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The journal publishes scientific and professional papers and information of interest to the professionals and industry subjects in the field of mechanical engineering and branches related to the field of application and study of mechanical engineering.

The following topics are treated in particular:

- > mechatronics, automation and robotics,
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- > design and construction of machines and facilities,
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- > energy and ecology,
- > maintenance of means for working and systems,
- > quality, system efficiency and management of production and business systems,
- > information on new books,
- > information on scientific conferences,
- > information from the University.

RIJEČ UREDNIKA

Poštovane kolegice i kolege,

u toku procesa pripreme, a s obzirom na još uvijek otežavajuće okolnosti rada i djelovanja u većem dijelu 2022. godine, kao i činjenicu da broj pristiglih i recenziranih radova nije mogao ispuniti uvjet za izdavanje u skladu s planiranim terminima, ovaj broj je imao u svom izdavanju i određene poteškoće tehničke prirode, te je sve to uvjetovalo štampanje s manjim vremenjskim pomakom.

Ipak, želeći održati kontinuitet izdavanja, u ovom broju časopisa MAŠINSTVO nudimo Vam pet radova iz različitih tematskih oblasti: usporedna analiza pokrivanja potrošnje električne energije tipičnog domaćinstva u BiH za različite geografske regije pomoću fotonaponskih panela s njihovom tehnno-ekonomskom analizom; prikaz procesa programiranja obrade glodanjem i prikaz mogućnosti aplikacije ESPRITA kroz realnu simulaciju samog procesa na mašini; implementacija tehnologija 3D skeniranja i 3D štampanja koja sve više pronalazi primjenu u digitalizaciji, prezentaciji i izradi replika različitih umjetničkih djela; primjer upotrebe u srednjoškolskom obrazovanju posebnog softverskog proizvoda NI Multisima koji se koristi za modeliranje i simulaciju rada elektroničkih sklopova i digitalnih elektroničkih sistema.

U cilju predstavljanja naučno-istraživačkih i stručnih kapaciteta časopis slijedi nove trendove i prakse u multidisciplinarnim područjima.

U sklopu odjeljka "Upustvo za autore" date su osnovne smjernice za pripremu i pisanje radova, te sve uvažene kolegice i kolege ljubazno pozivamo da uzmu učešće u objavljuvanju rezultata svojih naučno-stručnih istraživanja u okviru ovog časopisa, a koji predstavlja značajan projekt Mašinskog fakulteta Univerziteta u Zenici i priliku za prezentacije naučno-istraživačkih i stručnih rezultata istraživanja iz naglašenih i srodnih tematskih oblasti, pogotovo za naše mlade kolegice i kolege sa svih univerziteta i ostalih srodnih institucija.

U posebnim odjeljcima nastavlja se tradicija predstavljanja naučno-istraživačkih i privrednih kapaciteta iz okruženja.

INTRODUCTION BY THE EDITOR-IN-CHIEF

Dear colleagues,

During the process of preparing, and considering the still aggravating circumstances of work and activities through most of 2022, as well as the fact that the number of received and peer-reviewed papers could not fulfill the condition for publication in accordance with the planned dates, this issue also faced certain difficulties of a technical nature in the course of its publication, and consequently the printing had to be delayed for some time.

Nevertheless, wishing to continue the publication, this issue of MAŠINSTVO offers you five papers from different thematic areas: comparative analysis of electricity consumption coverage of a typical household in BiH for different geographical regions using photovoltaic panels with relevant techno-economic analysis; presentation of the programming process of milling processing and presentation of ESPRIT application possibilities through a realistic simulation of the process itself on the machine; implementation of 3D scanning and 3D printing technologies, which applications keep increasing in digitization, presentation and creation of replicas of various art pieces; an example of the use in high school education of a special NI Multisim software product used for modeling and simulating the operation of electronic circuits and digital electronic systems.

In order to present scientific-research and professional capacities, the journal follows new trends and practices in multidisciplinary areas.

The 'Guidelines for Authors' section provides basic instruction for preparing and writing papers, and we kindly invite all esteemed colleagues to take part and publish their scientific and professional research results in this journal, which is considered as a significant project of the Faculty of Mechanical Engineering of University of Zenica and gives the opportunity for presenting scientific research and professional research results from highlighted and related thematic areas, especially to our young colleagues from all universities and other related institutions.

In special sections, the tradition of presenting scientific-research and economic capacities continues.

S poštovanjem,
Fuad Hadžikadunić, glavni i odgovorni urednik

Sincerely,
Fuad Hadžikadunić, Editor-in-Chief

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KOMPARACIJA POKRIVANJA POTROŠNJE ELEKTRIČNE ENERGIJE TIPIČNOG DOMAĆINSTVA ZA RAZLIČITA PODRUČJA U BOSNI I HERCEGOVINI

COMPARISON OF COVERING THE ELECTRICITY CONSUMPTION OF A TYPICAL HOUSEHOLD FOR DIFFERENT AREAS IN BOSNIA AND HERZEGOVINA

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REZIME

Potrošnja električne energije, u doba kada potražnja za energijom i novim nekonvencionalnim energentima raste, predstavlja sve veći problem, kako u zemljama EU-a tako i u Bosni i Hercegovini. Prepoznajući značaj novih tehnologija, pogotovo baziranih na obnovljivim izvorima energije, novi načini smanjenja ukupne potrošnje energije, kao i karbonskog otiska, javljaju se i u zemljama regije. U ovom će radu biti provedena usporedna analiza pokrivanja potrošnje električne energije tipičnog domaćinstva u BiH za različite geografske regije pomoću fotonaponskih panela, kao i njihova tehno-ekonomска analiza.

Professional paper

SUMMARY

Electricity consumption, at a time when the demand for energy and new unconventional energy sources increases, represents a growing problem in the EU countries and Bosnia and Herzegovina. Recognizing the importance of new technologies, especially those based on renewable energy sources, new ways to reduce total energy consumption and carbon footprint are emerging in our region. This paper will conduct a comparative analysis of the coverage of electricity consumption of a typical household in B&H for different geographical regions using photovoltaic panels and it will provide their techno-economic analysis.

1. INTRODUCTION

According to Odyssee-Mure, there is a very uneven consumption of electricity in households among the European countries. The reason for this lies in the fact that in some countries electricity is, also, used for heating purposes, as is the case in France. As for the whole EU, the average annual electricity consumption per household is about 3700 kWh [1].

Compared to the European Union countries, the average household in Bosnia and Herzegovina consumes about 4500 kWh. This primarily applies to households in urban areas, while in rural areas consumption is slightly lower. The above analysis was taken from data available from the B&H Agency for Statistics [2].

For a long time, it has been known that the use of renewable energy sources, such as solar energy, can greatly contribute to the reduction of electricity consumption as well as the reduction of greenhouse gas emissions, such as carbon dioxide [3].

Among main obstacles for installing solar systems for electricity generation, especially for households, can be high investment costs, the geographical location of the household, climate conditions or the total available irradiated energy as well as the required space for panel installation.

In order to overcome economic problems and ensure a return on investment in a reasonable time, many countries choose to encourage electricity production by small producers through various forms of subsidies and

incentives such as feed-in tariffs, investment subsidies and other [4].

In Bosnia and Herzegovina, according to the latest FERK reports, the guaranteed purchase price of electricity from micro producers, such as traditional household, is 0.12 KM/kWh, or if the household is a privileged producer, the price goes up to 0.3 KM/kWh [5].

2. SOLAR ENERGY

Solar energy is a huge energy resource available on the Earth. Currently, there are about 700 GW of power plants installed worldwide. The spectrum of sunlight on the Earth's surface is mostly spread in the visible, infrared range and, to a smaller degree, in ultraviolet range [6]. Reaching the Earth's surface, solar energy is available in the form of direct, diffusion and reflective energy. In general, for calculations of solar systems, it is necessary to know the total radiated energy on a horizontal or inclined surface.

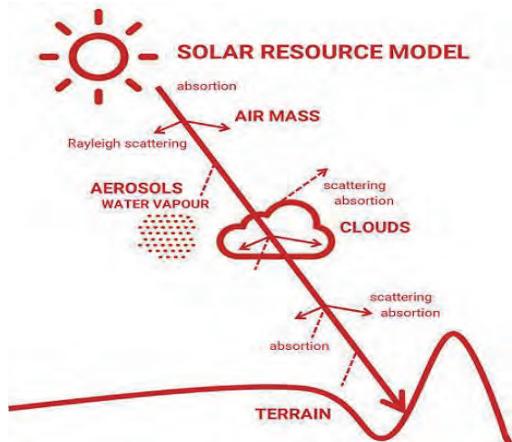


Figure 1 Solar resource model

As it can be seen from Figure 1, passing through the Earth's atmosphere, the radiated energy on the Earth decreases significantly. This is primarily affected by various impurities in the air, such as pollutants from emissions from the combustion of fossil fuels, clouds, etc.

Solar energy potential is not evenly distributed everywhere in the world. In general, the majority of the world's population lives in areas where the average daily radiated solar energy is between 3,5 and 7 kWh/m² [7].

The average annual global irradiance per square meter over the world can be seen in Figure 2.

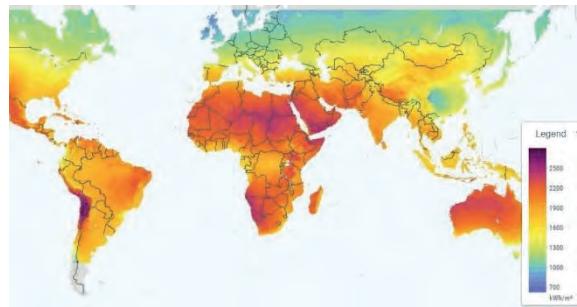


Figure 2 Global irradiance in kWh/m² all over the world

Data on solar potential for geographical areas around the world is currently available for download through various online databases as well as various pieces of software. Among the leading databases and software are:

- BSRN (Baseline surface radiation network),
- PV GIS (Photovoltaic geographical information system),
- NASA (Database for solar radiation and meteorological data),
- Global solar atlas,
- Homer pro (software),
- Helioscope (software) and
- Retscreen (software).

It is important to mention the above because of the way the data is collected. Most of the available data on solar energy radiated to the Earth's surface refers to satellite images taken over a period of time. The data available in this way is accepted when calculating solar systems in a scientific society, and many data validations are performed. Deviations of measured values from data downloaded from online databases, especially PV GIS, show satisfactory matches [8].

Although it is always better to have in-situ measurements, in this paper the values of global irradiation for different areas of B&H will be taken from the PV GIS web page.

2.1 Solar potential of Bosnia and Herzegovina

Knowledge of the solar potential of Bosnia and Herzegovina is crucial for sizing the photovoltaic power plants to cover household needs for electricity. Although long-term measurements of solar radiation have not been performed and available, most of the data required for sizing the system is available from the aforementioned databases. The solar potential of B&H can be seen in Figure 3.



Figure 3 Solar potential of Bosnia and Herzegovina

By comparing the values of the total available solar energy on a horizontal surface in the countries of Central and Northern Europe, where annual averages are 1150 and 1000 kWh / m² per year, respectively, it can be concluded that on average Bosnia and Herzegovina gets about 15% more energy compared to Central Europe, and 30% more than Northern Europe. For the areas of Herzegovina, these percentages are even higher, so that part of our country receives up to 50% more energy compared to Northern Europe.

For the purposes of the analysis done in this paper, the values of average annual insolations for 6 cities in BiH were taken from the PV GIS page. Areas of interest were distributed according to different geographical areas and regions in Bosnia and Herzegovina. The cities of Mostar, Sarajevo, Zenica, Tuzla, Banja Luka and Bihać were taken as representatives of 6 regions. With the help of the PV GIS page, data on global horizontal irradiation (G_{hi}) and global irradiation on the optimal inclined surface (G_{oi}) were taken. Data on global irradiation for different cities as well as optimal angles of panel inclination can be seen in Table 1.

Table 1 Global annual irradiation on flat and inclined surfaces for different B&H cities

City	G_{hi} [kWh/m ²]	G_{oi} [kWh/m ²]	Optimal angle [°]
Mostar	1505,70	1768,04	37
Sarajevo	1255,37	1420,97	33
Banja Luka	1270,80	1454,13	35
Tuzla	1292,48	1474,94	34
Zenica	1263,25	1421,95	33
Bihać	1242,94	1408,38	34

As previously stated, it can be seen from the table that the southern parts of the country, i.e. the city of Mostar has the highest insolation while the northern parts, like Bihać, have the lowest. The data were analyzed for a period of over 10 years that was available on the PV GIS database from 2005 to 2016 [9].

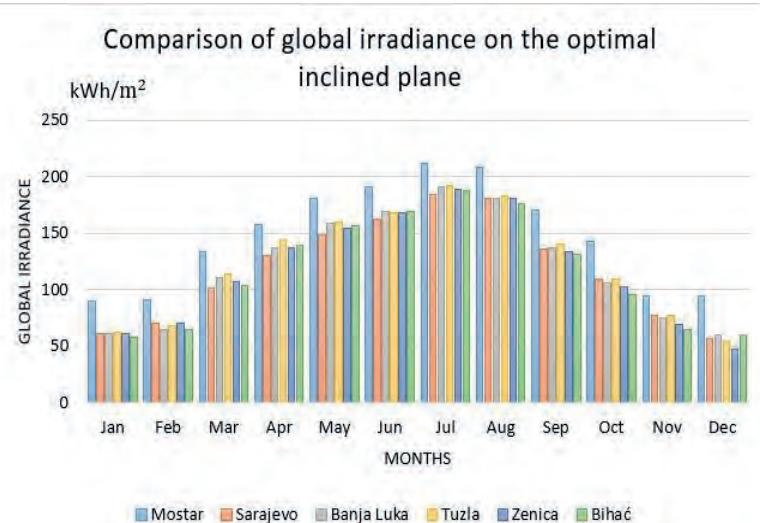


Figure 4 Comparison of global irradiance at different cities across Bosnia and Herzegovina

3. SIZING THE PHOTOVOLTAIC POWER PLANTS

In order to size the required number of PV panels and installed inverter power, the input parameters in the calculation will be the average household electricity consumption in B&H of approximately 4500 kWh per year and the average global irradiation to the optimally inclined surface for different cities in B&H, described in the previous chapter. Since the aim of this paper is to show a comparison of the required size of the solar power plant covering household electricity consumption for different cities in BiH as well as the required repayment period, certain assumptions are introduced:

- electricity consumption is assumed to be evenly distributed over a period of 12 months, more precisely evenly distributed over 365 days,
- a simplified calculation model will be used,
- households are located in the urban area, and are privileged producers,
- global irradiation per day will be taken to be evenly distributed over 365 days,
- households have enough area on the roof to install the required number of PV panels.

The first thing that needs to be calculated is the average number of peak hours of sunshine for a given location, which is calculated using the formula:

$$h_{ps} = \frac{G_{oid}}{1 \frac{kW}{m^2}}, \quad (1)$$

where are:

h_{ps} - sun peak hours [h],

G_{oid} - global irradiation on optimally inclined plate per day [kWh/m^2].

The required PV power size needed can be calculated using the formula:

$$P_{PV} = \frac{E_{HCD}}{h_{ps}} \cdot 1.3, \quad (2)$$

where are:

P_{PV} - required PV power size [kW],

1.3 - standard increase factor due to system losses, etc.,

E_{HCD} - average electrical energy consumption of household per day [kWh/day].

The number of PV panels is calculated using the following formula:

$$N_{PV} = \frac{P_{PV}}{P_N}, \quad (3)$$

where are:

N_{PV} - number of required PV panels,

P_N - nominal power of the panel [kW].

The inverter size will be determined using the following rule: the inverter size needs to be bigger from 20 to 30% than the P_{PV} of the PV panels.

The total costs are calculated using the following formula:

$$C_{Total} = \sum C_i, \quad (4)$$

where C_i are the costs of individual system components.

3.1. Calculated PV systems for households

Table 2 shows the calculated required power of PV power plants to cover household electricity needs. Formulas (1) and (2) were used for the purposes of the calculation. First, the number of sun hours for each city of interest was calculated, and then the required power of the PV system.

Table 2 Calculated PV power

City	Required PV power [kW]
Mostar	3,31
Sarajevo	4,12
Banja Luka	4,02
Tuzla	3,97
Zenica	4,11
Bihać	4,15

As expected, the lowest required power of photovoltaic panels to meet the electricity needs of the household is in Mostar, where the highest solar irradiation is, while the highest required PV power is in Bihać.

When calculating the required number of PV panels, it is necessary first to select the desired panel. For this purpose, a 375 Watt Longi PV panel with a price of 280 KM/piece was chosen. The number of required PV panels can be seen in Table 3.

When choosing an inverter, it is necessary to pay attention that the maximum input voltage V_{DC} on

the DC side (PV panel side) as well as the string current I_{SC} is lower than the allowed values recommended by the manufacturer.

Table 3 Required PV panels

City	Required PV panels
Mostar	9
Sarajevo	11
Banja Luka	11
Tuzla	11
Zenica	11
Bihać	11

Taking into account the previously mentioned rules for all cases, Fornius symo 5.0 inverter with a price of 2515,5 KM was chosen. Additional costs such as installation, cables, connectors, etc. are taken to be up to 20% of the total investment for panels and inverter. The total cost of each PV system is shown in Tabel 4.

Table 4 Total cost per PV system

City	Total cost [KM]
Mostar	6042,6
Sarajevo	6714,6
Banja Luka	6714,6
Tuzla	6714,6
Zenica	6714,6
Bihać	6714,6

4. TECHNO-ECONOMIC ANALYSIS OF PV POWER PLANTS

Techno-economic analysis of the systems was performed using the online software PV GIS. The annual production of PV systems for cities of interest was calculated as well as the average monthly production from the PV plants. Annual incomes are calculated on the assumption that households enjoy the status of privileged sellers of electricity, having a guaranteed purchase price of electricity of 0,29 KM/kWh. Return on investment periods were also calculated.

The average monthly production for PV power plants is shown in Figure 5, and the annual profit and return on investment in Tabel 5.

Table 5 Annual PV profit and return on investment

City	PV energy [kWh/a]	Income [KM/a]	Return on investment [year]
Mostar	4629,48	1342,55	4,50
Sarajevo	4618,56	1339,38	5,01
Banja Luka	4672,56	1355,04	4,96
Tuzla	4745,64	1376,24	4,88
Zenica	4551,6	1319,96	5,09
Bihać	4557,8	1321,76	5,08

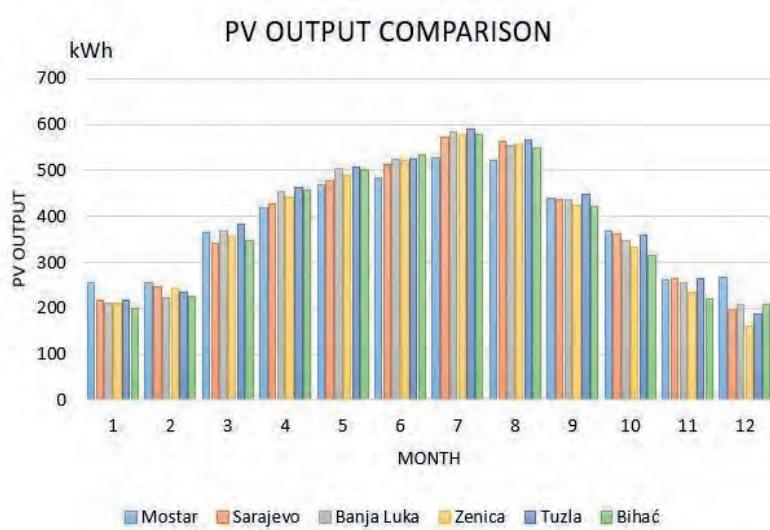


Figure 5 Avarage monthly PV output comparison

The return period on investment, calculated in relation to the lowest purchase price of electricity of 0.12 KM/kWh, is shown in Tabel 6.

