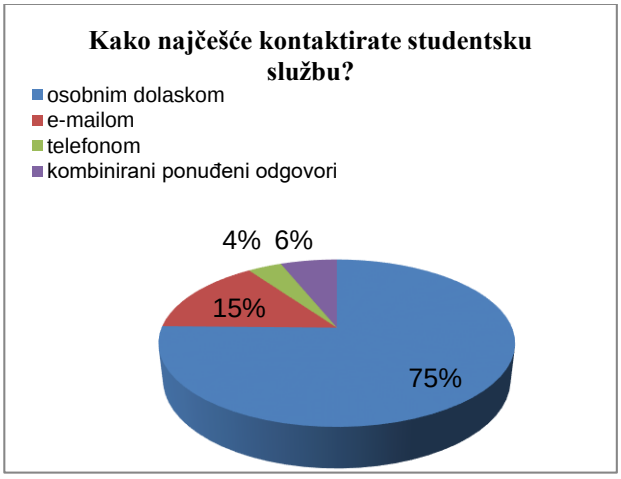
Anketiran je 571 student upisan na jednom od šest stručnih studija na Sveučilištu Sjever, odnosno na Sveučilišnom centru Varaždin.

Kao i kod ankete nastavnika i u ovom slučaju je sudjelovanje studenata bilo dragovoljno i anonimno uz prethodna pojašnjenja cilja i značaja istraživanja.

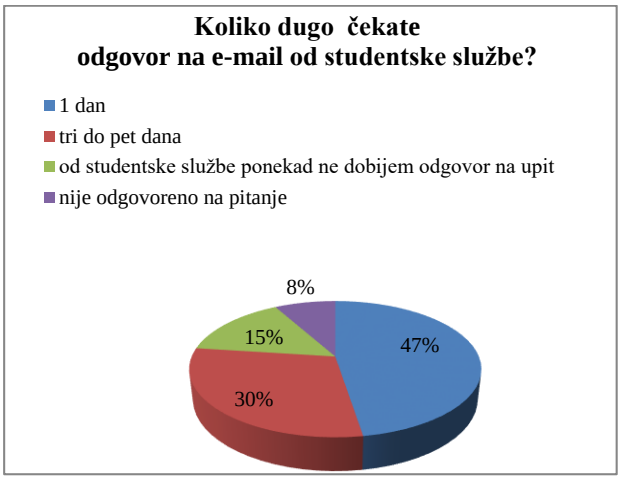
Korišten je polustrukturiran anketni upitnik od pet dijelova. U tablici 2 te slikama od 10 do 16 su prikazana pitanja kao i sumirani odgovori studenata.

Tabela 2. Anketa i sumirani odgovori studenata za ocjenu njihovog zadovoljstva radom studentske službe

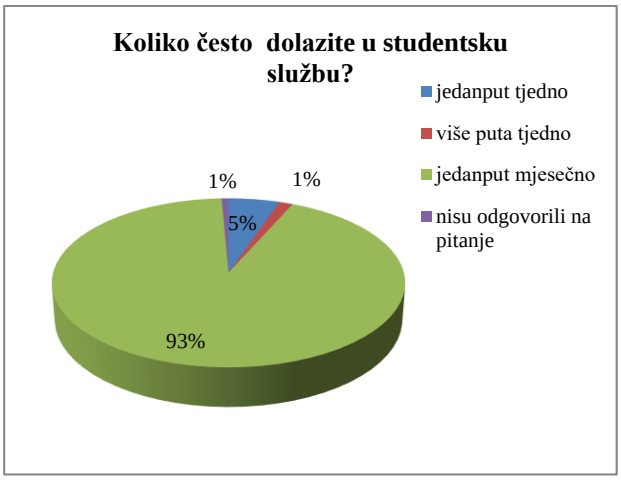
Na koji način najčešće kontaktirate studentsku službu:	osobnim dolaskom	430	75,30%
	e-mailom	85	14,89%
	telefonom	21	3,68%
	kombinirani odgovori	35	6,13%
Ukoliko kontaktirate elektroničkom poštom koliko dugo čekate da dobijete odgovor na vaš upit:	1 dan	271	47,46%
	tri do pet dana	169	29,60%
	od studentske službe ponekad ne dobijem odgovor na upit	85	14,89%
	nije odgovoreno na pitanje	46	8,05%
U studentsku službu dolazite:	jedanput tjedno	30	5,25%
	više puta tjedno	8	1,40%
	jedanput mjesečno	529	92,65%
	nije odgovoreno na pitanje	4	0,70%
Najčešće dolazite u studentsku službu radi:	pisanja zamolbi	127	22,24%
	plaćanja školarine	211	36,95%
	sami upišite razlog	200	35,03%
	nije odgovoreno na pitanje	33	5,78%
Vrijeme zadržavanja u studentskoj službi:	do 5 minuta	378	66,20%
	od 5 - 15 minuta	158	27,67%
	više od 15 minuta	32	5,60%
	nije odgovoreno na pitanje	3	0,53%
Odgovaralo bi vam da studentska služba radi:	od 9:00 - 13:00 sati	57	9,98%
	od 12:00 - 16:00 sati	160	28,02%
	od 13:00 - 17:00 sati	170	29,77%
	od 16:00 - 20:00 sati	96	16,81%
Vaši prijedlozi za rad ukoliko Vam ponuđeni termini ne odgovaraju:	cijeli dan	37	6,48%
	jutarnji termin (do 16:00)	19	3,33%
	popodnevni termin (do 20:00)	21	3,68%
	nije odgovoreno na pitanje	11	1,93%