It can be seen that the expected return on investment is the shortest for the city of Mostar. Other cities seem to have approximately the same return period.

Table 6 Annual PV profit and return on investment based on lowest purchase price

City	PV energy [kWh/a]	Income [KM/a]	Return on investment [year]
Mostar	4629,48	555,54	10,88
Sarajevo	4618,56	554,23	12,12
Banja Luka	4672,56	560,71	11,98
Tuzla	4745,64	569,48	11,79
Zenica	4551,6	546,19	12,29
Bihać	4557,8	546,94	12,28

Small anomalies can also be seen when comparing the production of electricity from PV systems for different cities. Although the city of Mostar has the highest solar irradiated energy, during the summer months some cities such as Tuzla produce more electricity. The reason for that is the total installed power in Mostar is smaller as well as the inclination of the panel, which is set for the annual optimal angle, and not the monthly one. The above mentioned statements lead to the conclusion that it would be ideal to have such installed solar panels whose inclination in relation to the horizontal surface could be adjusted to the optimal angle per month. Of course, the above-mentioned details entail negative consequences, such as increased investment cost and much greater difficulties in implementing the technical solutions of the panel carrier. Looking at the entire lifespan of solar systems, estimated at 20 years, it can be said that the investment certainly pays off. A rough estimate indicates that for a city like Bihać, even when calculated at the lowest purchase price of electricity, the profit after the payback period can be over 4000 KM, looking at the service life of the system of 20 years.

5. CONCLUSION

The paper presents a techno-economic analysis of PV power plants for different cities in Bosnia and Herzegovina. From the analysis, it can be concluded that to cover the average electricity consumption of a typical household in B&H, a power plant of about 4 kW of installed power is needed, and the average investment is from 6000 KM to 7000 KM. During the analysis, it can be seen that the southern parts of Bosnia and Herzegovina have a huge solar potential, but insufficiently used. This tells us that in the future the direction of electricity production from renewable sources should be directed towards its

use. Also, in order to have an insight into a more detailed techno-economic analysis of such systems in future research, it is necessary to carry out optimizations using new technologies available for this purpose. For that purpose, software such as Homer Pro has been developed, where minimization of costs for the end user can be set as a function of optimization. Also, the use of MCDM optimization algorithms would give a broader insight into the usefulness of PV systems as well as their combination with other technologies, such as heat pumps, or the use of solar energy to heat domestic hot water.

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PROGRAMIRANJE OBRADE GLODANJA UPOTREBOM ESPRITA

PROGRAMMING OF MILLING OPERATIONS BY USING ESPRIT

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REZIME

Brzina obrade je jedna od najbitnijih komponenti u procesu proizvodnje, pa je prema tome potrebno koristiti što kompletniji programski paket odnosno softver. Esprit je idealan izbor, jer je to CAD/CAM softver u kojem je moguće crtati, modelirati, programirati, a na kraju generirati G-kod za bilo koji alatni stroj. On je jako moćan alat visokih performansi sa punim spektrom programskega sistema za glodanje, tokarenje, bušenje itd. Kroz ovaj rad obraditi će se proces programiranja obrade glodanjem i prikazati neke od najčešće korištenih opcija koje nudi Esprit. Jedna od bitnijih mogućnosti ovog softvera jeste realna simulacija samog procesa na mašini, što je jako bitno kod procesa obrade, posebno glodanja na petoosnim mašinama.

Professional paper

SUMMARY

Machining speed is one of the most important components in the production process, so it is necessary to use the most complete program package or software. Esprit is the ideal choice, because it is a CAD/CAM software in which it is possible to draw, model, program, and finally generate G-code for any machine tool. It is a very powerful, high-performance tool with a full spectrum of programming systems for milling, turning, drilling, etc. This paper will cover the milling programming process and show some of the most used options offered by Esprit. One of important features of this software is the realistic simulation of the process itself on the machine, what bears significance in the machining process, especially in milling on five-axis machines.

1. UVOD

Esprit je softver koji omogućuje programiranje, simulaciju i automatski generiran G-kod za bilo koju klasu CNC alatnih mašina, uključujući horizontalne, vertikalne i portalne mašine. Izgrađen kroz 38 godina inovacija, danas je jedan od najboljih CAM programa. DP tehnologija Esprit je moćan sistem za CNC programiranje, simulaciju, kao i optimizaciju izrade tehnoloških procesa. Podržava cijeli proces proizvodnje od CAD datoteke do obrađenog dijela. Ovaj program je u potpunosti uskladen s industrijskim standardima i omogućuje simulaciju procesa obrade u stvarnom vremenu. Sve te karakteristike su se kroz dugi niz inovacija razvijale i još uvijek se razvijaju i upotpunjaju [1]. Ovaj program je veoma lako instalirati uz odgovarajuću licencu i odredene karakteristike koje računar mora posjedovati da bi instalacija bila moguća, a te karakteristike su radna memorija od 1 GB RAM-a, slobodni prostor na hard disku od 2 GB i procesor Intel Dual Core [2].

1. INTRODUCTION

Esprit is software that enables programming, simulation and automatically generated G-code for any class of CNC machine tools including horizontal, vertical and gantry machines. Software built through 38 years of innovation is one of the best CAM programs today. DP technology Esprit is a powerful system for CNC programming, simulation and optimization of technological processes. It supports the entire production process from the CAD file to the machined part. This program is fully compliant with industry standards and allows simulation of the machining process in real time. All these characteristics have been developed through a long series of innovations and are still being developed and completed [1]. This program is very easy to install with the appropriate license and certain characteristics that the computer must have in order for installation to be possible, and these characteristics are a working memory of 1 GB of RAM, free space on the hard disk of 2 GB, and an Intel Dual Core processor [2].

2. RADNI PROSTOR ESPRITA

Podešavanje radnog prostora Esprita je subjektivan izbor, što se tiče samog izgleda i postavljanja alatnih traka, ali postoje obavezne alatne trake koje se koriste pri izradi tehnološkog procesa odnosno pri programiranju komada koji će biti izrađeni na CNC mašinama. Prije samog definiranja alatnih traka i prečaca, koji će se koristiti tokom programiranja, potrebno je na računaru spremiti odgovarajuće postprocesore koji će služiti za kreiranje NC koda, te *template* mašine, koja se nalazi u proizvodnji, da bi se pri programiranju dobio stvarni izgled mašine i komada koji će se obradivati na toj mašini. Današnji CAM sistemi za izradu NC programa moraju imati definiran postprocesor koji se izrađuje za svaki alatni stroj zasebno. Postprocesor ima funkciju pretvaranja CL (engl. *Cutter location file*) u NC datoteku u obliku G-koda. Tako prilagođen program se pohranjuje u bazu podataka CAD/CAM sistema i po potrebi se koristi.

2.1 Kreiranje alatnih traka, steznih naprava i alata

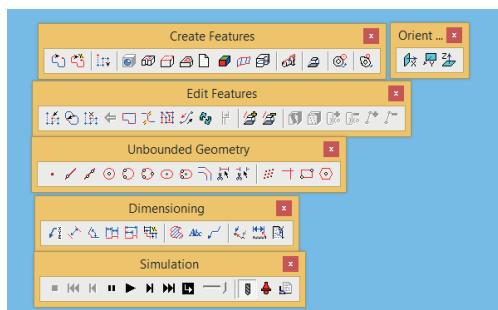
Espritov grafički interfejs dopušta brz i lak pristup komandama s potrebom definiranja maksimalnog područja za rad. Da bi se moglo brzo i efikasno programirati, potrebno je pozvati odnosno kreirati određene prečace koji će ubrzati sâm proces programiranja. Sva podešavanja se odvijaju pomoću glavne alatne trake. Izbor alatnih traka je velik i treba se ograničiti na određeni broj alatnih traka koje će se najčešće koristiti, tako da izgled radnog prostora ostane pregledan i lako upotrebljiv, slika 1. Alatne trake i postavke radnog područja se vrše s pretpostavkom da su sve prethodne postavke odradene, a koje se tiču prethodno spomenutih postprocesa i uzoraka različitih mašina koje se posjeduju u proizvodnom pogonu. Osnovna podešavanja jesu dijelovi mašine, kao npr. okvir mašine, radni stol, broj osovina mašina, revoler itd. Među prvim podešavanjima je definiranje radnog prostora mašine odnosno mesta na mašini gdje će se obradak uvijek nalaziti kada se pozove u program. To je bitna postavka, jer se tako dobija stvarna preglednost mašine i obratka, te se lako uoči ako je obradak veći od mašine.

2. ESPRIT WORKSPACE

Adjusting the Esprit workspace is a subjective choice as far as the appearance and placement of toolbars are concerned, but there are mandatory toolbars that are used when creating a technological process, i.e. when programming pieces that will be made on CNC machines. Before defining the toolbars and shortcuts that will be used during programming, it is necessary to save the appropriate post-processors on the computer that will be used to create the NC code, and the machine template, that is in production, in order to get the actual appearance of the machine and the pieces that will be processed on that machine. Today's CAM systems for creating NC programs must have a defined postprocessor that is created for each machine tool separately. The post-processor has the function of converting the CL (Cutter location file) into an NC file in the form of G-code. Such a customized program is stored in the database of the CAD/CAM system and used as needed.

2.1 Creation of toolbars, clamps and tools

Esprit's graphical interface allows quick and easy access to commands, but it is needed to define the maximum area for work. In order to be able to program quickly and efficiently, it is necessary to call or create certain shortcuts that will speed up the programming process itself. All adjustments are made using the main toolbar. The selection of toolbars is large and should be limited to a certain number of toolbars that will be used most often, so that the appearance of the workspace remains clear and easy to use, Figure 1. Toolbars and work area settings are made with the assumption that all previous settings have been done, which concern the previously mentioned post-processes and samples of the different machines that are owned in the production plant. The basic settings are the parts of the machine, such as the machine frame, work table, number of machine axes, turret, etc. Among the first settings, the working area of the machine is defined, i.e. the place on the machine where the workpiece will always be when it is called into the program. This is an important setting because this way you get a real view of the machine and the workpiece, and it is easy to see if the workpiece is bigger than the machine.



Slika 1. Često korištene alatne trake
Figure 1 Commonly used toolbars

Također, definira se i prozor koji sadrži glavni XYZ koordinatni sistem s pripadajućim operacijama, karticama pripadajućih alata te redoslijedom operacija. U tom prozoru postoje i detaljne informacije o svakoj operaciji koja se odabere te vrijednosti koordinata i vremena trajanja operacija. Pored osnovnih prozora kreiraju se i pomoći prozori sa slojevima (engl. *layers*) koji se mogu kreirati, uključivati i isključivati prema potrebi i broju operacija i geometriji koju posjeduje komad. Oni olakšavaju programiranje, jer program postaje pregledniji i jasno organiziran. Jedan od pomoći prozora jeste i prozor maske koji omoguće prikazivanje i sakrivanje nacrte geometrije, linija, putanje alata, 3D modela, krivulja, ploha, koordinatnih sistema itd. Za bolju preglednost u toku programiranja Esprit nudi i podešavanje boja radnog prostora i svega onoga što se selektira tokom rada. Tako je moguće odabrati različite boje komada, kao i boju za određene površine komada da se lakše prepoznaju kad se selektiraju. Dodatno, mogu se definirati boje prema alatima koji rade tako da su različite boje pri procesu grubog glodanja i finog glodanja. Kreiranje steznih naprava je izrazito bitan postupak kada se komadi rade na steznim napravama, jer se tako pri simulaciji programa može uočiti eventualni sudar stezne naprave i alata odnosno sudar sa bilo kojim dijelom u mašini. To je izuzetno bitno kod procesa glodanja na petosnim mašinama, gdje su u pitanju simultana kretanja stola i alata. Stezne naprave je moguće kreirati u SOLID-u ili drugom CAD programu, te ih kao takve uvesti u Esprit. Kreiranje alata je jako olakšano u Espritu, jer program pruža jasan izgled alata i svih dimenzija alata, koje se unose prema kataloškim karakteristikama i mogućnostima alata, ili ako su u pitanju specijalni alati, onda prema kreiranim dimenzijama alata.

A window is also defined that contains the main XYZ coordinate system with associated operations, tabs of associated tools, and the order of operations. In that window, there is also detailed information about each operation that is selected, as well as the coordinate values and duration of the operations. In addition to the basic windows, auxiliary windows with layers are created, which can be created, turned on and off according to the need and the number of operations and the geometry of the piece. They make programming easier because the program becomes more transparent and clearly organized. One of the auxiliary windows is the mask window, which allows the operator to display and hide the design geometry, lines, tool paths, 3D models, curves, surfaces, coordinate systems, etc. For better visibility during programming, Esprit also offers adjustment of the colors of the workspace and everything else needed during operation. So it is possible to choose different colors for the piece, and also the color of a certain surface of the piece can be selected to make it easier to recognize it when selected. The operator can also define colors according to the tools that work, so tools can be of one color during the process of rough milling and of other during fine milling. The creation of clamping devices is an extremely important procedure when pieces are worked on clamping devices, because during the simulation of the program it is possible to observe a possible collision between the clamping device and the tool, i.e. a collision with any part of the machine. This is especially important in the milling process on five-axis machines where simultaneous movements of the table and tool are involved. Clamping devices can be created in SOLID or any other CAD program, and imported as such into Esprit. Tool creation is greatly facilitated in Esprit because this program provides a clear view of the tool and all tool dimensions that

3. OBRADA GLODANJIEM UPOTREBOM ESPRITA

Glodanje je nakon tokarenja najvažniji postupak obrade metala skidanjem strugotine. Značajan broj radova ukazuje na aktuelnost istraživanja i optimizacije tehnologije, sistema, alata, softverskih aplikacija, upravljanja podacima itd. [3-5]. To je postupak obrade skidanjem čestica kod kojeg alat obavlja glavno kretanje. Obavlja se alatima s više jednakih oštrica ili sa sastavljenim alatima. Prema tome, glodanje je složenija operacija od tokarenja ili bušenja. Glodanje se može podijeliti prema različitim kriterijima, slika 2.:

- prema proizvedenom kvalitetu obrađene površine (grubo glodanje, završno glodanje, fino glodanje) i
- prema položaju reznih oštrica na glodalu (obodno i čeono) [6].

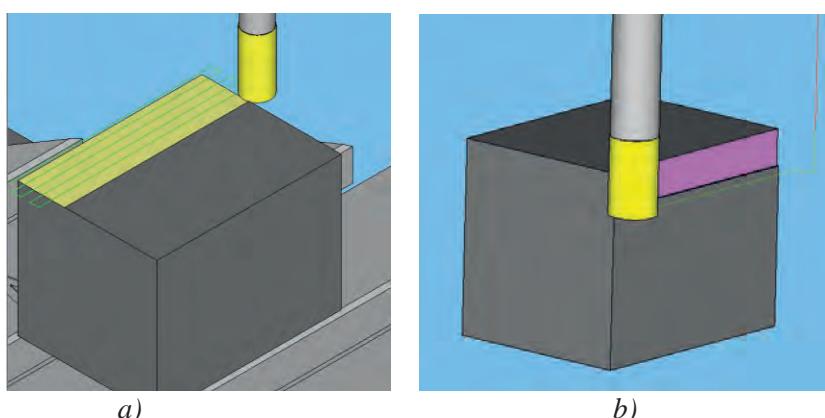
Programiranje obrade glodanjem u EPSRIT-u bit će predstavljano na jednom komadu, materijala En Aw 5083 (legura aluminija sa magnezijom i tragovima mangana i kroma). Komad će se raditi na petosnoj Haasovoj mašini UMC 750 i bit će stegnut u pakne LANG, jer je komad manjih dimenzija, stoga će se raditi u steznom uređaju.

are entered according to the catalog characteristics and capabilities of the tool or, if it is a question of special tools, then according to the created dimensions of the tool.

3. MILLING OPERATION USING ESPRIT

After turning, milling is the most important metal processing procedure by removing chips. A significant number of papers indicate the relevance of research and optimization of technology, systems, tools, software applications, data management, etc. [3-5]. It is a machining process by removing particles where the tool performs the main movement. It is performed with tools with several equal blades or with assembled tools. Therefore, milling is a more complex operation than turning or drilling. Milling can be divided according to different criteria, Figure 2:

- according to the produced quality of the processed surface: rough milling, final milling, fine milling,
- according to the position of the cutting blades on the milling cutter: contour and face milling [6].

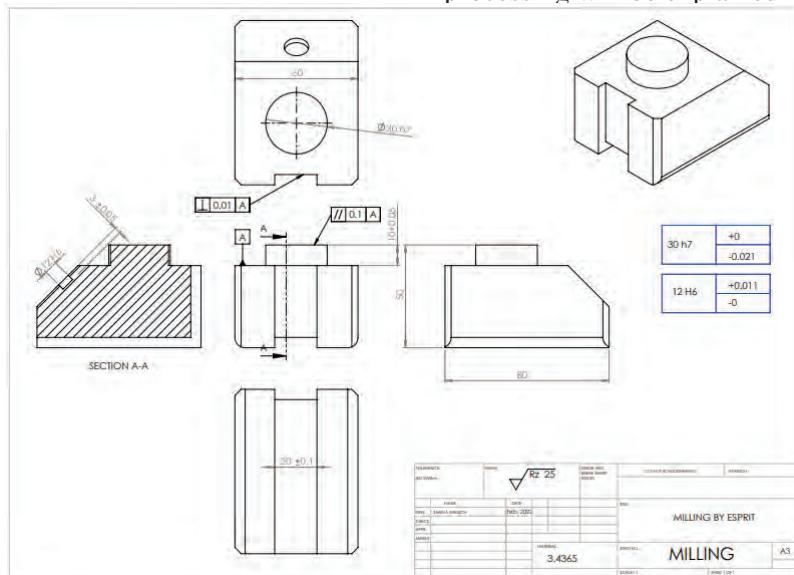


Slika 2. Vrste glodanja: a) čeono b) obodno
Figure 2 Milling types: a) face milling b) contouring

Da bi se uspješno programirao komad u Espritu, potrebno je najprije definirati sve alate odnosno glodala koja će se koristiti. To su u većini slučajeva standardni alati koje mašine posjeduju. U nastavku će biti objašnjene mogućnosti Esprita pri obradi glodanjem.