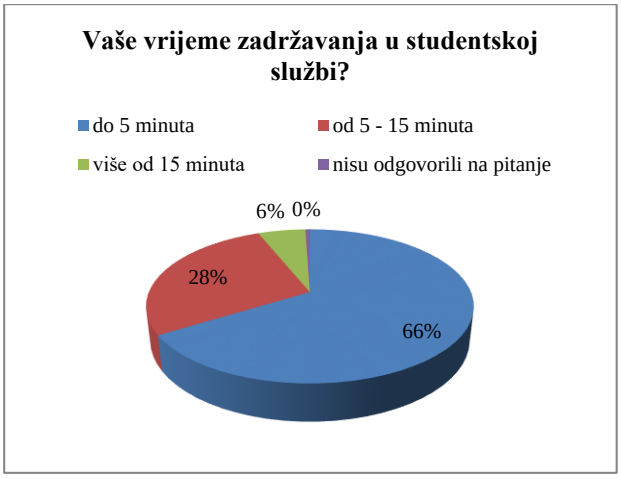
Slika 10. Prikaz najčešćih oblika komunikacija sa studentskom službom



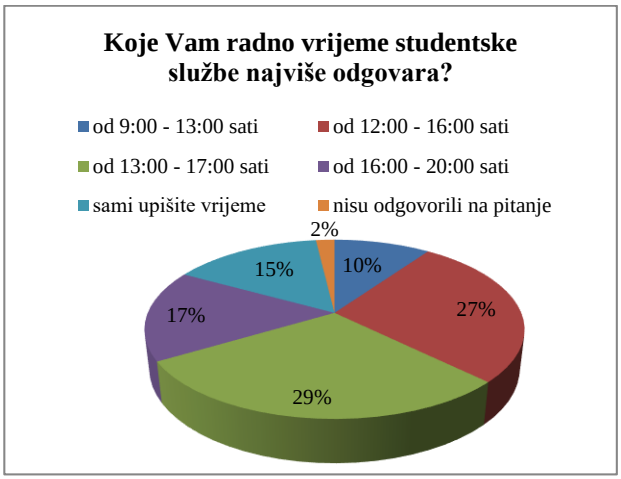
Slika 11. Prikaz vremena koliko dugo studenti čekaju odgovor na e-mail



Slika 12. Prikaz rezultata intenziteta dolaska studenata u studentsku službu



Slika 13. Prikaz vremena zadržavanja studenata u studentskoj službi

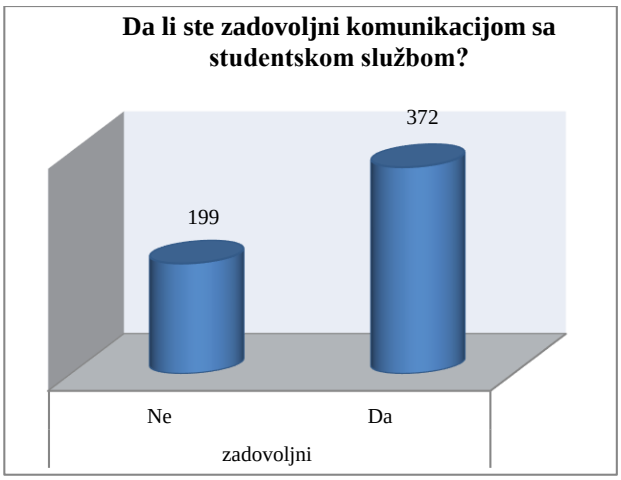


Slika 14. Prikaz radnog vremena studentske službe koje bi najviše odgovarao studentima

Drugi dio upitnika odnosio se na zadovoljstvo studenata komunikacijom sa studentskom službom. Ukoliko su studenti zadovoljni mogli su se izraziti kroz stupanj toga zadovoljstva putem Likertove skale kroz tri tvrdnje: oduševljeni, vrlo zadovoljni i zadovoljni. Ukoliko nisu zadovoljni komunikacijom svoje odgovore su posebno navodili.

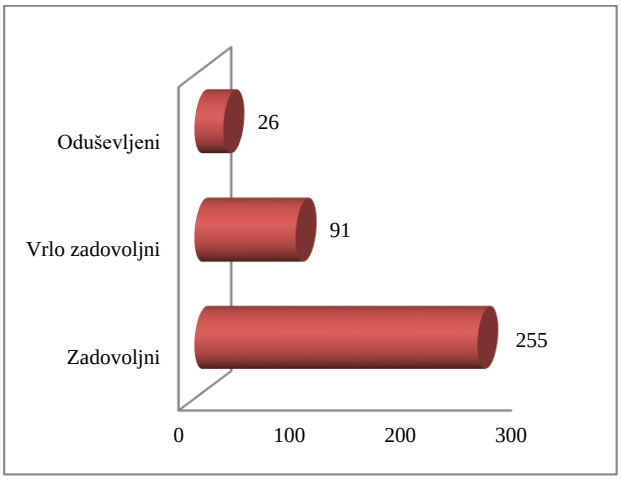
Tako je na pitanje o zadovoljstvu studenata s komunikacijom u studentskoj službi njih 199 (34,85%) izrazilo negativno mišljenje. Za razloge navode:

- ne odgovaranje na telefonske pozive,
- ne odgovaranje na elektroničku poštu,
- predugo čekanje na indekse i
- sporost u rješavanju problema.



Slika 15. Prikaz odgovora o zadovoljstva studenata komunikacijom sa studentskom službom

Studenata koji su svoje zadovoljstvo izrazili pozitivno o radu studentske službe bilo je 372. Slika 16 prikazuje odgovore.



Slika 16. Prikaz stupnja zadovoljstva studenata sa radom i komunikacijom u studentskoj službi