Milling programming in Esprit will be presented on a single piece, material En Aw 5083 (an alloy of aluminum with magnesium and traces of manganese and chromium), and the piece will be worked on a five-axis Haas machine UMC 750, and the piece will be clamped in LANG pads, because the piece is of small dimensions and will, therefore, be worked on in a clamping device. In order to successfully program a piece in Esprit, it is necessary to define all the tools or milling cutters that will be used, in most cases they are

standard tools that are available on machines. Therefore, only Esprit's options for milling processing will be explained further.

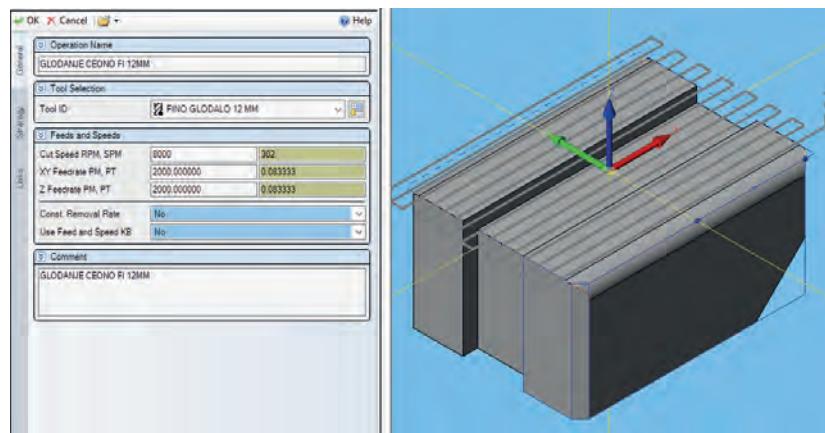


Slika 3. Komad za glodanje

Figure 3 Milling peace

Komad se radi na steznom uređaju, pa će prema tome komad biti urađen u dvije obrade. U prvoj obradi će biti odrđeno čeonog glodanja, te glodanje kontura, ivica i kanala na komadu, slike 3. i 4.

The piece is positioned in clamping device and, therefore, two operations will be applied. During the first one, face milling will be performed, as well as contour, edge and channel milling on the piece, Figures 3 and 4.

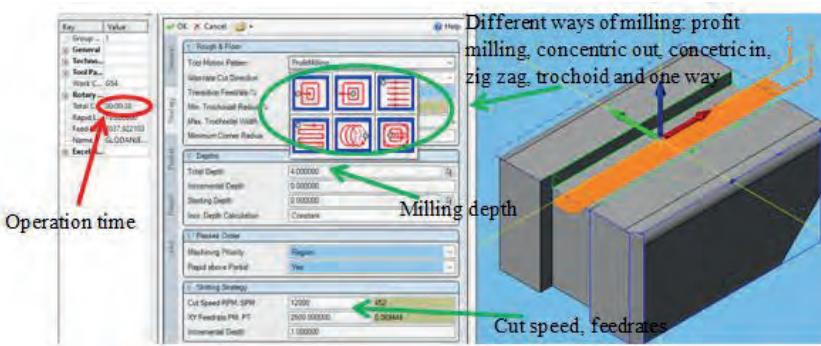


Slika 4. Čeono glodanje

Figure 4 Face milling

Ovaj program daje jasan prikaz operacija, identičan onome kako će se vršiti na mašini. U programu se podešavaju režimi obrade prema standardnim izrazima za izračunavanje tih vrijednosti ili iskustveno prema onome kako se odvija u proizvodnji. Kod obodnog glodanja i glodanja kanala na komadu, ovaj program nudi dosta mogućnosti kako bi se postigli najbolji rezultati i optimiziralo vrijeme izrade, a alat najbolje iskoristio.

This program provides a clear representation of operations identical to what will be performed on the machine. In the program, processing regimes are adjusted according to standard expressions for calculating these values or empirically according to what happens in production. For contour milling and channel milling on a piece, this program offers a lot of options to achieve the best results and optimize the production time, and make the best use of the tool.



Slika 5. Žlijebljjenje u softveru Esprit
Figure 5 Pocketing in Esprit software

Prostor glodanja se kreira ručno ili automatski, zavisno od toga koristi li se 3D ili 2D model, te ovisi o tome koliko je otvor na komadu pristupačan. Kod ručnog kreiranja *Chain-a*, potrebno je crtanje graničnih linija odnosno prostora koji će alat glodati. Potrebno je jasno definirati smjer glodanja, a to se može korigovati i jasno definirati u traci *Edit Features*. Ova traka nudi opcije promjene smjera, promjenu početka kretanja alata, a pored toga na tom *Chain-u* se može definirati je li on otvoren ili zatvoren. To automatski olakšava kretanje alata, jer alat ima otvoren prostor za početak i ne mora započeti svoje kretanje u punom materijalu. Kod korištenja 3D modela kreiranje otvora je uveliko olakšano, jer je na taj način moguće automatski prepoznati dijelove komada koje je potrebno glodati i nije potrebno ručno crtanje linija. Za takav način glodanja koristi se opcija *Pocket*, koja omogućuje automatsko kreiranje *Feature* džepa, slika 5. Kreira se tako što se označi površina gdje se taj džep nalazi i ta opcija odmah prepozna radi li se o otvorenom ili zatvorenom džepu. Kod odabira načina kretanja glodala mogu se odabrati *Profit Milling*, *Concentric In*, *Concentric Out*, *Zig Zag*, *One Way*. Opcija *Concentric In* znači da će alat glodati džep od ivica džepa prema centru. Ako u odabranom džepu postoji neko ostrvo koje ne bi trebalo biti odglodano, tada se to definira kao zatvoreni *Island Features* i glodalo će ga pri obradi zaobilaziti. Ako ne postoji nikakav oblik prepreke, glodalo će obraditi cijeli označeni džep, bilo da je označen kao *Pocket* ili kao *Chain*. *Concentric Out* je operacija kod koje će se glodalo kretati od centra prema ivici džepa. *One Way* znači da se alat kreće samo u jednom smjeru, dok opcija *Zig Zag* znači da će se kretati naizmjenično u oba smjera. Opcija *Profit Milling* se koristi kod otvorenih i zatvorenih džepova, i to kada je potrebna maksimalna iskorištenost alata. U ovom slučaju alat glodi sa svojom ukupnom dužinom u jednom prolazu zbog manjeg opterećenja na alat.

The milling space is created manually or automatically depending on whether a 3D or 2D model is used, and it depends on how accessible the opening on the piece is. When manually creating a *Chain*, it is necessary to draw boundary lines, that is, the space that the tool will mill. It is necessary to clearly define the milling direction, and this can be corrected and clearly defined in the *Edit Features* bar. This bar offers options for changing the direction, changing the start of the tool's movement, and in addition, it can be defined on that *Chain* whether it is open or closed. This automatically makes tool movement easier, because the tool has an open space to start and does not have to start its movement in full material. When using a 3D model, the creation of openings is greatly facilitated, because in this way it is possible to automatically recognize the parts of the piece that need to be milled, and manual drawing of lines is not required. For this type of milling, the *Pocket* option is used, which enables the automatic creation of a *Feature* pocket, Figure 5. It is created by marking the surface where that pocket is located and this option immediately recognizes whether it is an open or closed pocket. When choosing the way of movement of the milling cutter, the operator can choose *Profit Milling*, *Concentric In*, *Concentric Out*, *Zig Zag*, *One way*. The *Concentric In* option means that the tool will mill the pocket from the edges of the pocket towards the center, if there is an 'island' in the selected pocket that should not be milled, then it is defined as closed *Island Features* and the router will bypass it during processing. If there is no obstruction of any kind, the router will machine the entire marked pocket whether it is marked as *Pocket* or as *Chain*. *Concentric Out* is an operation where the milling cutter will move from the center towards the edge of the pocket.

Kod svih ovih opcija dodatno je potrebno definirati ulaz glodala, što je jako bitno, jer ako je nepravilan ulaz glodala, najčešći ishod jeste pucanje alata. Pri odabiru džepa (*Pocket*) postoji prozor naziva *Entry/Exit*, što zapravo označava mjesto u kojem se namješta ulaz i izlaz alata, pa je ponuđeno nekoliko opcija: *Plunge*, *Plunge at Point*, *Ramp along pass*, *Ramp contained*, *Helical contained* i *Helical at Point*. Opcija *Plunge* znači da alat ulazi u materijal po z osi, a *Plunge at Point* znači da će alat ulaziti u materijal u jasno definiranoj tački. To je najčešće rupa koja je većeg promjera od promjera glodala, tako da glodalo može nesmetano ući u tu rupu, a ne u materijal, dok ostale opcije dopuštaju ulaz glodalju spiralno pod uglom. Operaciju glodanja konture moguće je pozvati automatski, ako je uvezen 3D model, i to tako što se mišem označi odgovarajuća površina i pozove se opcija *Wall* u alatnoj traci *Create Features*. Kada se pozove opcija *Wall*, program kreira u stablu operacija *Profile*, na koji se zatim poziva grubo i fino glodalo koje će obrađivati označenu površinu. Ako nije stvorena baza operacija obrada, konture se mogu kreirati koristeći opciju *Machining* i *Contouring*. Za obrade za koje se ne posjeduje odgovarajuće glodalo, najčešće su to u pitanju prevelika skošenja ivica ili zaobljenja, bilo konkavna ili konveksna, kroz Esprit se može odabrati opcija 3D glodanja, koja dopušta samo da se obrađuje taj specifični dio komada. Za bilo kakav oblik 3D glodanja poziva se traka *SolidMill Mold*, koja nudi mnogo opcija glodanja i kretanja alata, a najčešće korištena jeste *Between Curves Finishing* - završna obrada između krivulja. Da bi takav način obrade funkcirao, definiraju se *Chain*-ovi, gornji i donji, koji zapravo određuje kretanje alata. Nakon njihovog kreiranja, poziva se navedena opcija i u prvom dijelu prozora, koji se naziva *Part*, označi se onaj dio koji će se obrađivati, dok se u drugom dijelu, naziva *Check*, označi onaj dio koji alat ne smije obrađivati. Pored navedenih mogućnosti Esprit nudi još mnogo opcija koje se koriste u zavisnosti od toga kakav komad se obrađuje. Nakon definiranja prve i druge obrade generira se 'kod', koji se na jednostavan način iz programa prebací na mašinu i kao takav je spreman za upotrebu.

One way means that the tool moves in one direction only, while the Zig Zag option means that it will move alternately in both directions. The Profit Milling option is used for open and closed pockets, and when maximum utilization of the tool is required. In this case, the tool mills with its total length in one pass due to less load on the tool.

With all these options, it is additionally necessary to define the entry of the milling cutter, which is very important, because if the entry of the milling cutter is incorrect, the most common outcome is tool breakage. When selecting Pocket, there is a window called Entry/Exit, which actually indicates the place where the entry and exit of the tool is set, so several options are offered. These options are: Plunge, Plunge at Point, Ramp along pass, Ramp contained, Helical contained and Helical at Point. The Plunge option means that the tool enters the material along the z axis, and the Plunge at Point means that the tool will enter the material at a clearly defined point. This is most often a hole with a larger diameter than the diameter of the router, so that the router can enter the hole (without hindrance), and not into the material, while the other options allow the router to enter spirally at an angle. The contour milling operation can be called automatically if a 3D model has been imported by selecting the appropriate surface, with the mouse and calling the Wall option in the Create Features toolbar. When the Wall option is called, a program creates a Profile in the operation tree, upon which is then called a rough and fine milling tool to process the marked surface. If the operation base has not been created, contour processing can be created using the Machining and Contouring options. For all pieces for which a suitable milling machine is not available, most often the issues are excessive chamfering of edges or rounding, whether concave or convex, through Esprit can be selected the 3D milling option that allows only that specific part of the piece to be processed. For any form of 3D milling, the SolidMill Mold bar is called, which offers many milling and tool movement options, and the most commonly used is Between Curves Finishing. In order for this method of processing to work, Chain's top and bottom are defined, which actually determines the movement of the tool. After creating the chains, the specified option is called, where in the first part of the window, called Part, the part that will be processed is marked, while in the second part,

4. ZAKLJUČAK

Savremene tehnologije obrade na CNC obradnim sistemima zahtijevaju profesionalno upravljanje cjelokupnim procesom, jer u suprotnom može doći do značajnih materijalnih oštećenja, kao i vremenskih gubitaka i zastoja u proizvodnji, što dovodi do probijanja rokova isporuke. Upravljanje savremenim zahtjevima CNC obrade korištenjem CAD/CAM sistema učinjen je značajan napredak, jer se može izvršiti kompletan simulacija obrade. Također, upravljačke jedinice CNC mašina daju mogućnost simulacije putanje alata. Ako su definirani svi parametri simulacije u CAD/CAM sistemu, to je dovoljno, a u toku same proizvodnje potrebno je osigurati odgovarajući broj kontrola obradaka i nadzor nad CNC proizvodnim sistemom.

Upravo Esprit predstavlja jedan od odličnih primjera softverskog CAD/CAM sistemski aplikativnog rješenja, jer nudi potpunu simulaciju onoga što se radi na mašini, te u procesu obrade glodanja ima veliki spektar definiranja parametara alata i načina obrade.

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called Check, the part that the tool must not process is marked. In addition to the above options, Esprit offers many more options that are used depending on the type of piece being processed. After defining the first and second operation, a 'code' is generated which is easily transferred from the program to the machine and as such is ready for use.

4. CONCLUSION

Modern processing technologies on CNC processing systems require professional management of the entire process, because otherwise there can be significant material damage, as well as time losses and stoppages in production, which leads to breaking delivery deadlines. Management of modern requirements of CNC processing using the CAD/CAM system has made significant progress, because a complete processing simulation can be performed. Also, control units of CNC machines provide the possibility of simulating the path of the tool. If all the simulation parameters are defined in the CAD/CAM system, that is enough, and during the actual production, it is necessary to ensure the appropriate number of workpiece controls and supervision of the CNC production systems.

Therefore, Esprit represents one of the excellent examples of a software CAD/CAM system application solution, because it offers a complete simulation of what is done on the machine, and in the milling process it has a wide range of defining tool parameters and processing methods.

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3D DIGITALIZACIJA I ŠTAMPANJE SKULPTURE IZ NACIONALNOG SPOMENIKA „SMRIKE”

3D DIGITALIZATION AND PRINTING OF A SCULPTURE FROM SMRIKE NATIONAL MONUMENT

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REZIME

3D skeniranje i 3D štampanje sve više pronađeni primjenu u digitalizaciji, prezentaciji i izradi replika različitih umjetničkih dijela. U radu su mogućnosti ovih tehnologija predstavljene na primjeru odabrane skulpture iz nacionalnog spomenika „Smrike“.

Primjenom ručnog 3D skenera napravljen je poligonalni 3D model skulpture. Koristeći dobiveni 3D model, FDM tehnologijom 3D štampanja izrađeno je dvanaest umanjenih replika skulpture. Navedeni su i opisani različiti tehnički detalji i parametri, kao i obrada u različitim softverima.

Stručni rad

Professional paper

SUMMARY

3D scanning and 3D printing finds more and more application in digitalization, presentation and replicas making of different artworks. In this paper the capabilities of these technologies are represented on the example of a selected sculpture from Smrike national monument.

Polygonal 3D model of the sculpture is made by using a manual 3D scanner. Using the obtained 3D model, twelve scaled-down replicas of the sculpture are made by FDM 3D print technology. Different technical details and parameters, as well as processing in different software are presented and described.

1. UVOD

Tehnološki razvoj i digitalizacija doveli su do novih mogućnosti u diseminaciji umjetničkih djela, arheoloških artefakata i drugih objekata od interesa javnosti. Različite metode 3D skeniranja široko se primjenjuju za 3D digitalizaciju različitih skulptura, građevina, spomenika, artefakata i slično [1,2]. Ovaj pristup omogućuje drugačiji i novi način doživljaja i promatranja ovih djela i objekata, koji je u nekim aspektima čak i kvalitetniji od klasičnog direktnog promatranja [3].

Paralelni razvoj tehnologija 3D štampanja omogućio je i relativno jednostavnu i kvalitetnu izradu replikâ ovih 3D digitaliziranih objekata [4,5].

1. INTRODUCTION

Technological advancements and digitalisation lead to new possibilities in dissemination of artworks, archaeological artefacts and other objects of public interest. Different 3D scanning methods are widely used for 3D digitalization of various sculptures, buildings, monuments, artefacts, and the like [1,2]. This approach enables different and new way of experience and observation of these works and objects, even in some aspects of more quality than the classical direct observation [3].

Parallel development of 3D printing technologies enabled also relatively simple and good quality production of replicas of these 3D digitalised objects [4,5].

U ovom radu su ove mogućnosti prikazane na primjeru jedne od skulptura iz nacionalnog spomenika „Smrike“, koji se nalazi u okolini Novog Travnika, Bosna i Hercegovina. Nacionalni spomenik „Smrike“ u Novom Travniku je nekropolja podignuta 1975. godine u spomen na 700 žrtava fašističkog terora iz 1941. godine. Spomenik je izведен prema projektu arhitekte Bogdana Bogdanovića, jednoga od najvećih regionalnih graditelja memorijalne arhitekture. U okviru spomenika je postavljeno dvanaest skulptura u nepravilno raspoređenim parovima. Skulpture predstavljaju dvanaest vojnika – stražara, koji zauvijek treba da ostanu na tom mjestu, širom otvorenih očiju. Oni su čuvari nedužnih, na straži sa zadatkom da spriječe stradanje. U septembru 2021. je završena je i restauracija ovog spomenika, koju ju provela Općina Novi Travnik.

These possibilities are presented in this paper on the example of one of the sculptures from Smrike national monument, located in the vicinity of Novi Travnik, Bosnia and Herzegovina. Smrike national monument in Novi Travnik is necropolis, built in 1975 to commemorate 700 victims of fascism terror in 1941. The monument is built according to the design of architect Bojan Bogdanovic, who was one of the greatest regional builders of memorial architecture. The monument consists of twelve sculptures placed in irregularly arranged pairs. The sculptures represent twelve soldiers – guards, who are supposed to stay for ever on that place, with eyes wide open. In September 2021, the restoration of this monument was finished, implemented by the Municipality of Novi Travnik.



Slika 1. Nacionalni spomenik „Smrike“

Figure 1 Smrike national monument

2. 3D SKENIRANJE SKULPTURE

Za 3D skeniranje je odabrana jedna od 12 skulptura iz spomenika, na osnovu najpovoljnijeg položaja i samog stanja i izgleda. Skeniranje odabrane skulpture je obavljeno pomoću ručnog 3D skenera Artec Eva (slika 1.) [6], spojenog na laptop sa softverom proizvođača, Artec Studio 16 Professional [7]. Skener Artec Eva radi na principu struktuiranog svjetla i namijenjen je za skeniranje objekata srednje i velike veličine. Radno rastojanje 3D skenera od objekta je od 0,4 do 1 m, s vidnim poljima od 214x148 mm (minimalno rastojanje) do 536x372 mm (maksimalno rastojanje). Proizvođač deklarira tačnost od 0,1 mm i rezoluciju od 0,2 mm. Model 3D skenera koji je korišten nije imao bateriju za napajanje, te je za rad skenera korišten benzinski agregat.