5. RASPRAVA I PRIJEDLOZI ZA POBOLJŠANJE

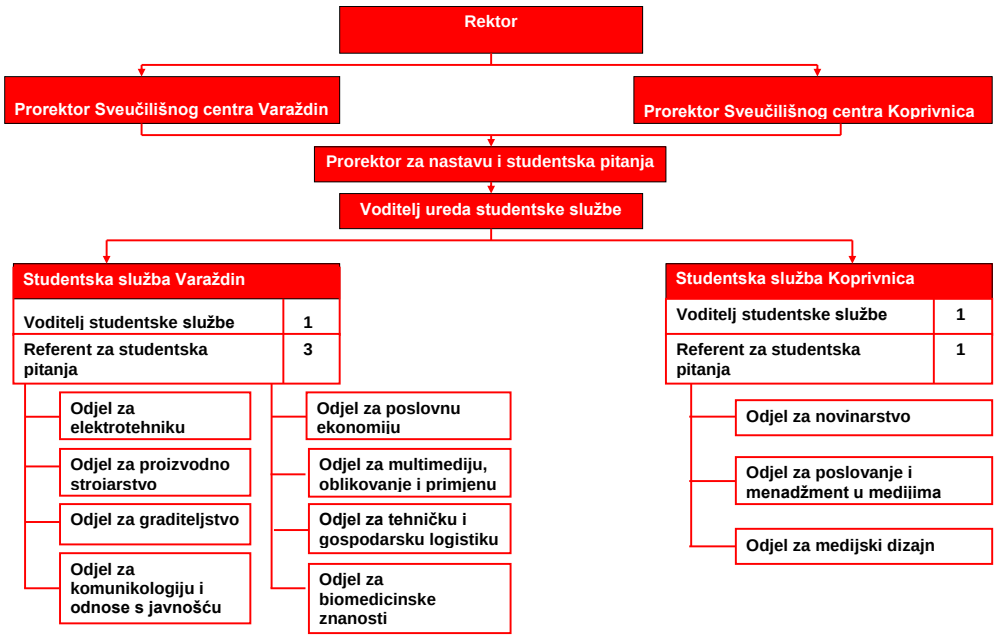
Iz provedenog prikupljanja podataka (mišljenja), te iz njihove analize potvrđena je postavljena nulta i pomoćne hipoteza. To drugim riječima znači da je opravdana tvrdnja da je nužna reorganizacija studentske službe ali u cilju podizanja njene efikasnosti i učinkovitosti i kako bi studenti i ostali zainteresirani bili čim više zadovoljni s njenim radom. U tom smislu nametnuta je:

- prostorna reorganizacija,
- kadrovska reorganizacija,
- regulativna reorganizacija i
- kombinacija navedenih mogućnosti.

Neki od konkretnih poboljšanja su mogući u vrlo kratkom vremenu i bez većih materijalnih ulaganja su primjerice:

- promjena radnog vremena,
- dijeljenje informacija,
- timski rad na poslovima s većim opsegom,
- poboljšanja u internoj i eksternoj komunikaciji,
- povećanje motivacije zaposlenika,
- stalna izobrazba zaposlenika,
- praćenje efikasnosti rada studentske službe
- okrugli stol na temu poslova u studenskoj službi,
- razmjena iskustava sa istim i sličnim službama na drugim institucijama,
- adaptacija prostora i dr.

Slika 17 prikazuje prijedlog organizacijske sheme kojom bi se jednim dijelom poboljšala efikasnost studentske službe. Uz druge prijedloge koje se odnose na temelje, definiranje procesa, odgovornosti i ovlasti smatralo se da bi služba dala svoj puni doprinos koji se od nje očekuje.



Slika 17. Prijedlog ustroja studentske službe Sveučilišta Sjever

6. ZAKLJUČAK

U članku je pokazano da u radu studentske službe, postoji manje ili veće zadovoljstvo studenata i svih dionika te prisutnost problema u organizaciji rada. S ovim se potvrđuje osnovna hipoteza o potrebi reorganizacije studentske službe kao i pomoćne hipoteze koje se odnose na povećanje zadovoljstva svih zainteresiranih strana i povećanje kvalitete usluga koje pruža studentska služba.

Stvarni doprinos provedenog istraživanja je u njegovim rezultatima i mogućnostima za primjenu u realnom sustavu, odnosno na Sveučilištu Sjever. Konkretizacija prijedloga moguća je kroz pokretanje projekata koji bi bili samostalni ili u sklopu nekih drugih kojima bi se obuhvatila i reorganizacija studentske službe.

Rad pruža i mogućnosti za daljnje istraživanje na ovome problemu i na iznalaženju utjecaja pojedinih faktora kao i na analizi sinergijskog utjecaja pojedinih

faktora na efikasnost i učinkovitost rada studentske službe.

7. LITERATURA

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DISTRIBUCIJA UPRAVLJANJA TROŠKOVIMA

COST MANAGEMENT DISTRIBUTION

Ivana Drožđek, Krešimir Buntak, Petra Vorih

Stručni članak

Sažetak: *Razumjeti sadašnje i buduće potrebe klijenata i znati kako ih ispuniti, zadatak je svakog uspješnog poduzeća. Stoga, da bi poduzeća uvijek bila u koraku s razvojem suvremenih gospodarstava ona pokušavaju organizacijski, tehnološki i informacijski preorijentirati svoje poslovanje kako bi se povećala njihova produktivnost. Povećanje produktivnosti u poslovanju, poduzeća mogu postići osiguranjem visoke kvalitete upravljanja troškovima, s naglaskom na troškove distribucije u ovom radu. Logistika distribucije je vrlo važna za poslovanje poduzeća, jer se poduzeća preko njega povezuje izravno s korisnicima ili kupcima. Stoga, logistika distribucije je usko povezana s marketingom. Najvažniji cilj logistike distribucije je postizanje najviše razine pružanja usluga, ali uz najmanje moguće troškove. Posebna pažnja u ovom radu odnosi se na troškove distribucije i njihovo pravilno upravljanje.*

Ključne riječi: *cross-docking, distribucija, logistika, trošak, upravljanje troškovima*

Professional paper

Abstract: *Understand current and future needs of clients and know how to fulfill them is the task of any successful company. Therefore, to make the company has always been in step with the development of modern economies they try organizationally, technological and IT reorient their business in order to increase their productivity. Increasing productivity in business enterprises can achieve with focus on high-quality of cost management, in this paper, with a focus on distribution costs. Logistics distribution is a very important item of the company because the company over it links directly with users or customers. Therefore, the logistics distribution is closely related to marketing. The most important aim of logistics distribution is to achieve the highest level of service delivery, but with the least possible cost. Special attention in this paper is dedicate to the distribution costs and their properly management.*

Key words*: cross-docking, distribution, logistics, costs, cost management*

1. INTRODUCTION

Logistics is defined as the process of planning, implementing and controlling the efficient and effective flow and storage of materials (raw materials, semi-finished and finished goods), services and related information from point of origin to point of consumption in order to meet the requirements of users. Distribution is one of the core activities of business enterprises. The distribution related to the movement of goods from manufacturer to consumer. Without it wouldn't be possible market supply of goods, and in some cases supply of manufacturing enterprises raw materials, semi-finished goods and other material necessary for the production process. All this must be done at minimal costs to the place where real and potential consumer expect and want, with fast and accurate feedback, in the shortest possible time, in the appropriate range and the optimum amount. The distribution costs are the most important factor in the distribution system companies. The largest share of the total distribution costs are the cost of storage, transportation and inventory management.