2. 3D SCANNING OF A SCULPTURE

One of the twelve sculptures from the monument is selected for 3D scanning, based on its optimal position and its condition and appearance. The scanning of the selected sculpture is conducted by using manual 3D scanner Artec Eva (Figure 1) [6], connected to a notebook with manufacturer's software Artec Studio 16 Professional [7]. Artec Eva scanner operates on structured light principle, and it is intended for scanning middle and large size objects. Working distance of 3D scanner from the object is from 0,4 up to 1m, with fields of view from 214x148 mm (minimal distance) up to 536x372 mm (maximal distance). The manufacturer declares accuracy of 0,1 mm and resolution of 0,2 mm. Used model of 3D scanner did not have power feeding battery, so for the scanner's operation a petrol generator was used.

Kako bi se pokrila cijela površina objekta napravljeno je 27 skenova skulpture u 4 odvojena Artec Studio dokumenta, ukupne veličine 11,1 GB. Skenovi su oblaci registriranih tačaka na objektu koje je potrebno naknadno obraditi. Skenovi su pravljeni tako da im se površine međusobno preklapaju, kako bi u naknadnoj obradi imali dovoljno zajedničkih površina (tačaka) za poravnavanje. Tokom skeniranja objekta bilo je moguće skenirati samo površine koje nisu izložene direktnom sunčevom svjetlu (slika 2.). Također, niti okular skenera nije mogao biti izložen direktnom sunčevom svjetlu. Cijelo skeniranje je obavljeno u jednom danu, tako da su tokom dana skenirane površine u hladovini (korištena je i tenda za zaklanjanje od sunčeve svjetlosti), a ostatak površina, koji nije bilo moguće skenirati tokom dana, skeniran je po zalasku sunca, u predvečerje.



Slika 2. Skener Artec Eva 3D
Figure 2 Artec Eva 3D scanner

3. OBRADA 3D SKENOVA I KREIRANJE 3D MODELA

Proces obrade skenova i kreiranje poligonalnog 3D modela (dokument u formatu STL), koji je korišten za 3D štampanje, shematski je prikazan na slici 4. U ovom su procesu primijenjena tri komercijalna softvera. Prva faza obrade je obavljena u softveru proizvođača 3D skenera, *Artec Studio Professional*. Prvo je sa svih skenova uklonjena pozadina koja je snimljena zajedno sa skulpturom. Zatim su svi skenovi „uvezeni“ (objedinjeni) u jedan dokument (slika 5.a).

In order to cover all of the object surface, 27 scans of the sculpture are made in 4 separate Artec Studio files, with total size of 11,1 GB. The scans are clouds of points registered of the object that require postprocessing. The scans are made in a way that surfaces overlap, so there would be enough common surfaces for alignment in postprocessing. During the scanning it was possible only to scan the surfaces not directly exposed to the sunlight (Figure 2). Also, the scanner lenses could not be exposed to the direct sunlight. A whole scanning process was done in a day, in a way that during the day surfaces in a shade were scanned (an awning was used as a sun shelter), and the remaining surfaces, that could not be scanned during the day, were scanned after sundown, in the early evening.

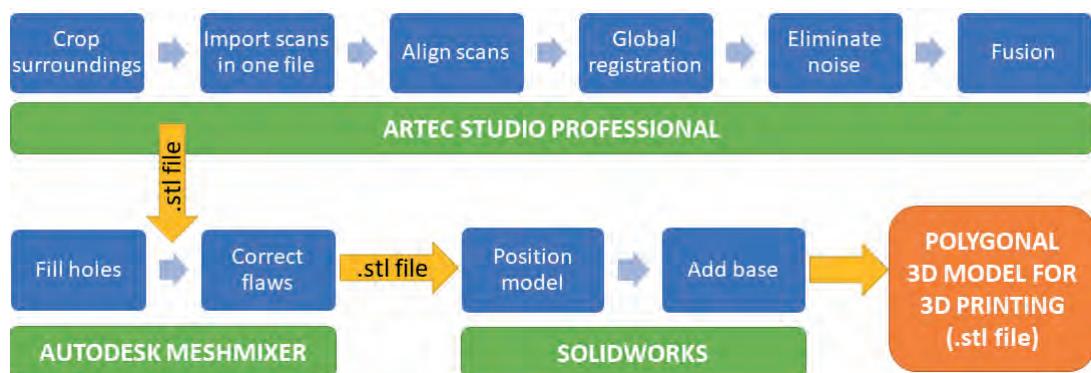


Slika 3. 3D skeniranje površine skulpture u hladovini skenerom Artec Eva

Figure 3 3D scanning of sculpture surface in the shade with Artec Eva scanner

3. EDITING OF 3D SCANS AND CREATING 3D MODEL

The process of scans editing and creating polygonal 3D model (an STL file format), used for 3D printing, is schematically presented in Figure 4. In the process, three commercial software were implemented. The first stage was accomplished in the 3D scanner manufacturer's software, Artec Studio Professional. First, the background, recorded together with the sculpture, was removed from the scans. Then, all the scans were imported in one file (Figure 5a).



Slika 4. Proces obrade skenova i kreiranja 3D modela za štampanje
Figure 4 Process of scans editing and creating the 3D model for printing



Slika 5. Artec Studio - obrada, neporavnati (a) i poravnati (b) 3D skenovi
Figure 5 Artec Studio - editing, unaligned (a) and aligned (b) 3D scans

Poravnavanje svih skenova je napravljenom pomoću algoritma za automatsko poravnavanje u softveru. Poravnavanje nije napravljeno za sve skene zajedno, nego su se pojedinačno dodavali i poravnivali skenovi, pri čemu je na početku jedan odabran kao bazni. Prilikom ovog procesa, kod svakog sljedećeg poravnavanja i dodavanja novog skena pazilo se da novi sken, koji se poravnava, ima dovoljno preklapajućih površina s već poravnatim skenovima. Prije dalje obrade skenova, svi su umanjeni na odabranu veličinu za 3D štampanje. Nakon što su svi skenovi poravnati (slika 5.b), napravljena je globalna registracija, proces koji optimira relativne pozicije skenova u zajedničkom koordinatnom sistemu. U algoritmu za globalnu registraciju su korišteni preporučeni parametri u softveru.

Alignment of all scans was made by using the option for the automatic alignment in the software. The alignment was not done for all the scans at once, but the scans were added and aligned separately, where one scan was selected as the base one at the beginning. During this process, for every next adding and aligning of a scan, it was taken care of the new scan to be aligned to have enough overlapping surfaces with the already aligned scans. Before any additional processing of the scans, all of them were scaled-down to the selected size for 3D printing. After all the scans were aligned, global registration was made, a process which optimise relative positions of all scans in a common coordinate system. Software default values were applied in the global registration algorithm.

Objedinjavanje skenova i izrada površinskog poligonalnog modela u formatu STL urađena pomoću *fusion* algoritma. Ovaj algoritam stapa i fiksira sve skenove. Primijenjena je opcija *sharp fusion*, pri kojoj se zadržavaju sitni detalji i kreiraju oštire ivice, bez zagladivanja, kako bi se dobio model koji što više odgovara originalnoj skulpturi. Nije upotrijebljena funkcija popunjavanja otvora, te u ovoj fazi nije kreiran potpuno zatvoren model koji bi se mogao koristit za 3D štampanje. Popunjavanje otvora i još neke dodatne korekcije su napravljene u sljedećim fazama, pomoću softvera Autodesk *Meshmixer* [8] i *Solidworks* [9]. Za popunjavanje otvora na površini modela je primijenjen automatski algoritam softvera Autodesk *Meshmixer*, koji na osnovu oblika okolnih površina i ivica zatvara otvore. Ovdje su upotrijebljene i alatke za uređivanje površine modela, kojim su otklonjene uočene nepravilnosti na površini modela (slika 6.). Konačna priprema modela za 3D štampanje je napravljena u softveru *Solidworks*. Uvezeni model bilo je prvo potrebno poravnati s osnovnim koordinatnim sistemom, a potom je na dnu modela dodatno izvučeno postolje na kojem stoji skulptura (slika 7.).



Slika 6. 3D model nakon obrade u softveru Meshmixer

Figure 6 3D model after editing in Meshmixer software

Unification of scans and creation of polygonal surface STL file was made with fusion algorithm. The algorithm melts and fixes all scans. The *sharp fusion* option was implemented, in which small details were preserved and sharp edges created, without smoothing, to obtain the model that resembles to the original sculpture as much as possible. Fill holes function was not used, so in this stage fully close model, that could be used for 3D printing, was not created. Holes filling and some additional corrections were made in the next stages, with Autodesk Meshmixer and Solidworks software. Automatic algorithm from Autodesk Meshmixer was implemented for holes filing, to close holes based on shape of adjacent surfaces and holes edges (Figure 6). There were also used surface editing tools to remove the observed flaws on the model surface. Final preparation of the model for 3D printing was done in Solidworks. First, it was necessary to align the imported model with the base coordinate system, and then a base on which model stands was extruded at the model bottom (Figure 7).



Slika 7. Konačni 3D model u softveru Solidworks

Figure 7 Final 3D model in Solidworks software

4. 3D ŠTAMPANJE

Za 3D štampanje replikâ skulpture korištena je tehnologija FDM (*Fused Deposition Modelling* - modeliranje topljenim depozitom) > najekonomičnija, najpristupačnija i najviše primijenjena tehnologija u posljednjim godinama. U radu su korištena dva štampača *Ultimaker 3D*: *Ultimaker S5* [10] i *Ultimaker S3* [11]. Ova dva modela imaju vrlo slične tehničke mogućnosti i karakteristike, te su pružili i vrlo sličan kvalitet izrade. Skulptura je originalne visine 2,2 m, dok je model za 3D štampanje pripremljen u visini od 12,5 cm.

Kada se radi priprema za 3D štampanje, prvo je potrebno pripremljeni 3D model uvesti u softver za štampanje. Korišten je besplatni softver proizvođača štampačâ *Ultimaker Cura* [12]. Osnovni zadatak prilikom pripreme 3D modela za 3D štampanje je njegova podjela na slojeve (slika 8.) na osnovu koje se pravi G-kod dokument (program), koji sadrži putanju kretanja mašine i druge parametre za štampanje. Kod pripreme se definiraju i različiti parametri i konfiguracija 3D štampanja, gdje se za većinu mogu primijeniti vrijednosti koje su unaprijed definirane ili se automatski proračunaju u softveru.

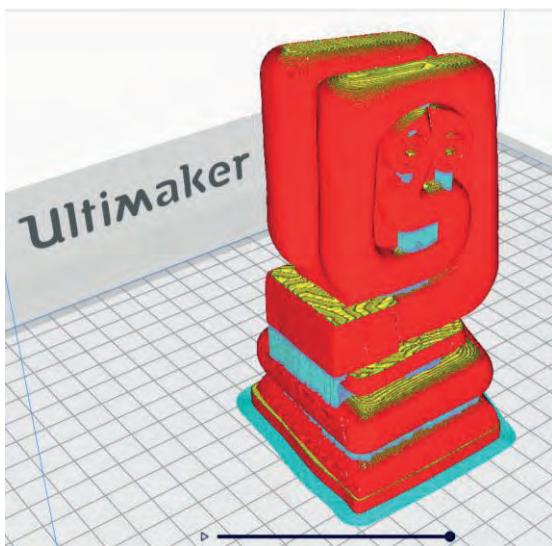
Za štampanje replikâ skulpture odabранa je debljina slojeva od 0,15 mm, s popunom unutrašnjosti modela od 10%. Ugao površine od 80° korišten je kao granična vrijednost od koje je potrebno primijeniti potpore. Ova granica za potpore je veća od preporučene, ali ipak je ostvaren zadovoljavajući kvalitet 3D štampe, a naknadna završna obrada je značajno olakšana, jer je smanjen broj potpora. Također, povećana je brzina štampanja u odnosu na preporučenu, osobito kod početnih slojeva. Ovim je smanjeno vrijeme štampanja s 12 sati (s preporučenim vrijednostima brzine) na 10 sati, uz i dalje dobar kvalitet izrade. Nakon štampanja (slika 9.) bila je potrebna ručna završna obrada modela radi otklanjanja potpora. Ovo je obavljeno uz pomoć skalpela i reznih kljišta (slika 10.). Površine na kojima su bile postavljene potpore bilo je potrebno dodatno obraditi ručnim brušenjem pomoću brusnog papira. Na slici 11. prikazan je konačni izgled replike skulpture izrađene 3D štampanjem.

4. 3D PRINTING

FDM (*Fused Deposition Modelling*) 3D printing technology was used for 3D printing of sculpture replicas: the most cost effective, available, and used technology in the last years. Two Ultimaker 3D printers were used: Ultimaker S5 [10] and Ultimaker S3 [11]. These two models have similar technical capabilities and features, hence they provide a very similar printing quality. The original sculpture height was 2,2 m, while the model prepared for 3D printing was high 12,5 cm.

When preparing for 3D printing, it is first necessary to import the prepared 3D model in the software for printing. The free software of the printer manufacturer named Ultimaker Cura [12] was used. The main task in 3D model preparation for 3D printing is slicing it into layers (Figure 8) and, based on it, a G-code file (program) will be made, containing machine trajectory and other printing parameters. Different parameters and configuration of 3D printing are defined in preparation, where for the most of them default or values automatically calculated in software can be applied.

Layers height of 0,15 mm and model inside infill of 10% was selected for the sculpture replicas printing. A surface angle of 80° was used as a limit value from which support application is necessary. This limit was greater than the recommended one, yet the appropriate quality of 3D print was achieved, and afterwards finishing process was considerably facilitated because number of supports was reduced. Also, the printing speed was increased comparing to the recommended one, especially for initial layers. Hence, the printing time was reduced from 12 hours (with recommended values for speed) to 10 hours, still with a good quality of a print. After printing (Figure 9), manual finishing was necessary to remove the supports. This was done using a precision knife and a cutting pliers (Figure 10). The surfaces on which supports were located needed additional manual grinding with grinding paper. Figure 11 shows final appearance of a sculpture replica made by 3D printing.



Slika 8. Model podijeljen na slojeve s pomoćnim strukturama u štampaču *Ultimaker Cura*

Figure 8 The sliced model with support structures in *Ultimaker Cura*



Slika 9. 3D štampanje replike skulpture

Figure 9 3D printing of a sculpture replica



Slika 10. Uklanjanje potpora s replike skulpture

Figure 10 Supports removal from a sculpture replica



Slika 11. Replika skulpture izrađena 3D štampanjem

Figure 11 A sculpture replica made by 3D printing

5. ZAKLJUČAK

3D skeniranje i 3D štampanje su savremene tehnologije koje nalaze sve širu primjenu u različitim granama ljudske djelatnosti. One nude velike moćnosti u digitalizaciji, prezentaciji i izradi replika različitih umjetničkih djela. U ovom radu je dio tih mogućnosti predstavljen na primjeru odabrane skulpture iz nacionalnog spomenika „Smrike“ u Novom Travniku.

Pomoću ručnog 3D skenera Artec Eva obavljeno je 3D skeniranje skulpture, čime je dobijeno više oblaka tačaka za različite prolaze pri skeniranju. Naknadnom obradom svi skenovi su spojeni i od njih je napravljen poligonalni 3D model (dokument u formatu STL). Ovaj 3D model je iskorišten za 3D štampanje 12 umanjenih replikâ skulpture od PLA materijala FDM tehnologijom (slika 12.). U radu je opisana provedena procedura 3D skeniranja i 3D štampanja, predstavljeni su tehnički detalji i parametri koji su primjenjeni, kao i različiti softveri koji su implementirani.

5. CONCLUSION

3D scanning and 3D printing are modern technologies that find more and more application in different fields of human activity. They offer great possibilities in digitalization, presentation and replicas making of various artworks. In this paper, a part of these possibilities is presented on an example of selected sculpture from Smrike national monument in Novi Travnik.

3D scanning of the sculpture is done by manual 3D scanner Artec Eva by which several points of clouds from different scanning runs are obtained. All scans are joined in postprocessing and polygonal 3D model (STL file) is made from them. The 3D model is used for 3D printing of 12 scaled-down replicas of sculpture from PLA material by FDM technology (Figure 12). In the paper, the conducted procedure of 3D scanning and 3D printing is described, applied technical details and parameters are presented, as well as different implemented pieces of software.



Slika 12. Dvanaest replikâ skulpture
Figure 12 Twelve sculpture replicas

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KORIŠTENJE PROGRAMA NI MULTISIM U IZVOĐENJU LABORATORIJSKIH VJEŽBI IZ ELEKTRONIČKIH SKLOPOVA I DIGITALNE ELEKTRONIKE

UTILIZING THE NI MULTISIM PROGRAM FOR THE EXECUTION OF LABORATORY EXERCISES IN ELECTRONIC CIRCUITS AND DIGITAL ELECTRONICS

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REZIME:

Konvencionalni školski laboratorijsi često su neadekvatno opremljeni u smislu potrebnog hardvera, prostora i druge pomoćne opreme za kvalitetno izvođenje vježbi iz područja koje spada u elektrotehniku. Posebni softverski proizvodi poput programa NI Multisim otklanjanju tu prepreku, te omogućuju kvalitetno savladavanje nastavnog gradiva. Ovaj članak govori o upotrebi, u srednjoškolskom obrazovanju, posebnog softverskog proizvoda NI Multisima, koji se koristi za modeliranje i simulaciju rada elektroničkih sklopova i digitalnih elektroničkih sustava. Opisani su konkretni slučajevi u izvođenju laboratorijskih vježbi iz elektroničkih sklopova i digitalne elektronike kroz koje se mogu naslutiti mogućnosti proizvoda NI Multisim. Na kraju članka predstavljeni su zaključci o obavljenom radu.

Review article

SUMMARY:

Conventional school laboratories are often inadequately equipped in terms of the necessary hardware, required space and other supporting equipment needed to guarantee the quality of laboratory exercises in the field of electrical engineering. Special software products such as NI Multisim remove many obstacles and enable better mastering of learning materials. This article discusses the use of a special software product called NI Multisim in modeling and simulating operations of electronic circuits and digital electronic circuits at the high school level. Specific cases of performing laboratory exercises on electronic circuits and digital electronics are described, what also gives a glimpse of potentials of NI Multisim. At the end of the article, conclusions about the work performed are presented.