2. GENERALLY ABOUT LOGISTICS

2.1. The definition, content and tasks of logistics

According to the American Society of logistics, logistics is: "The process of planning, realization and control of efficient, cost-effective flows and storage of raw materials, semi-finished and finished goods and related information from point of delivery to the point of receiving, appropriate to the requirements of customers." [1] Definition of logistics to the Council of Europe reads: "Logistics can be defines as controlling the flow of goods and raw materials, manufacturing process, finished products and associated information from point of origin to the point of end-use in accordance with customer needs. In a broader sense, logistics includes the return and disposal of waste material." [2] The central role of logistics result of its multidisciplinary nature, which takes into account the technical, technological, economic, organizational, environmental and legal aspects. In accordance with these aspects, manager of logistics activities must be able and capable to match all external and internal factors in order to generate profits. It is equally important to manage all the logistics processes,

starting with the transport, storage, transport resources and their variables that determine traffic flow and marketing traffic.

2.2. The economic importance of logistics as the enterprise level

The significance of logistics in the economy is growing steadily. Logistics in the last twenty years has developed and established itself more than the previous hundred years. The importance of logistics is that the application of logistics principles and methods can greatly reduce costs, and which leads to the increase in their profits. Logistics in the economy has a specific significance because a significant portion of the time and cost of reproduction process waste on logistics activities.

2.3. Logistics as a business function

The need for the introduction of logistics occurred in the conditions when the supply of goods could not meet existing demand, and the task of the company was to find the optimal way of increasing the volume of production and improving labor productivity. This was achieved by technical and technological development, automation and realization, which was later the problem of market saturation. The goal of logistics as a business function, is to find and meet the needs and desires of consumers. Therefore, companies pay special attention to distribution channels, and their expansion and constant renewal. The purpose of logistics, ie. new logistics thinking is cost-favorable production and distribution, and continuous improvement of the flow of goods and information throughout the enterprise.

Logistics consists of three components: [3]

- economic, value (how much);
- technical (eg. in order to be stored, in order to transport, in order to pack);
- information (which is the criterion for deciding).

The market requires companies to ever shorter periods of coming up with new and diverse products. Customers are demanding faster delivery of decreasing amount, and the company must be ready to meet their requirements.

Also, in order to lower costs of production should be reduced warehouse stocks of materials, semi-finished and finished products, and parallel with this, and shorten the response time to the execution of orders and the decision to create a new product. Therefore, the high cost of production, handling, storage and transportation should be reduced.

In the area of distribution costs can be reduced by optimizing the distribution, on the basis of better transport and storage systems, timely delivery of goods in the desired quality in the right place and the like.

The ability to rationalize costs should be used in components of information, particularly in the preparation and distribution of data within and outside the company. Here is very important speed and timeliness of data and their exchange throughout the entire company. For fulfilling all the requirements necessary logistical processes that connect all of the components which is achieved by the overall concept, which makes logistics becomes an integral part of the success of the company.

3. ECONOMIC OF LOGISTICS FUNCTION IN THE COMPANY

For the proper functioning of a company it is important to establish a proper balance between all business sector. One of the preconditions for business success is to know the proper way to manage the resources within individual groups of tasks. Therefore, it is in every company needs to optimize logistics process: purchase, storage, production, and most importantly sales and transportation. Every company aims at the highest possible income, less expenses, to make a difference between them was a much. Each business function group related activities companies which together form a whole.

Economics of business functions is part of the economics of the company that studies and rational use of resources by individual business processes in the company. [4] It explores the essential factors efficiency of business functions to improve the performance of the enterprise. Key areas of research within the economics of the business functions are the costs of action and performance of the operating functions.

Research costs includes their classification and measurement. The cost of business functions usually classified into four main groups: [4]

- the costs of materials;
- labor costs;
- the cost of funds for the work;
- miscellaneous expenses.

The cost of materials we include the cost of all types of objects work. These are the costs of raw materials, intermediate products, primary and auxiliary materials, components, energy, inventory, packaging and so on. The labor costs included amounts to gross wages and salaries. The cost of funds for the operation include depreciation, insurance and maintenance costs of property, plant and equipment. Miscellaneous expenditures include obligations of business functions for taxes and fees, fines, fees, court costs, etc.

Modern and effective tool in the study and improvement of the business functions of the company is functional analysis values. It is a scientific method that examines the expenditure for each business function. Functional analysis of the value is a set of procedures for the effective detection and reduce unnecessary costs and at the same time improving the quality pf products and services company. [4]

Regular monitoring and analyzing the performance of the business function allows timely take specific measures to eliminate the problems, as well as achieve better change within the company. The analysis is based on research on external and internal factors that influence changes in the performance of business functions. Close scrutiny of the results of operations can be performed on an annual basis through the annual financial statements, but depending on the speed of change, performance information can be monitored regularly throughout the year.

3.1. The use of logistics within business functions

Total business logistics system of an enterprise can be observed to the business functions. Business functions of the company in the logistics sense are: logistics procurement, logistics production, logistic distribution and logistics storage.

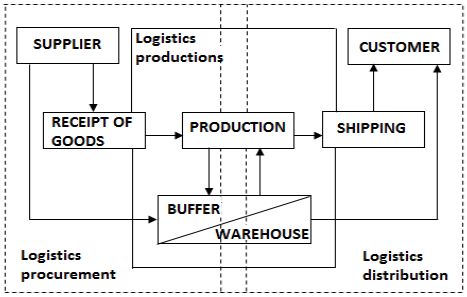

Figure 1. Relationship between procurement, production and distribution [3]

3.1.1. Logistics procurement

Logistics procurement presents a logistics system that is associated with the market. It represents the link between logistics distribution suppliers and logistics of production analyzed companies.

In logistics procurement enter the following logistical tasks: [5]

- considerations “make or buy”;
- harmonization of procurement with production;
- minimize transport costs;
- the degree of cooperation with suppliers;
- choice of suppliers;
- security of supply;
- optimizing procurement costs;
- choice of packaging;
- quality control.

Economics procurement is part of the economics of the company that deals with the rational use of available resources in the field of activity of supply companies necessary material resources or means of production. The economic efficiency of procurement measured-value generated effects and acquisition costs, as well as on other human and material resources that affect the productivity, efficiency and profitability of the purchasing function.

In certain phases of the execution of the procurement process, the company incurred costs that directly depend on the procurement activities of organizational units of the company. These are, primarily, the purchasing value of procured resources, then transport costs, insurance costs, handling costs in transportation, admission costs and so on. Each of these costs can be reduced by increasing the amount of the purchase. Therefore, the good organization of the procurement function can provide significant cost savings enterprise.

The share of the purchasing function in the whole enterprise is examined according to the amount of total costs, number of employees and total damages due to delays at certain points in the production or sale of which were the fault of procurement.

3.1.2. Logistics production

According to the order in the logistics chain’s procurement follows production. Logistics production situated between logistics procurement and logistics distribution and interconnects them. Logistics production is the totally of the tasks and their procedures to ensure optimal flow of information, materials and values in the transformation process of production. [4] The task of the production function is not in line with market needs and available human and material resources company produce certain types of products, suitable quality, in the right time and with the lowest possible costs.

Logistics production includes: [5]

- considering whether to produce or buy;
- structuring of production;
- planning and control;
- formation of the physical and information flow through production.

Economics production studies the possibilities and conditions for rational use of resources in the field of creating finished products in order to achieve the greatest possible profit. In a broader sense, the economics production are related to the optimization of production. The optimization consists in choosing the most appropriate solutions from the standpoint of the relation between income and expenses. The cost of production functions can be divided to: [4]

- material costs;
- gross salaries to employees;
- costs for depreciation;
- miscellaneous expenses.

3.1.3. Logistics distribution

The flow of goods ends in consumption, based on the distribution functions. Here is important logistics distribution. In warehouse is unrolling two group of processes, namely the storage processes and the processes of movement. [5] In this way the function significantly determines the location and storage technique. Distribution is the end point that is extremely important because through it comes to sales and end-users, or customers. The cost of the tool storage can be divided into constant and variable. The constant costs include the costs of storage capacity (depreciation of buildings and equipment, interest, rent, insurance, maintenance) and warehouse management costs (salaries of the manager and the employees). The variable costs include the costs of labor, in charge of transport and handling (reception, accommodation, examination and handling of inventory, internal transport and issuance) and the cost of holding inventory that depend on the value of stored material resources (interest on invested funds, insurance stocks, spillage and wastage, breakage, breakdown, theft and other losses in inventories).

Logistics distribution includes: [4]

- determination of the distribution channels;
- a decision on setting up representative;
- a decision for their own or other transport;

- a decision on a minimum quantity order;
- a decision to produce or buy;
- the location of each warehouse;
- inventories at certain locations;
- storage system;
- distribution with minimum costs.

3.1.4. Logistics storage

Basic functions of warehouse include the transfer, sorting and transmitting information. For correct storage of the product, it is necessary to move, and this takes place in four distinct areas: [7]

1. Receiving – receiving incoming goods from the carrier and performing verification of quality and quantity.
2. Storage – transfer of goods from the warehouse entrance and move to different places for storage within the warehouse.
3. Commissioning – commissioning the ordered products to meet customer orders including checking, packing and transport to shipping ramp.
4. Issuing – shipping goods to customers certain mode of transportation

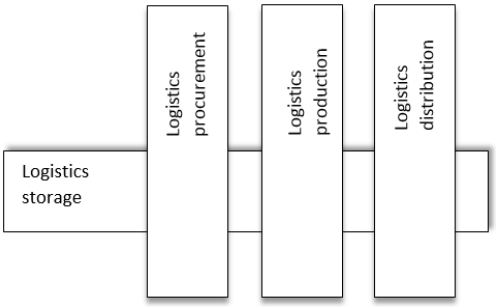

Figure 2. Logistics storage [5]

Economics storage is part of economics that studies the possibilities for enterprises rational use of resources in the field of storage activities. Rational use of available storage space, equipment and labor in a warehouse affects the costs of storage operation and its business success. On the rational use of storage affects the way the schedule of material resources, capacity utilization of warehouse space, inventory turnover rate, the degree of mechanization, and methods of manipulation and transport of material resources within the warehouse.

The cost of the storage functions are divided into constant and variable. The constant costs include the cost of storage capacity and the cost of managing storage. The variable costs include the cost of work on the transport and handling, and the costs of holding inventory that depend on the value of stored material resources.

4. ROLE OF LOGISTICS DISTRIBUTION

National Council of Physical Distribution Management term of distribution is defined as: "An effective movement of finished goods from the production line to the consumer, and in some cases included the movement of raw materials supplying to the start of production. " [8] The modern purpose of the distribution is to enable the placing of the goods available to consumers in a manner and conditions that best meets their needs. The basic task of the distribution is to provide safe, fast and rational flow of goods from production to consumption, that space and time coordinates the productions and consumption, to increase capacity for goods traffic and facilitate its continuous flow, to direct production towards the needs of the consumer, to act on placement new products and to affect change in consumer habits and culture and protect the interests of consumer.