1. UVOD

Osim teoretskog znanja o raznim elektroničkim i digitalnim skloporama bitno je i znanje koje učenici stječu kroz praktične vježbe. Ta dva oblika nastave, teoretska i praktična, treba da se međusobno nadopunjavaju i, kao jedinstvena cjelina, omoguće usvajanje znanja i vještina u skladu sa sposobnostima pojedinih učenika. Praktična nastava se obično izvodi u konvencionalnim školskim laboratorijima. Međutim, kako su oni nerijetko neadekvatno opremljeni, često se koriste posebni softverski proizvodi koji otklanjanju tu prepreku, te omogućuju kvalitetno savladavanje nastavnog gradiva.

1. INTRODUCTION

In addition to theoretical knowledge about analog and digital circuits, the knowledge that students acquire through practical exercises is also important. These two forms of teaching, theoretical and practical, should complement one other and, as a whole, enable the acquisition of knowledge and skills in accordance with the abilities of individual students.

Practical classes are usually held in conventional school laboratories; however, as they are often inadequately equipped, specialized software products are often used to remove this obstacle and allow the mastering of teaching materials at a higher level.

Na tržištu postoji nekoliko softverskih proizvoda za simulaciju rada elektroničkih sklopova i digitalnih elektroničkih sustava. Najpopularniji simulator je SPICE (*Simulation Program with Integrated Circuit Emphasis*) [1,2], osmišljen na Kalifornijskom sveučilištu u Berkeleyu u ranim 70-im godinama XX stoljeća.

NI Multisim [3,4], u nastavku teksta *Multisim*, simulator je zasnovan na SPICE-u, proizведен od NI, američke multinacionalne kompanije, ranije poznate kao *National Instruments Corporation*, sa sjedištem u Austinu, Teksas. Dizajniran je s naglaskom na upotrebi u obrazovanju, te uključuje akademske značajke koje pojednostavljaju podučavanje koncepta iz elektronike.

Korištenjem ovog simulatora na računalu, korisniku programa je omogućeno simuliranje rada elektroničkih sklopova i na taj način korisnik produbljuje znanje o načinu na koji ti skloovi funkcioniraju. Korisnik ima na dispoziciji razne komponente i mjerne instrumente koji se primjenjuju u elektroničkim mjerjenjima kako bi postigao svoje ciljeve.

Upotreba softverskih proizvoda za simulaciju [5,6] poput Multisima nije uvijek samo zbog neadekvatne opremljenosti laboratorija. Oni se mogu koristiti i zbog sigurnosti koju pružaju u pokusima koji se izvode sa visokim naponima i strujama. Kod takvih pokusa simulacijom se može vidjeti ponašanje sklopova, bez opasnosti od strujnog udara ili oštećenja sklopa.

Simulacijske vježbe obično se izvode na način da učenici dobivaju zadatak iz prethodno teoretski obrađenog gradiva. Oni treba da samostalno izvedu zadatak te dobivene rezultate protumače s učiteljem i zabilježe rješenja u odgovarajuća izvješća.

2. ZNAČAJKE MULTISIMA

Multisim predstavlja jednostavno okruženje za podučavanje, jer se koncepti mogu oživjeti simulacijom bez brige o sintaksi SPICE-a, što obezbjeđuje da se učenici mogu usredotočiti na razumijevanje koncepta sklopova, umjesto da budu frustrirani učenjem okoline. Oni mogu u hodu mijenjati vrijednosti određenih komponenata i vidjeti kako se rezultati simulacije mijenjaju u stvarnom vremenu.

There are numerous software products on the market that simulate the operation of electronic circuits and digital electronic systems. The most popular simulator is SPICE (Simulation Program with Integrated Circuit Emphasis) [1,2] designed at the University of California at Berkeley in the early 1970s of XX century.

NI Multisim [3,4], hereinafter referred to as Multisim, is a SPICE-based simulator, manufactured by NI, a US multinational company formerly known as National Instruments Corporation, based in Austin, Texas. It is designed with an emphasis on educational use, and incorporates academic features that simplify the teaching of electronics concepts.

By using this simulator on a computer, the user of the program is enabled to simulate the operation of electronic circuits and deepen own understanding of how these circuits work. The user has various components and measuring instruments at disposal that can be used for electronic measurements in order to achieve goals.

Use of software products for simulation [5,6], such as Multisim, does not come always as a consequence of lacking the adequate laboratory equipment. They can also be preferred for the security they provide in experiments which use relatively high voltages and currents. In such experiments, simulation can provide an insight into the behavior of the circuits, without the risk of electric shock or damage to the circuit.

Simulation exercises are usually based on material previously studied by the students. They should independently perform the required tasks, interpret results they obtained with the teacher and record the solutions in the appropriate reports.

2. MULTISIM'S FEATURES

Multisim is a straightforward teaching environment, because concepts can be brought to life via simulation, without worrying about SPICE syntax, enabling students to focus on understanding circuit concepts, rather than being frustrated by learning environment. They can change the values of certain components in real time and see how simulation results change in real time as well.

Multisim posjeduje mogućnost prilagođavanja korisničkog sučelja, kao i dostupnih instrumenta i analiza, radi bolje kontrole nad onim što učenik može vidjeti i čemu može pristupiti, u svrhu pružanja fleksibilnosti pri uvođenju koncepata na kontrolirani način, tako da učitelj može prilagoditi složenost softvera trenutnoj razini znanja učenika. Navođenje učenika da istražuju scenarije "što ako" pomoću simulacije pojačava koncepte koji se predaju u učionici ili laboratoriju.

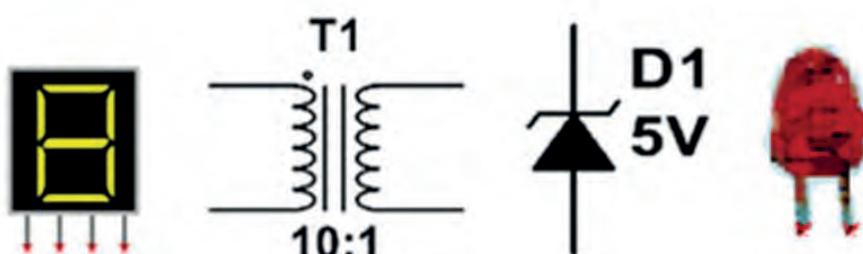
Bitan aspekt *Multisima* je bogata knjižnica električkih i digitalnih komponenti. Knjižnica omogućava korisniku pristup više od 14 000 različitih komponenti od poznatih svjetskih proizvođača poput *Analog Devices*, *Maxim Microchip*, *Texas Instruments* i mnogih drugih u lako pretraživim kategorijama. Komponente se mogu podijeliti u sljedeće tipove:

- interaktivne komponente poput sklopki i potenciometara kojima se može upravljati za vrijeme trajanja simulacije,
- animirane komponente (poput LED-a i 7-segmentnih LED zaslona) koje mijenjaju svoj izgled kao odgovor na rezultate simulacije,
- virtualne komponente koje omogućuju postavljanje njihovih parametara na bilo koju vrijednost,
- tzv. *rated* komponente koje "pregore" ako su prekoračeni određeni parametri (naprimjer, snaga ili struja) i
- 3D komponente koje koriste fotografije koje izgledaju poput stvarnih komponenti kako bi zamijenile tradicionalne shematske simbole.

Multisim has the ability to adapt the user interface, as well as available tools and analyses, to provide a better control of what a student can see and access, in order to provide flexibility in introducing concepts in a controlled way, so that the teacher can adjust the software complexity to the student's current level of knowledge. Encouraging students to explore "what if" scenarios through simulation reinforces concepts already taught in the classroom or laboratory. An essential aspect of *Multisim* is the rich library of electronic and digital components.

The library provides the user with access to more than 14 000 different components from world-renowned manufacturers such as Analog Devices, Maxim Microchip, Texas Instruments, and many others, in easily searchable categories. Components can be divided into the following types:

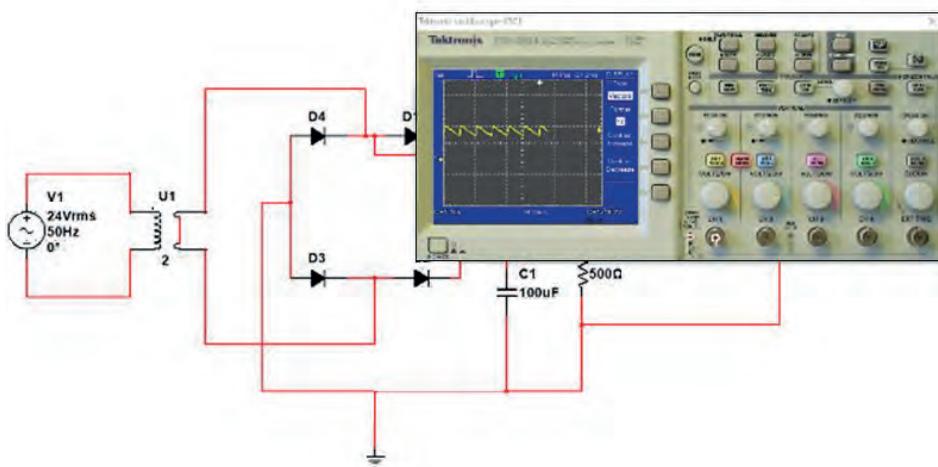
- interactive components such as switches and potentiometers, that can be controlled during the simulation,
- animated components (such as LED and 7-segment LED screens) that change their appearance in response to simulation results,
- virtual components that allow you to set their parameters to any value,
- so-called rated components that "burn out" if certain parameters are exceeded (e.g. power or current),
- 3D components that use photos that look like real components to replace traditional schematic symbols.



Slika 1. Primjeri raznih tipova komponenti u Multisimu
Figure 1 Examples of different kinds of Multisim components

Korištenje simulacijskih instrumenata se postiže jednostavnim *drag-drop* principom na radnu površinu unutar Multisima. Tada se može provoditi sva interakcija koja bi se mogla provoditi u stvarnom laboratoriju. Učenici mogu mjeriti ili vršiti postupak otklanjanja problema pomoću raznih virtualnih instrumenata (multimetra, funkcionalnog generatora, osciloskopa, Bodeovog plotera, generatora riječi, logičkog analizatora, logičkog konvertora itd.). Pored standardnog paketa instrumenata, Multisim raspolaže i sa simuliranim osciloskopima tvrtki Agilent i Tektronix, koje omogućuju učenje učenika na stvarnim instrumentima ovih dobavljača.

Utilisation of simulation instruments is achieved via a straightforward drag-drop principle within the Multisim desktop. All interactions that could be performed in an actual laboratory can therefore be performed here as well. Students can measure or perform a troubleshooting procedure using a variety of virtual instruments (multimeter, function generator, oscilloscope, Bode plotter, word generator, logic analyzer, logic converter, etc.). In addition to the standard instrument package, Multisim also has simulated oscilloscopes from Agilent and Tektronix, what enable students to learn using real instruments from these suppliers.



Slika 2. Tektronixov osciloskop
Figure 2 Tektronix oscilloscope

3. UTISCI O VJEŽBAMA IZ ELEKTRONIČKIH SKLOPOVA

Stečeno teoretsko znanje iz elektroničkih sklopova učenici su spremni proširiti unutar Multisima izvođenjem laboratorijskih vježbi. Osim toga, cilj je da učenici postanu sposobni koristiti simulacijske instrumente unutar Multisima (ampermetar, voltmeter, ohmmeter, digitalni multimeter, vatmeter itd.) i mjerne instrumente s dvodimenzionalnim prikazom mjerne veličine (katodni osciloskop).

Kao mjeritelji imaju ozbiljnu zadaću da odaberu pravu mjeru metodu kojom će najtočnije izmjeriti mjerenu veličinu, da pravilno odrede mjerne opsege i provedu mjerjenje na ispravan način. Poslije svega toga treba da samostalno obrade i prikažu mjereni rezultat, te da izvedu zaključak.

3. IMPRESSIONS OF EXERCISES FROM ELECTRONIC CIRCUITS

The students are ready to expand their theoretical knowledge of electronic circuits, acquired within Multisim, by performing laboratory exercises. In addition, the goal for students is to become able to use basic simulation instruments (ammeter, voltmeter, ohmmeter, digital multimeter, wattmeter, etc.) and electronic test equipment with two-dimensional display of measurement (cathode oscilloscope) within Multisim.

As the measurers, they have an important task in choosing the correct measuring method to obtain the most accurate measurements, to accurately determine the ranges of measurement and to execute the measurements correctly. After all this, they should independently process and present the measurement result, and be able to draw a conclusion.

3.1. Snimanje strujno-naponske karakteristike energetske diode

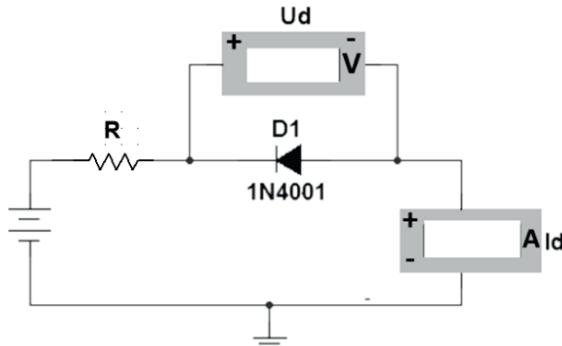
Energetska poluvodička dioda predstavlja pojačanu izvedbu poluvodičke diode. Energetske diode u energetskim pretvaračima moraju provoditi struje jačine do nekoliko kiloampera u propusnoj polarizaciji, te primati na sebe nekoliko kilovolti napona u reverznoj polarizaciji. Takvi ekstremni zahtjevi za podržavanje izuzetno velikih vrijednosti napona i struje čine analizu ove komponente u školskom laboratoriju nepraktičnom.

Isječak iz laboratorijske vježbe prikazan na slici 3. i predviđen za rad u Multisimu predstavlja shemu za snimanje strujno-naponske karakteristike za zaporan (reverzan) P-N spoj. Za snimanje karakteristike u propusnom području dovoljno je promijeniti polaritet izvora.

3.1. Recording of the current-voltage characteristic of power diode

The power semiconductor diode represents an amplified type of semiconductor diode. Power diodes in power converters must conduct currents of up to several kiloamperes in forward bias, and receive several kilovolts of voltage in reverse bias. Such extreme requirements to support extremely high voltage and current values make analysis of this component in school laboratories impractical.

The excerpt from the laboratory exercise shown in Figure 3, intended for analysis in Multisim, is a diagram for recording the current-voltage characteristic for the reverse biased P-N junction. To record the characteristic in the forward bias, it is enough to change the polarity of the source.



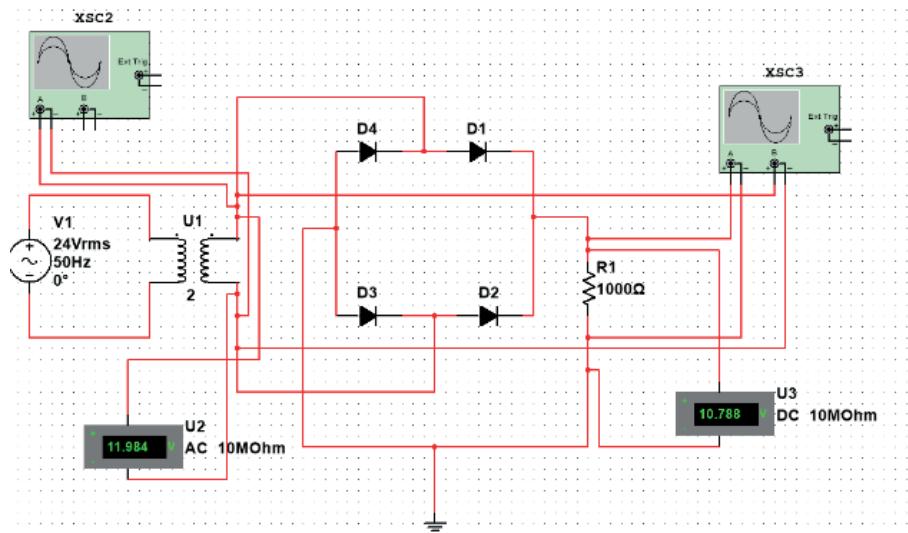
Slika 3. Shema spoja za zapornu polarizaciju energetske diode
Figure 3 Diagram for reverse biasing of a power diode

3.2. Punovalni spoj ispravljачa u mosnom spoju

Isječak iz laboratorijske vježbe prikazan na slici 4. i predviđen za rad u Multisimu ilustrira koncept punovalnog ispravljачa u mosnom spoju, tzv. Greatzov spoj, koji postiže punovalno ispravljanje primjenom četiri diode. Kroz ovu vježbu učenici dobivaju zadatak da odrede srednju vrijednost ispravljenog napona i nacrtaju dijagrame napona sekundara i izlaznog (ispravljenog) napona. Učenici kroz vježbu obogaćuju teoretsko znanje o punovalnom ispravljanju.

3.2. Full-Wave Bridge Rectifier

The excerpt from the laboratory exercise shown in Figure 4, intended for analysis in Multisim, illustrates the concept of a full-wave bridge rectifier, sometimes referred to as the Graetz bridge that achieves full-wave rectification using four diodes. Through this exercise, students are tasked with determining the average value of the rectified voltage, then drawing the resultant output waveform of the secondary voltage and the output of rectified voltage. Through this exercise, students enrich their theoretical knowledge of full-wave rectification.



Slika 4. Punovalni ispravljač u mosnom spoju

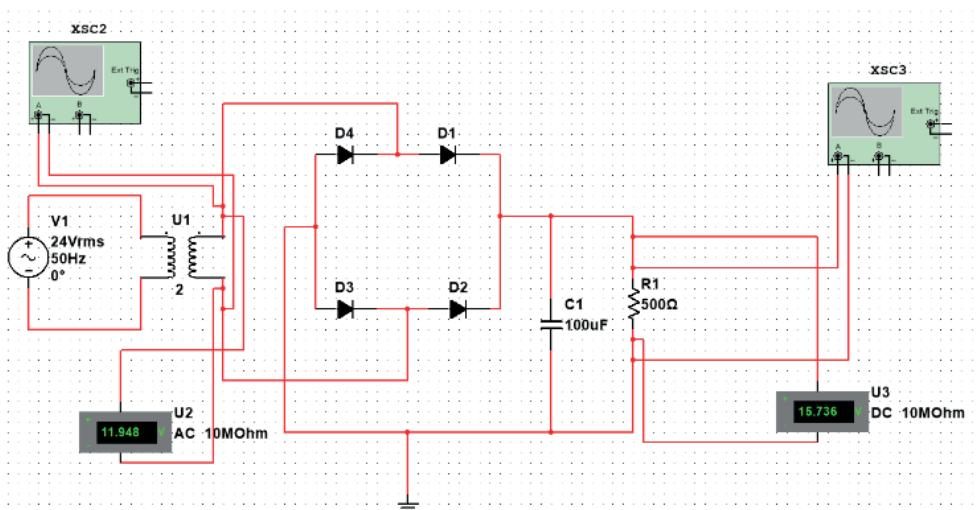
Figure 4 Full-Wave Bridge Rectifier

3.3. Filtriranje izlaznog napona punovalnog ispravljača u mosnom spoju

Isječak iz laboratorijske vježbe prikazan na slici 5. ilustrira spoj za filtriranje izlaznog napona punovalnog ispravljača s kapacitivnim opterećenjem. Kroz ovu vježbu učenici dobivaju zadatak da za različite vrijednosti otpora trošila i kapaciteta kondenzatora provedu mjerjenja srednje vrijednosti izlaznog napona, maksimalne i minimalne vrijednosti izlaznog napona, valovitosti izlaznog napona, vremena nabijanja i izbijanja kondenzatora i proračuna vremenske konstante izbijanja. Osim toga, potrebno je da nacrtaju valne oblike napona na trošilu za neko od mjerjenja.

3.3. Full-Wave Rectifier with Capacitor Filter

The excerpt from the laboratory exercise shown in Figure 5 illustrates the scheme for filtering the output voltage of a full-wave rectifier with a capacitive load. Through this exercise, students are tasked with determining the average value of the output voltage, maximum and minimum values of the output voltage, the ripple of the output voltage, the rate of charging and discharging of the capacitor and the calculation of the time constant for different values of load resistance and capacitor capacity. In addition, they need to draw voltage waveforms of the load for one of the measurements.



Slika 5. Punovalni ispravljač u mosnom spoju s kondenzatorom

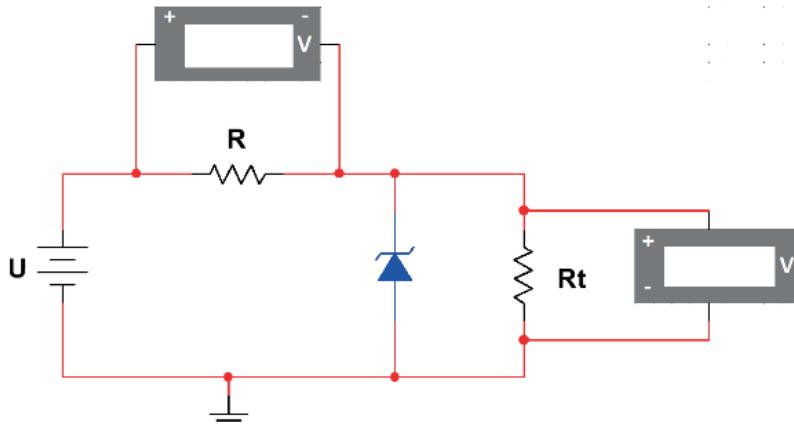
Figure 5 Full-Wave Bridge Rectifier with Capacitor Filter

3.4. Stabilizator napona sa Zenerovom diodom

Isječak iz laboratorijske vježbe prikazan na slici 6. ilustrira spoj za stabiliziranje napona sa Zenerovom diodom, koji mora osigurati stalan izlazni napon, koji se neće mijenjati promjenom ulaznog napona ni promjenom otpora trošila, kao niti promjenom temperature. Učenici tijekom vježbe utvrđuju teoretsko gradivo o stabilizatoru napona sa Zenerovom diodom i uočavaju da Zenerova dioda preuzima na sebe sve promjene ulaznog napona promjenom struje, dajući konstanti izlazni napon trošilu koji je spojen paralelno s njome.

3.4. Zener Diode as Voltage Stabilizer

The excerpt from the laboratory exercise shown in Figure 6 illustrates a voltage stabilization with a Zener diode which must provide a constant output voltage that will remain unaffected by changes to the input voltage or by changes to the resistance of the load, nor by temperature changes. During the exercise, students reinforce their theoretical knowledge about Zener diodes as a voltage stabilizer, and will notice that the Zener diode takes on itself all changes of input voltage by changing the current, thus providing a constant output voltage to a load connected in parallel with it.



Slika 6 Stabilizator napona sa Zenerovom diodom
Figure 6 Zener Diode as Voltage Stabilizer

4. UTISCI O VJEŽBAMA IZ DIGITALNE ELEKTRONIKE

Laboratorijske vježbe iz digitalne elektronike pomoću simulacijskog alata poput Multisima omogućuju učenicima nadogradnju vještina i znanja kroz odabране edukativne primjere pod vodstvom učitelja. Osim toga, cilj je da učenici postanu sposobni koristiti specifične simulacijske instrumente unutar Multisima, koji su vezani za digitalnu logiku (generator riječi, logički analizator, logički pretvornik itd.).

4.1. Logička algebra

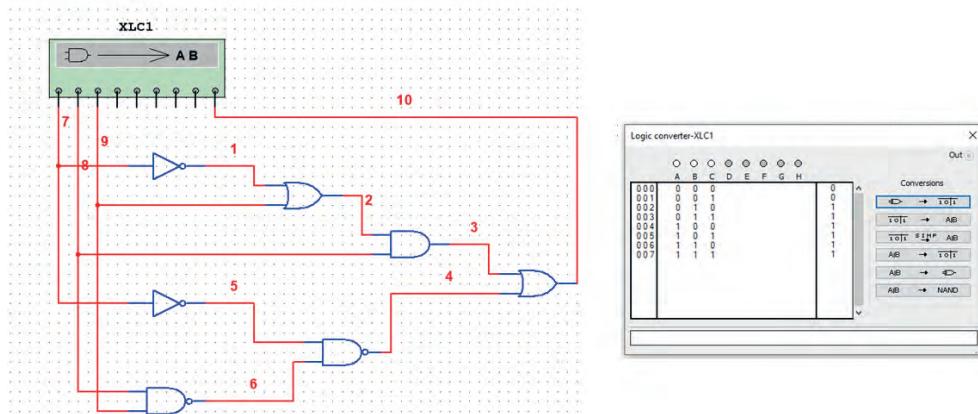
Logički sklopovi spajaju se međusobno radi izvođenja složenijih logičkih operacija. Postupnim spajanjem logičkih sklopova unutar Multisima dobije se odgovarajuća logička shema složenog logičkog sklopa. Nad takvom shemom učenici provode analizu pomoću logičkog pretvornika, kao što je prikazano na slici 7.

4. IMPRESSIONS OF EXERCISES FROM DIGITAL ELECTRONICS

Laboratory exercises in digital electronics using a simulation tool, such as Multisim, allow students to advance their skills and knowledge through educational examples under the guidance of a teacher. In addition, the goal for students is to become able to use specific simulation instruments within Multisim that are related to digital logic (word generator, logic analyzer, logic converter, etc).

4.1. Boolean Algebra

Logic gates connect together to make more complicated logical operations. By gradual combination of logic gates within Multisim, an appropriate logic scheme of a complex logic circuit is obtained. Students perform an analysis of such a scheme using a logic converter as shown in Figure 7.



Slika 7. Primjer s logičkom algebrom

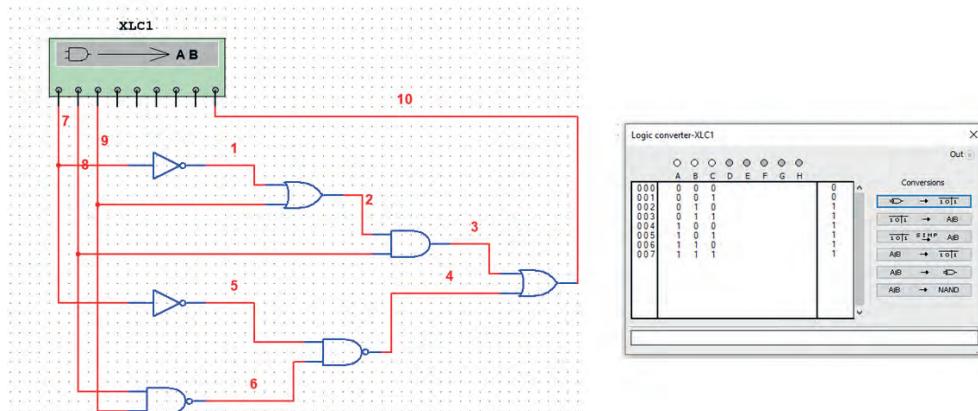
Figure 7 Logic algebra example

4.2. Uvjetno invertiranje sklopom isključivo NILI

Integrirani skloovi, građeni od logičkih skloova isključivo NILI, mogu se iskoristiti za uvjetno invertiranje ulaznog signala, kao što je prikazano na slici 8. Učenici upisu u generatore riječi stanja ulaza A i B prema prethodnom zadanom vremenskom dijagramu, te s pomoću logičkog analizatora snime signal na izlazu Y.

4.2. Conditional Inversion With Exclusive-NOR Gates

Integrated circuits built with exclusive-NOR gates can be used for conditional inversion of the input signal as shown in Figure 8. Students write in the word generators the state of inputs A and B, according to the previously given time diagram, and use a logic analyzer to record the signal at output Y.



Slika 8. Primjer s integriranim skloovima isključivo NILI

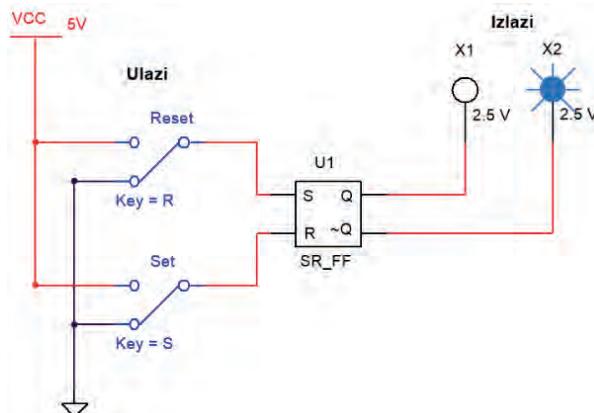
Figure 8 Exclusive-NOR Gates example

4.3. Bistabil SR

Temeljni sklop sa svojstvom pamćenja u digitalnoj elektronici je bistabilni multivibrator, kraće bistabil (engl. *bistable multivibrator*, flip-flop), koji predstavlja bitan aspekt digitalne elektronike. Spajanjem logičke sheme prema slici 9. učenici dobivaju integriranu verziju bistabila SR, jednog od tipova bistabila, te mijenjanjem stanja ulaza preko indikatorskih svjetala vide stanja izlaza.

4.3. Bistable SR

The basic circuit with memory properties in digital electronics is a bistable multivibrator, shorter bistable (flip-flop or latch), which represents an important aspect of digital electronics. By connecting the logic scheme according to Figure 9, students get an integrated version of the bistable SR, one of the types of bistable, and by changing the state of the input through the indicator lights see the state of the output.



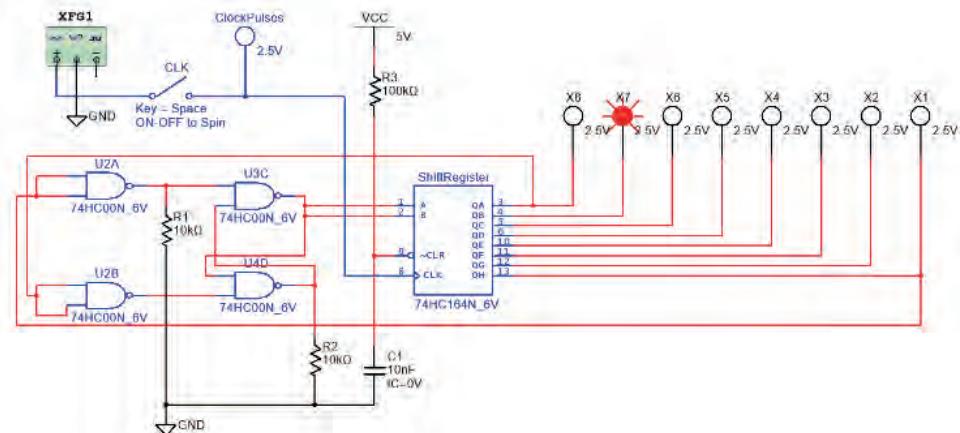
Slika 9. Shema integrirane izvedbe bistabila SR
Figure 9 Scheme of Integrated Version of Bistable SR

4.4. Digitalni rulet

Na slici 10. dat je prikaz realizacije složenog projekta – digitalni rulet. Samo jedna LED žaruljica može svijetliti u nekom trenutku. Prstenasti brojač je zadužen da LED diode svijetle, jedna po jedna, u slijedu. Prstenasti brojač je jednostavno realiziran s posmačnim registarom s dodatnim sklopovima. Složeniji projekti poput ovoga mogu biti prikladni za darovite učenike.

4.4. Digital Roulette

In Figure 10, there is the implementation of a complex project - digital roulette. Only one LED bulb can light up at a time. The ring counter is in charge of making the LED light up, one by one, in sequence. The ring counter is simply done with a shift register with additional circuits. More complex projects like this one may be suitable for gifted students.



Slika 10. Digitalni rulet
Figure 10 Digital Roulette

5. ZAKLJUČAK

U slučaju da ne postoji adekvatno opremljen školski laboratorij, moguće je koristiti simulacijske pakete u nastavi elektroničkih sklopova i digitalne elektronike. U ovome radu opisano je izvođenje takve nastave pomoću jednog od najpoznatijih alata koji omogućuju simulaciju – Multisima. Ukratko su navedene značajke samog programa, te se pristupilo

5. CONCLUSION

If there is no adequately equipped school laboratory, it is possible to use computer simulation software for the teaching of electronic circuits and digital electronics. This paper described the implementation of such types of teaching using one of the most famous tools that allow simulation - Multisim. The features of the program were briefly described,

upotrebi samog alata na odabranim primjerima. Treba napomenuti da interakcije između učitelja i učenika tijekom izvođenja laboratorijskih vježbi potiču aktivno učenje i dovode do maksimiziranja učinka teoretskih predavanja.

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and the use of the program was studied with selected examples. It should be noted that interactions between teachers and students during the performance of laboratory exercises encourage active learning and maximize the effects of theoretical lectures.

MATEMATIČKA I NUMERIČKA ANALIZA ODNOŠA IZMEĐU LOSCHMIDTOVE KONSTANTE, AVOGADROVE KONSTANTE I BRZINE ZVUKA U IDEALNOM I REALNOM PLINU U STANDARDNOM STANJU

MATHEMATICAL AND NUMERICAL ANALYSIS OF THE RELATIONSHIP AMONG THE LOSCHMIDT CONSTANT, THE AVOGADRO CONSTANT, AND THE SPEED OF SOUND IN IDEAL AND REAL GASES AT STANDARD STATE

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REZIME:

U ovom radu izvedena je diferencijalna jednadžba koja daje odnos između Loschmidtove konstante, Avogadrove konstante i brzine zvuka u plinovima kao funkcije termodinamičkih svojstava plina (pritisak, temperatura i volumen). Kako bi se potvrdila valjanost izvedene jednadžbe, omjer konstanti N_L/N_A i odstupanje omjera N_L/N_A za nekoliko idealnih plinova (vodik, helij, ugljikov monoksid, dušik, kisik, ugljendioksid, metan) izračunati su pomoću jednadžbe stanja idealnog plina ($Pv=RT$). Izračun omjera konstanti N_L/N_A i odstupanja omjera N_L/N_A od vrijednosti za plinove u standardnom stanju (tj. temperatura 273,15 K i pritisak 101325 Pa) pokazuje dobro slaganje s objavljenim rezultatima u literaturi, s obzirom na činjenicu da literaturni podatak omjera N_L/N_A iznosi 0,04461498 u standardnom stanju. Kao drugi korak za potvrdu valjanosti izvedene jednadžbe, omjer konstanti N_L/N_A i odstupanje omjera N_L/N_A za nekoliko stvarnih plinova (vodik, helij, ugljenmonoksid, dušik, kisik, ugljendioksid, metan) izračunati su korištenjem van der Waalsove jednačine stanja stvarnog plina. U ovom slučaju rezultati proračuna također pokazuju dobro slaganje s referentnom vrijednošću.

Short original scientific paper

SUMMARY:

In this paper, a differential equation is derived relating to the relationship among the Loschmidt constant, the Avogadro constant, and the speed of sound in gases as a function of the thermodynamic properties of the gas (pressure, temperature, and volume). To confirm the validity of the derived equation, the ratio of the constants N_L/N_A and the deviation of the N_L/N_A ratio for several ideal gases (hydrogen, helium, carbon monoxide, nitrogen, oxygen, carbon dioxide, methane) were calculated using the ideal-gas equations of state ($Pv=RT$). The calculation of the ratio of the constants N_L/N_A and the deviation of the N_L/N_A ratio from the value for the gases at standard state (i.e., temperature 273,15 K and pressure 101325 Pa) is in a good agreement with the results published in literature, given the fact that the literature data of the N_L/N_A ratio is 0,04461498 at standard state. As the second step in confirming the validity of the derived equation, the ratio of the constants N_L/N_A and the deviation of the N_L/N_A ratio for several real gases (hydrogen, helium, carbon monoxide, nitrogen, oxygen, carbon dioxide, methane) were calculated using the real-gas Van der Waals equation of state. In this case, the calculation results are also in agreement with the reference value.

1. INTRODUCTION

In 1811, Amadeo Carlo Avogadro, an Italian professor of physics, suggested an important hypothesis that equal volumes of all gases at

the same temperature and pressure contain the same number of molecules, or the volume of a gas at a given pressure and temperature is proportional to the number of atoms or

molecules regardless of the nature of the gas, what is well known as the Avogadro's Principle (law) or Avogadro's constant (number). The greatest problem Avogadro had to resolve in his time was the confusion regarding atoms and molecules. One of his most important contributions was clearly distinguishing one from the other, stating that gases are composed of molecules, and these molecules are composed of atoms. Avogadro did not actually use the word "atom" as the words "atom" and "molecule" were used almost without difference. He believed that there were three kinds of "molecules," including an "elementary molecule" ("atom") [1]. Thus, the hypothesis was extremely visionary and its confirmation, using the kinetic theory of gases, came decades later.

The scientific community gave no great attention to his theory, so Avogadro's hypothesis was not immediately accepted. The studies by Charles Frédéric Gerhardt and Auguste Laurent on organic chemistry made it possible to demonstrate and explain the Avogadro's law, i.e. why the same quantities of molecules in a gas have the same volume. Unfortunately, related experiments with organic substances showed exceptions to the law. This was finally resolved by Stanislao Cannizzaro, as announced at the Karlsruhe Congress in 1860, four years after Avogadro's death. Cannizzaro explained that these exceptions were due to molecular dissociations at certain temperatures, and that Avogadro's law determined not only molecular masses, but atomic masses as well. In 1911, a meeting in Turin commemorated the hundredth anniversary of the publication of the Avogadro's classic 1811 paper. Thus, Avogadro's great contribution to chemistry was recognised. Rudolf Clausius, with his kinetic theory on gases, gave another confirmation of Avogadro's Law. Jacobus Henricus van't Hoff showed that Avogadro's theory was also relevant for dilute solutions. Avogadro is hailed as a founder of the atomic-molecular theory [1].

Despite the fact that Avogadro did not specify the ratio of the number of constituent particles in a sample to the amount of substance, the French physicist Jean Baptiste

Perrin (1909) proposed naming the constant in honor of Avogadro. Jean B. Perrin won the Nobel Prize in Physics (1926) in a large part for his work in determining the Avogadro's constant. Perrin's method was based on the Brownian motion [2].