4.1. Logistics within the distribution system

4.1.1. Distribution channels

According to the American Association for the marketing, distribution channels are: "The internal organizational units and external agents through which circulating goods and services." To L.P. Bucklin, distribution channels are: "Groups of institutions conducting those activities that are presenting at moving product and its ownership from production to consumption." [6]

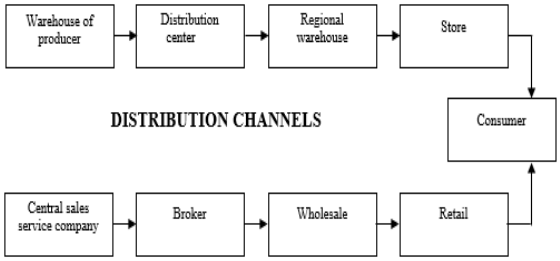

Figure 3. Schematic representation of distribution channels [9]

4.1.2. Physical distribution

Physical distribution is a set of activities that enable the efficient movement of finished goods from the end of the manufacturing process to the consumer. In some cases, including the movement of raw materials from the source of supply to the beginning of the production line. These activities include system orders and delivery of goods, inventory management, storage, handling of goods and transport.

The basic characteristic of the physical distribution is continuous flow of material or products, provided that the flow at certain points halts. The reason for these delays is the need to store goods for a time, processing, packing, etc. is mounted. The strategic and operational problem is that logistics management should solve the delays to a minimum. It should do so by their shortened without affecting consumer satisfaction and the excessive increase in distribution costs.

4.2. Goals and tasks of logistics distribution

The goals of physical distribution is to achieve a certain level of quality service delivery, taking into account the costs required to achieve the goal. Many companies thanks to service delivery to achieve their

success. Important elements of service delivery are the delivery terms. They can be compared to the products according to consumer groups, to the geographical location and the like. Raising the level of service delivery should not affect the above-average increase in costs. The largest contribution to profit isn't maximum level of service.

For all logistics subsystems is very important orientation to customers. This orientation in the companies is important because the company is in distribution directly connected with the customers. From orientation to customers follows the great significance of thinking about the service of logistics distribution. Therefore logistics distribution should constantly tear for better, innovative solutions to the problems of customers.

Based on the stated objectives of logistics distribution should establish its system, which can distinguish the following cost elements: [10]

- TS = storage costs
- TT = transport costs
- TN = cot of executing orders
- TG = cost of losses (claims and lost orders)
- TP = packaging costs

According to this, the total distribution costs will be: UTD = TS + TT + TN + TG + TP

5. DISTRIBUTION COSTS

5.1. Types of distribution costs

Distribution costs incurred directly behind the manufacturing process, and refer to: [6]

- selling costs, storage costs, transportation costs, costs of processing orders;
- salary costs of administration, communication costs, service costs to customers;
- other costs related to the distributions of goods.

Distribution costs are important for companies, and for consumers. They vary from company to company. Of them is largely dependent competitive ability. Reduce distribution costs should be achieved by balancing the cost of all elements of the distribution system and customer demands for an appropriate level of quality distribution services.

5.2. Cost Management

Cost Management is part of the overall process of managing the business success of enterprises. Cost management is a special way of running a business that the greatest importance in achieving organizational goals given to the optimization of costs. Every procedure in which the business enterprise assesses the relationship between costs and benefits. The goal of the company in the long term to maximize profits. The purpose of cost management is to undertake activities for ensuring lasting profitable business.

The basic goal of cost management is to achieve the highest possible long-term benefit from the resulting cost or to achieve a particular goal of management with the lowest costs without long-term negative consequence on the results of company business. Cost management includes: [11]

- forecasting, planning, budgeting and cost control;
- analyzes that show the behavior of costs depending on the circumstance changes in which they are incurred;
- analysis of the causes of deviations from the planned size;
- keeping costs within acceptable limits;
- providing information to managers to choose between alternatives in order to achieve optimal economic results.

Good cost management is feature of the successful organizations and educated and motivated management. In an effort to better cost management, developed a number of methods and procedures that management provide certain information necessary to make decisions in order to optimize costs based on facts. These are the following methods: [12]

- Traditional Product Costing (TPC);
- Process Based Costing (PBC);
- Activity Based Costing (ABC);
- Target Costing (TC);
- Activity Based Budgeting (ABB);
- Balanced Score Card (BSC);
- "Kaizen" Costing (KC);
- Value Engineering (VE);
- Quality Cost Management (QCM).

Traditional Product Costing (TPC) – this model is used for the delimitation of the costs of the organization. This method seeks to cover the cost accounting of direct materials and direct labor, while the overheads connected to direct costs. The traditional product costing answer to the question where payment is?

Process Based Costing (PBC) – the production costs is monitored and evaluated next logical stage in the production process. Within the PBC model direct costs of materials and labor are charged with and follow through phases of the production process, and the costs of manufacturing overheads are added to the direct costs to the level of each stage. PBC models should show the causes of the cost of production overheads and the level of their joining the direct costs of each stage in the production process. Answer the question where are the causes of the cost of production overheads?

Activity Based Costing (ABC) – includes deployment costs per activity. This method follows the movement of the cost per individual activities or part of the production process. The team allows easier monitoring of costs in certain parts of the process, and managers easier to focus on the elimination of redundant costs and work. Answer the question why payment is?

Target Costing (TC) – is a form of accounting coverage and systematic measurement of costs involved in a product or service with which achieves the planned profit. In order to target at all costs could be considered necessarily a good knowledge and understanding of the existing cost structure. Because the primary interest of the

organization for a balance of quality and functionality, combined with the level of price that the market accepts. Answers the question how costs may be?

Activity based Budgeting (ABB) – a model which is based on the determination of the application, rather than costing. The interest of this method is focused on the capacity of the equipment and the level of its sufficiency to meet the requirements of the customer. Analyzing the capacity is it important to determine capacity of the equipment and number of employees. After making initial calculations this method analyzes the costs arising from the use of material resources and human potentials. Therefore, this method is suitable for management decision-making on the level of available capacity of the organization. It gives an answer to the question what are the organizational capacities required for the product or service?

Balanced Score Card (BSC) – is based on knowledge about the processes encompassing the costs of four main perspectives through which management has the ability to transform their vision and strategy in business activities. The four perspectives of the development of the organization are: financial perspective, customer perspective, internal business perspective, perspective of development and growth of the number of employees. It answers the question about the results of linking and balancing the factors of success?

"Kaizen" Costing (KC) – are designed in Japanese companies. The essence of this model is the continuous reduction of costs during the production process using the procedures. This model assumes that everything can always do better. Answers the question of whether even better?