In the years since then, several different methods (coulometry, electron mass measurement, x-ray crystal density method) have been used to estimate the magnitude of this fundamental constant. In general, accurate determinations of the Avogadro's number require the measurement of a single quantity on both the atomic and macroscopic scales, using the same unit of measurements. This became possible for the first time when physicist Robert Millikan measured the charge on an electron in 1910. The charge of a mole of electrons had been known since 1834, when Michael Faraday published his works on electrolysis. The charge was called the Faraday constant, and the best value of the constant is 96,485.3383 (3) C/mol, according to the NIST. The best estimate of the charge on an electron, based on modern experiments, is $1.60217653 \cdot 10^{-19}$ C/electron. When we divide the charge on a mole of electrons by the charge on a single electron, we obtain a value of the Avogadro's number of $6.02214154 \cdot 10^{23}$ particles/mole [3]. Since 1910, new calculations have more accurately determined the value of Faraday's constant and elementary charge. Another approach to determining Avogadro's number starts with careful measurements of the density of an ultrapure sample of a material on the macroscopic scale.

In fact, Perrin originally proposed the name Avogadro number to refer to the number of molecules in one gram-molecule of oxygen, and this term is still widely used in introductory works. The change of the name to Avogadro's constant came with the introduction of the mole as a unit in the International System of Units (SI) in 1971, what recognised amount of substance as an independent dimension of measurements. Thus, Avogadro's constant was no longer a pure number, it now has a unit of

measurements, the reciprocal mole (mol^{-1}) [4,5].

The Avogadro's constant is a scaling factor between macroscopic and microscopic observations of nature, and can be applied to any substance. The most significant consequence of Avogadro's law is that the gas constant has the same value for all gases. Because of its role as a scaling factor, it provides the relation between other physical constant and properties. For example, it establishes a relationship between:

- the universal gas constant (R_u) and the Boltzmann constant (k_B): $R_u=k_B \cdot N_A = 8.314472 \cdot 10^{-3} \text{ J/mol} \cdot \text{K}$;
- the Faraday constant (F) and the elementary charge (e): $F=N_A \cdot e=96,485.3383 \cdot 10^3 \text{ C/mol}$, and
- the Avogadro constant within the definition of the unified atomic mass unit (u): $1 \text{ u}=M/N_A=1.660538782(83) \cdot 10^{-24} \text{ g}$.

The Loschmidt number is defined as the number of atoms in a gram atom or the number of molecules in a gram molecule. In literature, this number is frequently referred to as the Avogadro's number. But, the term Loschmidt number is reserved for the number of molecules in a cubic centimeter of a gas under standard conditions. In German language literature, it may refer to both constants by the same name, distinguished only by the units of measurement. The first actual estimation of the number of molecules in one cubic centimeter of a gas under standard conditions was made in 1865 by the Austrian physicist Johan Josef Loschmidt, a professor at the University of Vienna. The density of particles in a gas is now called the Loschmidt constant in his honor, and is approximately proportional to the Avogadro constant. The Loschmidt's method was based on the kinetic theory of gases. The kinetic theory was developed with a great success by the efforts of two scientists James Clerk Maxwell and Rudolph Clausius. Loschmidt was the first to estimate the physical size of molecules in 1865, but he did not actually calculate a value for the constant which now bears his name. The Loschmidt number is, by virtue of its definition, the same for atoms and molecules of all kinds. Though molecules may

vary in size, shape and mass, the number of molecules in a gram molecule is a universal constant for all solids, liquids and gases, elements and compounds [6]. Thus, the number of molecules in a specific volume of gas is independent of the size or mass of the gas molecules. As an example, equal volumes of molecular hydrogen and nitrogen, as ideal gases, would contain the same number of molecules, as long as they are at the same temperature and pressure.

The Loschmidt constant is usually quoted at standard state of substance (i.e., temperature $T_0=273,15 \text{ K}$ and pressure $p_0=1 \text{ atm}=1.01325 \text{ bar}=101325 \text{ Pa}$), and recommended value is $2.6867774(47) \cdot 10^{25} \text{ particles/m}^3$. The pressure and temperature can be chosen freely, and must be quoted with values of the Loschmidt constant. The precision to which the Loschmidt constant is currently known is limited entirely by the uncertainty in the value of the gas constant.

The sound waves are a result of the movement of the elastic pieces of the substance environment, whether a substance is in gaseous, liquid or solid state. A change in gas density (or pressure) is transmitted in all directions with a certain speed. Number of compression and expansion of the environment, performed by the sound source by a sinuous curve in the unit of time is called *frequency* – unit is the number of cycles per second (c/s). The distance between the two maximum and minimum values in a sinuous curve represents *wavelength* – unit is the meter (m). Pressure changes represent *sound pressure* – the unit is N/m^2 . Sound energy (J) per unit time (s) passing through a unit area (m^2) normal to the direction of propagation is called *the intensity of sound waves* or alternatively *the power density* – the unit is W/m^2 [7]. The quantity has a practical importance. The human ear is a very sensitive organ and at the same time it is very flexible. The lower limit of the audible intensity of sound is of the order of 10^{-12} W/m^2 and the maximum safety limit is the order of 1 W/m^2 . The sound waves intensity of ordinary

conversation is the order of 10^{-6} W/m², street traffic is 10^{-5} W/m² and jet plane is 10^{-2} W/m².

Propagation speed of sound waves depends only on the properties of the medium through which the propagation takes place. The speed of sound varies from substance to substance, for instance: sound travels most slowly in gases (the average gas speed of sound is about 330 m/s); it travels faster in liquids (the average gas speed of sound is about 1,500 m/s); and it travels at the fastest speed in solids (the average gas speed of sound is about 4,000 m/s). In an exceptionally stiff

material such as diamond, sound travels at 12,000 m/s - which is around the maximum speed that sound will travel under normal conditions. In common everyday speech, speed of sound refers to the speed of sound waves in air. At 20°C, the speed of sound in air is about 343 m/s. The speed of sound in an ideal gas depends only on its temperature and composition. The speed of sound has a weak dependence on frequency and pressure in ordinary air, deviating slightly from ideal behavior.

2. MATHEMATICAL ANALYSIS

2.1. The thermodynamic speed of sound

The thermodynamic speed of sound (i.e., the speed of sound at zero frequency) in a fluid u ,

$$u^2 = \left(\frac{\partial p}{\partial \rho} \right)_s \quad (1a)$$

where: ρ , kg/m³ is the density of the substance; p , N/m² is the pressure; s , J/kg·K is the specific entropy of the substance. Since $\rho=1/v$, the

m/s is defined by the Laplace equation

$$u^2 = -v^2 \left(\frac{\partial p}{\partial v} \right)_s \quad (1b)$$

By combining the above equation with the important relationship that determines the

Laplace equation has the following form, according to Ref. [8, p.127]:

$$\left(\frac{\partial p}{\partial v} \right)_s = \left(\frac{\partial p}{\partial v} \right)_T - \frac{T}{c_v} \left(\frac{\partial p}{\partial T} \right)_v^2 \quad (2)$$

it is obtained that

$$u^2 = v^2 \left[\frac{T}{c_v} \left(\frac{\partial p}{\partial T} \right)_v^2 - \left(\frac{\partial p}{\partial v} \right)_T \right] \quad (3)$$

An equivalent form of Eq. (3) can be found by replacing the derivative $(\partial p / \partial T)_v$ in

following derivative, rarely mentioned in the literature, according to Ref. [8, p.124]:

$$\left(\frac{\partial p}{\partial T} \right)_v = - \left(\frac{\partial v}{\partial T} \right)_p \left(\frac{\partial p}{\partial v} \right)_T \quad (4)$$

so that Eq. (3) results

$$u^2 = v^2 \left[\frac{T}{c_v} \left(\frac{\partial p}{\partial v} \right)_T^2 \left(\frac{\partial v}{\partial T} \right)_p^2 - \left(\frac{\partial p}{\partial v} \right)_T \right] \quad (5)$$

terms of the cyclic equation, according to Ref. [9, p.636]:

or

$$v = u \left[\frac{T}{c_v} \left(\frac{\partial p}{\partial v} \right)_T^2 \left(\frac{\partial v}{\partial T} \right)_p^2 - \left(\frac{\partial p}{\partial v} \right)_T \right]^{-\frac{1}{2}} \quad (5a)$$

2.2. Relationship among the Loschmidt constant, the Avogadro constant, and the speed of sound

The Loschmidt constant is related to the Avogadro constant by relation, according to Ref. [10, p.418]:

$$N_L = \frac{p}{R_u T} N_A = \frac{\rho(p, T)}{M} N_A = \frac{1}{v(p, T) \cdot M} N_A, \quad \frac{\text{particles}}{\text{m}^3}, \quad (6)$$

where: N_L , particles/m³ is the Loschmidt constant; p , N/m² is the pressure; T , K is the temperature; R_u , J/kmol·K is the universal gas constant; $\rho(p, T)$, kg/m³ is the density of the substance; $v(p, T)$, m³/kg is the specific volume of the substance; M , kg/kmol is the

atomic mass of the substance, and N_A , particles/kmol is the Avogadro constant.

Combining Eq. (5a) and (6), we obtain relationship among the Loschmidt constant, the Avogadro constant, and the speed of sound, in the following form:

$$\frac{N_L}{N_A} = \frac{1}{u \cdot M} \left[\frac{T}{c_v} \left(\frac{\partial p}{\partial v} \right)_T^2 \left(\frac{\partial v}{\partial T} \right)_p^2 - \left(\frac{\partial p}{\partial v} \right)_T \right]^{\frac{1}{2}} \quad (7)$$

Since the specific volume and density are inversely proportional, that is $v=1/\rho$, the

following relation for the partial derivatives is obtained:

$$\left(\frac{\partial p}{\partial v} \right)_T = \left(\frac{\partial p}{\partial \rho} \right)_T \left(\frac{\partial \rho}{\partial v} \right)_T = -\rho^2 \left(\frac{\partial p}{\partial \rho} \right)_T \quad (a)$$

and

$$\left(\frac{\partial v}{\partial T} \right)_p = \left(\frac{\partial \rho}{\partial T} \right)_p \left(\frac{\partial v}{\partial \rho} \right)_p = -\frac{1}{\rho^2} \left(\frac{\partial \rho}{\partial T} \right)_p \quad (b)$$

When the previous relations are inserted in Eq.

(7), relation in the following form is obtained:

$$\frac{N_L}{N_A} = \frac{1}{u \cdot M} \left[\frac{T}{c_v} \left(\frac{\partial p}{\partial \rho} \right)_T^2 \left(\frac{\partial \rho}{\partial T} \right)_p^2 + \rho^2 \left(\frac{\partial p}{\partial \rho} \right)_T \right]^{\frac{1}{2}} \quad (8)$$

The relative deviations of the N_L/N_A ratio from the literature ratio value 0.04461498 at standard state, according to Ref. [3,6], for the

gases (hydrogen, helium, carbon monoxide, carbon dioxide, nitrogen, oxygen, and methane) are calculated as follows:

$$\Delta\left(\frac{N_L}{N_A}\right) = \frac{0.04461498 - \left(\frac{N_L}{N_A}\right)_{gas}}{0.04461498} 100\% \quad (9)$$

3. NUMERICAL ANALYSIS

3.1. Numerical analysis of the ratio of the constants and the deviation of the N_L/N_A for the ideal gases at standard state (i.e., temperature 273.15 K and pressure 101325 Pa)

As the first step to confirm the validity of the derived equation (8), the ratio of the constants N_L/N_A and the deviation of the N_L/N_A ratio for several ideal gases (hydrogen, helium, carbon monoxide, argon, nitrogen, oxygen, carbon dioxide, methane) were calculated using the ideal gas equations of state ($Pv=RT$). Namely, the PvT behavior of many gases at low pressures and moderate temperatures can be modeled quite well by the ideal gas equation of state. For example, nitrogen approximates

ideal behavior over a wide range of pressures up to 30 atm; argon begins to deviate after about 10 atm, and carbon dioxide is essentially independent of pressure only at extremely low pressures at a given temperature. Nevertheless, for monatomic and diatomic gases, the ideal gas eqution is usually a good approximation up to pressures of 10 to 20 atm at room temperature and above, for errors in accuracy not exceeding several percent, according to Ref. [9]. The maximum pressure at which a gas can be modeled by the ideal gas equation of state depends on the desired degree of accuracy.

If gases are ideal, the partial derivatives in equation (8) have the form:

$$\left(\frac{\partial p}{\partial \rho}\right)_T = RT, \quad \frac{\text{Pa}}{(\text{kg}/\text{m}^3)} \quad (10a)$$

and

$$\left(\frac{\partial \rho}{\partial T}\right)_p = -\frac{p}{RT^2}, \quad \frac{\text{kg}}{\text{m}^3\text{K}} \quad (10b)$$

The speed of sound in ideal gases is calculated using equation (3), and the

corresponding partial derivatives of the ideal gas equation ($Pv=RT$) are:

$$\left(\frac{\partial p}{\partial T}\right)_v = \frac{R}{v}, \quad \frac{\text{Pa}}{\text{K}} \quad (11a)$$

and

$$\left(\frac{\partial p}{\partial v}\right)_T = -\frac{RT}{v^2}, \quad \frac{\text{Pa}}{(\text{m}^3/\text{kg})} \quad (11b)$$

Table 1 The data, the speed of sound and the partial derivatives of the ideal gas equation

Gas	c_v , J/kgK	R , J/kgK	v , m ³ /kg	M , kg/kmol	$(\partial p/\partial T)_v$, Pa/K eq. (11a)	$(\partial p/\partial v)_T$, Pa/(m ³ /kg) eq. (11b)	u , m/s; eq.(3)
	Data according to Ref. [9,11]						
H ₂	10070.55	4125	11.1256	2.01588	370.7655	-9102.8686	1258.203
He	3116.176	2079	5.60284	4.002602	371.0618	-18090.0285	972.96
CO	743.170	297	0.799679	28.0101	371.399	-126860.457	337.01
N ₂	742.885	296.7	0.799753	28.013	370.989	-126708.863	336.839
O ₂	655.221	259.9	0.699774	31.9988	371.405	-144974.587	314.695
CO ₂	632.016	189	0.505865	44.0098	373.617	-201740.802	257.963
CH ₄	1656.75	518.8	1.393808	16.0428	372.217	-72944.956	429.047

Table 2 The N_L/N_A ratio calculations for the ideal gases

Gas	$(\partial p/\partial \rho)_T$, Pa/(kg/m ³) eq. (10a)	$(\partial p/\partial T)_p$, kg/m ³ K eq. (10b)	N_L/N_A ; eq. (8)	$(N_L/N_A)_{\text{Ref.}[3,6]} - (N_L/N_A)_{\text{gas}}$	$\Delta(N_L/N_A)$, %; eq. (9)
H ₂	1126743.75	-0.000329223	0.0446670296	-0.0000520486	-0.116664
He	567878.85	-0.0006532	0.04458756	0.00002742	0.061459
CO	81125.55	-0.00457254	0.0446234316	-0.0000084516	-0.0189434
N ₂	81043.605	-0.004577165	0.0446247865	-0.0000098065	-0.02198028
O ₂	70991.685	-0.00522526	0.04469970413	-0.00008472413	-0.1899006
CO ₂	51625.35	-0.0071854	0.04501832124	-0.00040334124	-0.9040489
CH ₄	141710.22	-0.002617666	0.0449278715	-0.0003128915	-0.70131489

The calculation of the ratio of the constants N_L/N_A and the deviation of the N_L/N_A ratio for the ideal gases at standard state (i.e., temperature 273.15 K and pressure 101,325 Pa) are in a good agreement with the results in literature, given the fact that the literature data of the N_L/N_A ratio is 0.04461498 at standard state. **Table 2** presents the absolute and relative deviations of the N_L/N_A ratio for the

ideal gases, calculated using equations (8) and (9) at standard state in relation to the reference value 0.04461498 from Ref. [3,6] for the same condition. Thus, **Table 2** shows that the absolute deviation ranges from 0.0000084516 for carbon monoxide to 0.00040334124 for carbon dioxide, while the relative deviation ranges from 0.0189434% for carbon monoxide to 0.9040489% for carbon dioxide.

3.2. Numerical analysis of the ratio of the constants and the deviation of the N_L/N_A for the real gases at standard state (i.e., temperature 273.15 K and pressure 101325 Pa)

As the second step to confirm the validity of the derived equation (8), the ratio of the constants N_L/N_A and the deviation of the N_L/N_A ratio for several real gases (hydrogen, helium, carbon monoxide, nitrogen, oxygen, carbon dioxide, methane) were calculated using the Van der Waals equation of state, according to Ref [9].

In 1873, Van der Waals proposed an equation of state, what was the first attempt to correct the ideal gas equation, so that it would be applicable to real gases. On the bases of

simple kinetic theory, particles are assumed to be point masses, and there are no intermolecular forces among particles. As the pressure increases on a gaseous system, the volume occupied by the particles may become a significant part of the total volume, and intermolecular attractive forces become important under this condition. To account for the volume occupied by the particles, Van der Waals proposed that the specific volume in the ideal gas equation to be replaced by the term $v - b$. Also, the ideal pressure was to be replaced by the term $P + a/v^2$. Thus, the Van der Waals equations of state are:

$$\left(p + \frac{a}{v_m^2} \right) (v_m - b) = R_u T \quad (12)$$

or

$$v_m^3 - \left(b + \frac{R_u T}{p} \right) v_m^2 + \frac{a}{p} v_m - \frac{b}{p} a = 0 \quad (13)$$

or

$$\rho_m^{-3} - \left(b + \frac{R_u T}{p} \right) \rho_m^{-2} + \frac{a}{p} \rho_m^{-1} - \frac{b}{p} a = 0 \quad (14)$$

where: p , bar is the pressure; ρ_m (p, T), kmol/m^3 is the molar density of the substance; v_m (p, T), m^3/kmol is the molar specific volume of the substance; a , $\text{bar} \cdot (\text{m}^3/\text{kmol})^2$ is constant;

b , m^3/kmol is constant; R_u , $\text{J}/\text{kmol} \cdot \text{K}$ is the universal gas constant.