Value Engineering (VE) – procedure that tends to influence continuous cost reduction. Answer the question of whether the costs are reduced?

Quality Cost Management (QCM) – reduced to the recognition, identification and optimization of quality costs in a structural element of the total cost of the organization. Quality costs are incurred in securing satisfactory quality and gaining confidence in it, as well as the losses suffered when it has not been achieved. The purpose of cost management is to determine the quality of non-compliance in business processes in order to permanently eliminate the cause of their creation and business processes are done with the greatest care. The model provides an answer to the question that the costs would not be incurred if every job well done for the first time?

Each of these models can be used to manage costs. This is particularly important in a market-oriented economy in which the business results achieved at the end of the accounting period is considered significant and objective measure of the success of the organization's management.

6. CONCLUSION

Distribution plays a major role in the progress of the entire logistics system. The speed at which the product must reach the destination, time alignment of production and consumption, the price at which the transport must be carried out, increasing competitiveness of goods, the impact of the changing habits of consumer and the placement of new products on the market are just some of the tasks that must be executed in order to distribution took place successfully. The costs in distribution have a significant impact on the entire business enterprise so the goal of each company strive to minimize distribution costs. The most significant costs in the distribution are storage costs, transportation costs and costs of inventory management. Distribution costs are one of the most important factors in logistics distribution. With minimal costs and greater efficiency, the company will have a long-term successful business, so that it can compete in the market.

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NASLOV NA HRVATSKOM JEZIKU (Stil: Arial Narrow,14pt, Bold, Verzal, Center)

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NASLOV NA ENGLESKOM JEZIKU (Stil: Arial Narrow,14pt, Verzal, Center)

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Ivan Horvat, Thomas Johnson (Stil: Times, 12pt, Bold, Italic, Center)

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Kategorizacija članka

Sažetak: *Sažetak članka na hrvatskom jeziku sa najviše 150 riječ pisan jezikom članka (obično hrvatski). Sažetak mora što vjernije odražavati sadržaj članka. U njemu se navode upotrijebljene metode i ističu ostvareni rezultati kao i doprinos članka. Časopis TEHNIČKI GLASNIK / TECHNICAL JOURNAL objavljuje znanstvene i stručne radove iz područja strojarstva, elektrotehnike, graditeljstva, multimedije, logistike .... a također i iz njihovih graničnih područja. Ovaj dokument se koristiti kao predložak za pisanje članka kako bi svi članci imali isti način prijeloma (Stil: Times New Roman, 10 pt, Italic)*

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Ključne riječi: *Abecedni popis ključnih riječi na hrvatskom jeziku (5-6 ključnih riječi). Ključne riječi u pravilu su iz naslova članka, a samo eventualno iz sažetka člank., (Stil: Times New Roman, 10 pt, Italic)*

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Categorization article

Abstract: *Sažetak članka na engleskom jeziku (Stil: Times New Roman, 10 pt, Italic)*

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Key words: *ključne riječi na engleskom jeziku (Stil: Times New Roman, 10 pt, Italic)*

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1. OBLIKOVANJE ČLANKA (Stil: Arial Narrow,12pt, Bold, Verzal, Align Center)

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Članak se piše latiničnim pismom, a za oznake se može koristiti i grčko pismo. Opseg članka u pravilu se ograničava na osam stranica A4 formata (sukladno predlošku s uključenim svim slikovnim prilozima). Pri oblikovanju teksta članka ne smije se koristiti postavka za automatsko rastavljanje riječi.

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1.1. Osnovna uputstva (Stil: Arial Narrow,12pt, Bold, Align Left)

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(Uvlaka prvog reda 5mm) Dokument je formata A4 sa marginama 20 mm sa svake strane. Koristi se prijelom u dvije kolone međusobno udaljene 7 mm. Za tekući tekst se koristi vrsta pisma Times New Roman sa jednostrukim proredom, veličina pisma 10 pt, obostrano poravnanje.

Naslov članka mora jasno odražavati problematiku članka (sadrži ne više od 15 riječi).

Tekst članka dijeli se na poglavlja, a po potrebi poglavlja se dijele na podpoglavlja. Poglavlja se označavaju rednim arapskim brojevima. Podpoglavlja, kao dijelovi poglavlja, označavaju se s dva redna arapska broja kao npr. 1.1, 1.2, 1.3, ... Podpoglavlje se može podijeliti na još manje cjeline koje se označavaju sa tri redna arapska broja, npr. 1.1.1, 1.1.2, ... Daljnja podjela nije poželjna.

Nazivi glavnih poglavlja se pišu velikim slovima (verzalom) i poravnavaju se u centar, a nazivi podpoglavlja (kao i manjih cjelina) pišu se malim slovima (kurentom) te se poravnavaju u lijevo. Ako tekst naziva podpoglavlja i manjih cjelina prelazi u više redaka tada se definira viseća uvlaka (*Hanging intent*) 0,7 mm.

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Grafičke oznake (*Bullet*) koje se koriste za označavanje stavki u nekoj listi, odnosno za nabrajanje započinju na početku retka, a nakon zadnje stavke dolazi razmak od 10pt:

- Stavka 1
- Stavka 2
- Stavka 3

10pt

Isto pravilo vrijedi prilikom numeriranja stavki u nekoj listi:

1. Stavka 1
2. Stavka 2
3. Stavka 3

10pt

1.2. Oblikovanje slika, tabela i jednadžbi (Stil: Arial Narrow,12pt, Bold, Align Left)

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Slike (crteži, dijagrami, fotografije) koje čine sadržaj ugrađuju se u članak te poravnavaju se u centar. Kako bi slika uvijek zauzimala isto mjestu u odnosu na tekst prilikom uvoza moraju se definirati postavke *Text wrapping / Inline with text.*

Slike moraju biti pripremljene za grafičku reprodukciju sa minimalnom rezolucijom od 300dpi. Slike skinute s interneta sa 72dpi u veličini 1:1 nisu primjerene za reproduciranje u tisku zbog loše kvalitete.