If gases are real, the partial derivatives in equation (8) have the form:

$$\left(\frac{\partial p}{\partial \rho} \right)_T = \frac{p(3p - 2bp\rho_m - 2R_u T \rho_m + a\rho_m^2)}{\rho_m^2(R_u T - a\rho_m + ab\rho_m^2)} \cdot 10^5, \quad \frac{\text{Pa}}{(\text{kg}/\text{m}^3)} \quad (15)$$

and

$$\left(\frac{\partial \rho}{\partial T} \right)_p = \frac{R_u \rho_m^2}{-3p + 2bp\rho_m + 2R_u T \rho_m - a\rho_m^2} \cdot M, \quad \frac{\text{kg}}{\text{m}^3 \text{K}} \quad (16)$$

The speed of sound in real gases is calculated using equation (3), and the

corresponding partial derivatives of Van der Waals equation (13) are:

$$\left(\frac{\partial p}{\partial T} \right)_v = \frac{R_u}{v_m - b}, \quad \frac{\text{Pa}}{\text{K}} \quad (17)$$

and

$$\left(\frac{\partial p}{\partial v} \right)_T = \left[-\frac{R_u T}{(v_m - b)^2} + \frac{2a}{v_m^3} \right] \cdot M \cdot 10^5, \quad \frac{\text{Pa}}{(\text{m}^3/\text{kg})} \quad (18)$$

Table 3 The calculation of the speed of sound for the real gases using Van der Waals equation

Gas	a , $\text{bar}(\text{m}^3/\text{kmol})^2$	b , m^3/kmol	ρ_m , kmol/m^3	M , kg/kmol	$(\partial p / \partial T)_v$, Pa/K eq. (17)	$(\partial p / \partial v)_T$, $\text{Pa}/(\text{m}^3/\text{kg})$ eq. (18)	u , m/s; eq.(3)
	Data according to Ref. [9,11]						
H ₂	0.247	0.0265	22.4281	2.01588	371.1795	-9114.844	1261.261
He	0.0341	0.0234	22.426	4.002602	371.162	-18111.345	973.458
CO	1.463	0.0394	22.3991	28.0101	371.874	-126516.944	336.7637
N ₂	1.361	0.0385	22.4035	28.013	371.786	-126521.44265	336.7949
O ₂	1.369	0.0315	22.3919	31.9988	363.8119	-144557.668	312.741
CO ₂	3.643	0.0427	22.2630	44.0098	366.106	-199541.173	256.6828
CH ₄	2.285	9.0427	22.3605	16.0428	372.566	-72498.121	430.465

Table 4 The N_L/N_A ratio calculations for the real gases using Van der Waals equation

Gas	$(\partial p/\partial \rho)_T, \text{Pa}/(\text{kg/m}^3)$ eq. (15)	$(\partial \rho/\partial T)_p, \text{kg/m}^3\text{K}$ eq. (16)	$N_L/N_A;$ eq. (8)	$(N_L/N_A)_{\text{Ref.}[3,6]} -$ $(N_L/N_A)_{\text{gas}}$	$\Delta(N_L/N_A, \%)$ eq. (9)
H ₂	1112900.794	-0.000329119	0.0442006	0.00041438	0.92879
He	567411.299	-0.000653797	0.04455534	0.00005964	0.133677
CO	81031.722	-0.004591028	0.044674349	-0.000059369	-0.1330696
N ₂	81061.654	-0.00460508	0.0447150155	-0.0001000355	-0.2242195
O ₂	70864.336	-0.00524875	0.0449547837	-0.0003398037	-0.76163589
CO ₂	50086.82	-0.00736251	0.0446578458	-0.0000428658	-0.096079388
CH ₄	140915.435	-0.002642338	0.0447241547	-0.0001091747	-0.2447041

The calculation of the ratio of the constants N_L/N_A and the deviation of the N_L/N_A ratio for the real gases at standard state (i.e., temperature 273.15 K and pressure 101,325 Pa) are in a good agreement with the results in literature, given the fact that the literature data of the N_L/N_A ratio is 0.04461498 at standard state. **Table 4** presents the absolute and relative deviations of the N_L/N_A ratio for the

real gases calculated using Vder Waals equation at standard state in relation to the reference value 0.04461498 from Ref. [3,6] for the same condition. Thus, **Table 4** shows that the absolute deviation ranges from 0.0000428658 for carbon dioxide to 0.00041438 for hidrogen, while the relative deviation ranges from 0.096079388% for carbon dioxide to 0.92879% for hidrogen.

4. CONCLUSION

- The contribution of the paper is in the derivation of equation (8), which defines the analytical relationship between the Avogadro and Loschmidt numbers as a function of the speed of sound and pV/T (the thermodynamic properties of the gas). The Loschmidt constant is approximately proportional to the Avogadro constant, according to Ref. [6], which is also numerically confirmed for ideal and real gases (hydrogen, helium, carbon monoxide, carbon dioxide, nitrogen, oxygen, and methane) in the paper.
- The number of particles (atoms or molecules) in the same volume for all gases is equal at the same temperature and pressure. The conclusion is based on the fact that the N_L/N_A ratio is calculated using equation (8) and it is almost the same for all considered gases. Namely, the absolute differences appear on the fourth decimal place for the considered gases. This conclusion corresponds to the Avogadro's hypothesis *that equal volumes of all gases at the same temperature and pressure contain the same number of molecules*.
- The speed of sound is different in gases under the same pV/T (the thermodynamic properties of the gas), even though in these circumstances all gases have the same number of particles in the same volumes (Avogadro's hypothesis). Thus, it is clear that the speed of sound in gases depends on the type of gas (i.e., molecular weight and heat capacity of the gas) and temperature. In other words, all gases under the same pV/T (the thermodynamic

properties of the gas) have the same number of particles (atoms or molecules) in equal volumes, but in these circumstances have different speed of sound.

- The explanation of the previous conclusion is possible by analogy with the conduction of thermal energy in gases. Sound is an energy form, as is a thermal energy. Thus, the propagation of sound in gases can be compared to the propagation of thermal energy. In the theory of heat transfer in gases and liquids, there are very successful correlations between the coefficient of heat conduction and the speed of sound in these fluids. It can be observed that the heat conduction coefficient of gases is several times higher for hydrogen and helium, compared to the coefficients of other gases, and that the same goes for the speed of sound. This is explained by the fact that hydrogen and helium have small molecular masses compared to other gases and, therefore, have a higher mean velocity of elementary particles in volume, what is directly proportional in functional relations to both the coefficient of heat conduction and the speed of sound in gas. Thus, the mean velocity of elementary particles in the volume of a gas directly and in the same way affects both the conduction of thermal energy and the propagation of sound.
- Experimental data indicate the fact that the speed of sound in gases increases as pressure increases, i.e., gas density. On the other hand, according to the kinetic theory of gases, increasing the pressure (density) of a gas

reduces the mean trajectory of a particle (atom, molecule) during the interval between two collisions. This indicates the increase of gas pressure (density) will not have as significant impact on the increase of the speed of sound in

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the gas as the type and temperature of the gas, because in functional relations the density and mean particle path between two collisions are proportional to both the heat conduction coefficient and the speed of sound.

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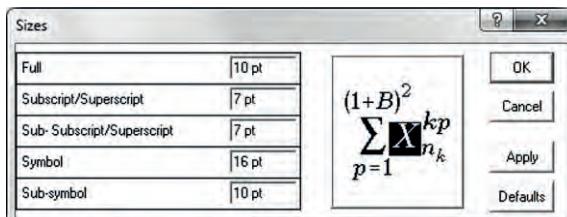


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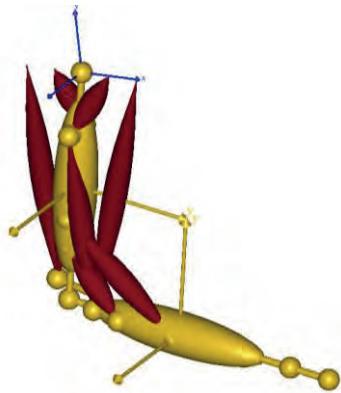


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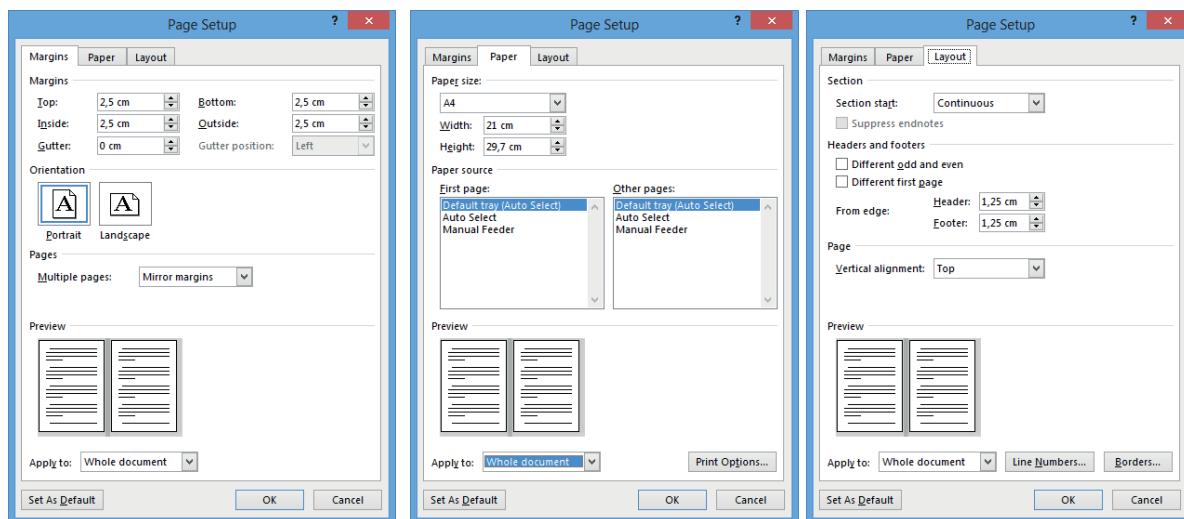


Figure 3 Page setup
(Style: Times New Roman, 11pt, Italic)



Figure X Photography resolution of 300 dpi (min.)
(Style: Times New Roman, 11pt, Italic)

3. PUBLICATION ETHICS AND PUBLICATION MALPRACTICE STATEMENT

The publication of an article in a peer reviewed journal is an essential model for our journal "Mašinstvo".

It is necessary to agree upon standards of expected ethical behaviour for all parties involved in the act of publishing: the author, the journal editor, the peer reviewer and the publisher.

Publication decisions. The editor of the "Mašinstvo" is responsible for deciding which of the articles submitted to the Journal should be published.

The editor may be guided by the policies of the Journal's Editorial Board and constrained by such legal requirements as shall then be in force

regarding libel, copyright infringement and plagiarism. The editor may confer with other editors or reviewers in making this decision.

Fair play. An editor at any time evaluate manuscripts for their intellectual content without regard to race, gender, sexual orientation, religious belief, ethnic origin, citizenship, or political philosophy of the authors.

Confidentiality. The editor and any editorial staff must not disclose any information about a submitted manuscript to anyone other than the corresponding author, reviewers, potential reviewers, other editorial advisers, and the publisher, as appropriate.

Disclosure and conflicts of interest. Unpublished materials disclosed in a submitted manuscript must not be used in an editor's own research without the written consent of the author.

Contribution to editorial decisions. Peer review assists the editor in making editorial decisions and through the editorial communications with the author may also assist the author in improving the paper.

Acknowledgement of sources. Reviewers should identify relevant published work that has not been cited by the authors. Any statement that an observation, derivation, or argument had been previously reported should be accompanied by the relevant citation. A reviewer should also call to the editor's attention any substantial similarity or overlap between the manuscript under consideration and any other published paper of which they have personal knowledge.

Table 1 Table titles

(Style: Times New Roman, 11pt, Normal)

Engineering stress σ_e / MPa	Engineering plastic strain $\varepsilon_{e,pl}$ / %	True stress σ_t / MPa	True plastic strain $\varepsilon_{t,pl}$ / %
250,0	0,00	250,8	0,00
250,0	0,21	250,8	0,21
285,7	1,35	290,0	1,34
322,7	2,13	330,1	2,10
358,4	3,06	370,0	3,00
393,1	4,35	411,0	4,24
423,6	6,05	450,1	5,85
449,7	8,76	490,1	8,36
457,0	15,79	530,1	14,59
467,9	21,58	570,0	19,45
475,0	29,77	617,5	25,94

(Style in table: Times New Roman, 11pt, Normal)

4. CONCLUSION

Paper manuscripts, prepared in accordance with the Instructions for Authors, are to be submitted to the Editorial Board of the "Mašinstvo" journal. Manuscripts and the CD-ROM are not returned to authors. When prepared for printing, the text may undergo small alternations by the Editorial Board. Papers not prepared in accordance with the Instructions shall be returned to the first author. When there are several authors, the first author will be contacted. The Editorial Board shall accept the statements made by the first author.

5. STYLE CITATION GUIDE

Bibliography

(Style: Times New Roman, 11pt, Normal)

The following recommendations are from The Chicago Manual of Style, University of Chicago Press, 15th ed., 2003. For further information and examples of additional types of sources, please visit <http://www.chicagomanualofstyle.org>

In the bibliography, please state your sources in accordance with the examples given below. Also, indent the second and subsequent lines.

Online sources that are analogous to print sources (such as articles published in online journals, magazines, or newspapers) should be cited similarly to their print counterparts but with the addition of a URL. Some publishers or disciplines may also require an access date. For online or other electronic sources that do not have a direct print counterpart (such as an institutional website or a weblog), give as much information as you can in addition to the URL.

Books

One author

- [1] Doniger, Wendy. *Splitting the Difference*. Chicago: University of Chicago Press, 1999.

Two authors

- [2] Cowlishaw, Guy, and Robin Dunbar. *Primate Conservation Biology*. Chicago: University of Chicago Press, 2000.

Four or more authors

- [3] Laumann, Edward O., John H. Gagnon, Robert T. Michael, and Stuart Michaels. *The Social Organization of Sexuality: Sexual Practices in the United States*. Chicago: University of Chicago Press, 1994.

Editor, translator, or compiler instead of author

- [4] Lattimore, Richmond, trans. *The Iliad of Homer*. Chicago: University of Chicago Press, 1951.

Chapter, essay or other part of a book

- [5] Wiese, Andrew. “‘The House I Live In’: Race, Class, and African American Suburban Dreams in the Postwar United States.” In *The*

New Suburban History, edited by Kevin M. Kruse and Thomas J. Sugrue, 99–119. Chicago: University of Chicago Press, 2006.

Books published electronically

If a book is available in more than one format, you should cite the version you consulted, but you may also list the other formats, as given below.

[6] Kurland, Philip B., and Ralph Lerner, eds. *The founders' Constitution*. Chicago: University of Chicago Press, 1987. <http://press-pubs.uchicago.edu/founders/>. Also available in print form and as a CD-ROM.

Journals

Scholarly journal (show volume & date)

[7] Smith, John Maynard. "The Origin of Altruism." *Nature* 393 (1998): 639–40.

Popular magazine article (show date alone)

[8] Martin, Steve. "Sports-Interview Shocker." *New Yorker*, May 6, 2002.

Article in an online journal, magazine or newspaper

Add the article's URL to the basic citation. However, for articles accessed through a third-party database (e.g., JSTOR), list the URL of the "main entrance" page of the database instead of the individual article, e.g. <http://www.jstor.org/> or <http://muse.jhu.edu/> If an access date is required by your discipline, include it parenthetically at the end of the citation.

[9] Hlatky, Mark A., Derek Boothroyd, Eric Vittinghoff, Penny Sharp, and Mary A. Whooley. "Quality-of-Life and Depressive Symptoms in Postmenopausal Women after Receiving Hormone Therapy: Results from the Heart and Estrogen/Progestin Replacement Study (HERS) Trial." *Journal of the American Medical Association* 287, no. 5 (February 6, 2002), <http://jama.ama-assn.org/issues/v287n5/rfull/joc10108.html#aai-nfo>.

Websites

Websites may be cited in running text ("On its website, the Evanston Public Library Board of Trustees states . . .") instead of in an in-text citation, and they are commonly omitted from a bibliography or reference list as well. The

following examples show the more formal versions of the citations. If an access date is required by your discipline, include it parenthetically at the end of the citation, as in the example below.

[10] Evanston Public Library Board of Trustees. "Evanston Public Library Strategic Plan, 2000–2010: A Decade of Outreach." Evanston Public Library. <http://www.epl.org/library/strategic-plan-00.html> (accessed June 1, 2005).

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Phone: + xxx xx xxxxxx

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17
GODINA
POSLUJEMO U BiH

+12,000

INDIREKTNO ZAPOSLENIH



UKUPNA INVESTICIJA

465

MILIONA KM
OD 2004. GODINE



UKUPNO PLAĆENO
DOBavljačima i
partnerima

5,5

MILJARDI KM
OD 2004. GODINE



450
PROJEKATA IZ PROGRAMA
INVESTICIJA U LOKALNU
ZAJEDNICU
OD 2004. GODINE

OKO
2,300
DIREKTNO ZAPOSLENIH



OKO
900
DIREKTNO ZAPOSLENIH
U ArcelorMittal Prijedor

2,5% BDP BIH

INVESTICIJE
U ZAŠTITU OKOLIŠA

200
MILIONA KM
OD 2004. GODINA



TOPLANA ZENICA
100
MILIONA KM



UKUPNA UPLATA ZA
PLATE I POREZE
60
MILIONA KM
GODIŠNJE

30% ŽFBiH
50% ŽRS

PROMETA
ŽELJEZNICA
FBIH I RS

GODIŠNJE



600
LOKALNIH DOBavljača



UKUPNA UPLATA
LOKALnim DOBavljačima
400 MILIONA KM
GODIŠNJE

+ 2,5 MILIONA KM

UKUPNA INVESTICIJA U LOKALNU ZAJEDNICU
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ArcelorMittal
Zenica

IZVOZNIK #1 U BiH



ArcelorMittal



ArcelorMittal Zenica je najveći proizvođač dugih proizvoda na Balkanu sa proizvodnim kapacitetom od skoro milion tona godišnje, kao i najveći strani investitor u zemlji.

Jedan je od ključnih pokretača privrede u Bosni i Hercegovini i doprinosi BDP-u Bosne i Hercegovine sa 2,5%.

U fabrici je integralna proizvodnja čelika, korištenjem željezne rude i proces se odvija na koksari, visokoj peći, čeličani, dok se gotova roba proizvodi u valjaonicama.

U samoj Zenici, Kompanija direktno zapošjava više od 2.300 ljudi, ali broj indirektnih zaposlenika iznosi oko 12.000 zbog velikog broja domaćih kompanija koje svoje poslovanje zasnivaju na saradnji sa nama.

Postoji više od 600 ovakvih lokalnih dobavljača kojima ArcelorMittal Zenica godišnje za usluge plaća više od 250 miliona KM. Neki od njih, poput Željeznica RS imaju 50% godišnjeg prometa zahvaljujući poslovanju sa ArcelorMittalom Zenica, dok Željeznice Federacije ostvaruju 30% svog prometa kroz saradnju sa Kompanijom.

ArcelorMittal Zenica uložio je 100 miliona KM u Toplanu Zenica, potpuno novu energetiku koja radi isključivo na interne gasove (visoke peći i koksni gas), proizvodeći toplotnu energiju za ArcelorMittal Zenica i gradsko grijanje u Zenici. Toplana Zenica je zajednički poduhvat, u 50% vlasništvu ArcelorMittala Zenica, 30% finskih partnera i 20% Grada Zenice.

ArcelorMittal Zenica IZVOZNIK #1 U BIH