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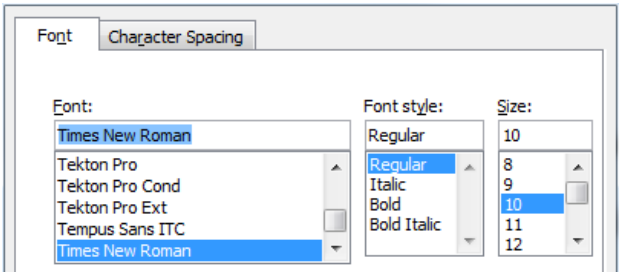

Slika 1. Tekst ispod slike [1]
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Tabela 1. Naslov tabele poravnat u centar
(Stil: Times New Roman, 10pt, Align Center)

	1	2	3	4	5	6
ABC	ab	ab	ab	ab	ab	ab
DEF	cd	cd	cd	cd	cd	cd
GHI	ef	ef	ef	ef	ef	ef

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Tekst i ostali podaci u tabelama oblikuju se kao Times New Roman, 8pt, Normal, Align Center.

Prilikom opisivanja slika i tabela fizikalne veličine i njihovi faktori ispisuju se kosim slovima latinične abecede ili grčkog alfabeta, dok se za mjerne jedinice i brojke upotrebljavaju uspravni znakovi.

Jednadžbe u tekstu numeriraju se arapskim brojevima u okruglim zagradama uz desni rub teksta, a na njih se u tekstu poziva pomoću broja jednadžbe u okruglim zagradama, npr. " .... iz (5) slijedi ...."
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$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \quad (1)$$

10pt

$$\cos\alpha + \cos\beta = 2\cos\frac{1}{2}(\alpha+\beta)\cos\frac{1}{2}(\alpha-\beta) \quad (2)$$

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Veličine (varijable) koje se koriste u jednadžbama, ali i u tekstu članka ili u tabelama oblikuju se kao *kurziv* u istoj veličini teksta.

Slike i tabele koje su sastavni dio članka moraju se spomenuti u pratećem tekstu i na taj način povezati sa sadržajem, npr. „ … prikazano na slici 1 …" ili „ podaci iz tabele 1 …" i slično.
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2. UVODNE NAPOMENE

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Ponuđeni članak ne smije biti ranije objavljen, bilo u jednakom ili sličnom obliku, niti smije biti istodobno ponuđen drugom časopisu. Za sadržaj članka, autentičnost podataka i tvrdnji u njemu isključivo i u cijelosti odgovara autor ili autori.

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Pregledni članak sadrži cjelovit prikaz stanja i tendencija određenog područja teorije, tehnologije ili primjene. Članci ove kategorije su preglednog karaktera s kritičkim osvrtom i ocjenom. Citirana literatura mora biti dovoljno cjelovita tako da omogući dobar uvid i uključivanje u prikazano područje.

Stručni članak može sadržavati prikaz originalnog rješenja nekog uređaja, sklopa ili instrumenta, prikaz važnijih praktičnih izvedbi i slično. Rad ne mora biti vezan uz originalna istraživanja, nego sadrži doprinos primjeni poznatih znanstvenih rezultata i njihovoj prilagodbi potrebama prakse, pa je doprinos širenju znanja, itd.

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3. PISANJE ČLANKA

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Članak se piše hrvatskim jezikom te se metrološki i terminološki valja uskladiti sa zakonskim propisima, normama (ISO 80000 serija) i međunarodnim sustavom jedinica (SI). Materija u članku izlaže se u trećem licu jednine.

Uvod sadrži opis problema i prikaz važnijih rezultata radova opisanih u citiranoj literaturi. Navodi se način rješavanja problema, koji se opisuje u članku, kao i prednosti predloženog postupka.

Središnji dio članka može se sastojati od nekoliko dijelova. Treba izbjegavati matematičke izvode koji opterećuju praćenje izlaganja. Neizbježni matematički izvodi mogu se po potrebi, dati kao cjeline u obliku jednog priloga ili više njih. Preporuča se navođenje primjera kad je potrebno ilustrirati proceduru eksperimenta, postupak primjene rezultata rada u konkretnom slučaju ili algoritam predložene metode. Razmatranje treba u pravilu eksperimentalno potvrditi.

Zaključak u kojem se navode ostvareni rezultati i naglašava efikasnost korištenog postupka. Istaknuti treba eventualna ograničenja postupka kao i područja moguće primjene dobivenih rezultata.
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4. ZAKLJUČNE NAPOMENE

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knjige:

[1] Franklin, G. F.; Powel, J. D.; Workman, M. L.: Digital Control of Dynamic System, Addison-Wesley Publishing Company, Massachusetts, 1990

[2] Kostrenčić, Z.: Teorija elastičnosti, Školska knjiga, Zagreb, 1982.

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[3] Michel, A. N.; Farrell, J. A.: Associative Memories via Artificial Neural Networks, IEEE Control System Magazine, Vol. 10, No. 3 (1990) 6-17

[4] Dong, P.; Pan, J.: Elastic-Plastic Analysis of Cracks in Pressure-Sensitive Materials, International Journal of Solids and Structures, Vol. 28, No. 5 (1991) 1113-1127

[5] Kljajin, M.: Prijedlog poboljšanja proračuna parametara dodira na primjeru evolventnih bokova zubi, Tehnički vjesnik/Technical Gazette, Vol. 1, No. 1,2 (1994) 49-58

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[6] Albertsen, N. C.; Balling, P.; Laursen, F.: New Low Gain S-Band Satellite Antenna with Suppressed Back Radiation, Proc. 6th European Microwave Conference, Rome, September 1976, 14-17

[7] Kljajin, M.; Ergić, T.; Ivandić, Ž.: Izbor robota za zavarivanje uvjetovan konstrukcijom proizvoda, Zbornik radova - 3. međunarodno savjetovanje proizvodnoga strojarstva/3rd International Conference on Production Engineering CIM '95, Zagreb, November 1995, C-35 - C-41

poveznice (linkovi):

[8] http://www.sciencedaily.com/articles/w/wind_power.htm (Dostupno:19.06.2012.)

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