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RAZVOJ EDUKACIJSKOG MODELA MJENJAČKE KUTIJE

DEVELOPMENT OF AN EDUCATIONAL GEARBOX MODEL

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SAŽETAK

Ovaj rad objašnjava razvoj edukacijskog modela mjenjačke kutije. Razvoj modela dotiče se ponajviše područja strojarstva od samog modeliranja pojedinačnih strojnih elemenata u programu SolidWorks, spajanja elemenata u jednu cjelinu u programu, proizvodnje pomoću aditivne tehnologije 3D printanja i laserskog rezanja te programiranja proizvodnje strojnih elemenata u softveru PrusaSlicer pa do konačnog sklapanja. Osim strojarstva, razvoj modela također se dotiče područja elektrotehnike jer se za pokretanje same mjenjačke kutije koristi elektromotor napona 12 V, za mjerenje brzine okretaja ulaznog i izlaznog vratila koriste se brojači okretaja napona 12 V i adapter koji pretvara izmjeničnu struju u istosmjernu te ju ispravlja na napon od 12 V kako bi se oba brojača okretaja i elektromotor mogli spojiti na nj. U ovom radu fokus je približiti proučavatelju mehanički rad mjenjačke kutije koja se primjenjuje u svim prijevoznim sredstvima, strojevima itd. Modeliranje i izrada ovog edukacijskog modela omogućava studentima dublje razumijevanje složenih tehničkih sustava kroz praktičan rad. Proces uključuje ne samo teorijsko znanje već i praktične vještine kao što su precizno modeliranje, uporaba modernih proizvodnih tehnika i integracija elektroničkih komponenti. Ovaj rad predstavlja interdisciplinarnu suradnju integrirajući strojarstvo i elektrotehniku u jednu cjelinu.

Ključne riječi: *mehanika, mjenjačka kutija, aditivna tehnologija, CAD*

ABSTRACT

This article explains the development of the gearbox educational model. The development of the model mainly pertains to the field of mechanical engineering, from the modeling of individual machine parts in the SolidWorks program, assembling the elements into one whole in the program, production using the additive technology of 3D printing and laser cutting, and programming the production of machine parts in the PrusaSlicer software all the way to the final assembly. In addition to mechanical engineering, the development of the model also touches the field of electrical engineering, because a 12 V electric motor is used to drive the same gearbox, 12 V revolution counters, and an adapter that converts alternating current into direct current and rectifies it to 12 V voltage so that both the rev counter and the electric motor can be connected to it. In this paper, the focus is to bring the mechanical operation of a gearbox which is used in all means of transport, machines, etc., closer to the researcher. The modeling and creation of this educational model enables students to gain a deeper understanding of complex technical systems through practical work. The process involves not only theoretical knowledge but also practical skills such as precise modeling, the use of modern manufacturing techniques, and the integration of electronic components. This work represents an interdisciplinary collaboration integrating mechanical and electrical engineering into one unit.

Keywords: *mechanics, gearbox, additive technologies, CAD*

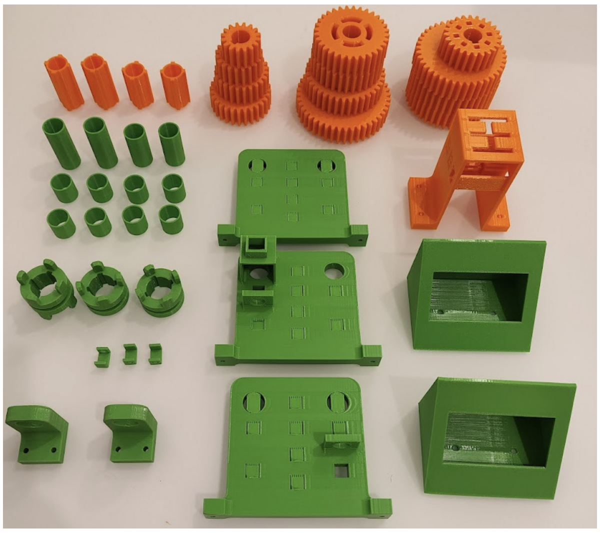
1. UVOD
1. INTRODUCTION

The use of a gearbox is widespread today, and foremost in the automotive industry. Because of the frequent use of gearbox on a daily basis, the idea arose to develop a gearbox educational model in order to familiarize students with machine elements, tolerances, kinematics and similar parts of such a system. A gearbox using different gear ratios is used to make the most of the engine's power and torque in certain cases. This model is designed as a so-called 5-speed automotive manual gearbox and consists of 5 forward speeds and one reverse speed. The model was constructed using SolidWorks CAD software, from which STL files of individual parts were generated and transferred to the PrusaSlicer software, which generates G-code in a way that cuts the parts into layers and thus prepares the parts for further production on a 3D printer. Given that this is an educational model, there was a need for an electric motor in order to maintain a constant rotation speed of the input shaft, while the output shaft speed of rotation would change depending on the engaged gear. The input and output shaft speed counters are used to display the ratio of various speeds to give the observer a clearer picture of what is happening inside the gearbox.

This paper touches on the various processes involved in the production of such a model, from 3D printing, laser cutting to the actual assembly of the finished components into one functional unit. It also touches on the use of various software that are key to being able to program machines to work and generate G-codes. RDWorksV8 laser G-code generation software processes a DXF file from which it produces 2D cutting lines that can then be further edited by the operator by changing the cutting line arrangement and the cutting power of each line. By regulating the cutting power and the speed of the laser advance, it is capable of performing engraving work of given depths up to cutting objects of a thickness dependent on the object's material.

2. 3D ISPIS DIJELOVA
2. 3D PRINTING OF PARTS

Most of the parts of the educational model of the gearbox (Figure 4) were made on a 3D printer based on FDM technology (Fused Deposition Modelling), i.e., deposition hardening technology. This 3D printing technology is the most widespread due to its simplicity of execution and affordable price, which makes it easily accessible. The material used to print the parts is PETG, i.e., polyethylene terephthalate glycol. PETG is a polymer with good characteristics such as high strength, chemical resistance, good adhesion to the working surface of the 3D printer and relatively small cooling shrinkage. Thanks to these properties, this material is ideal for making gearbox models.

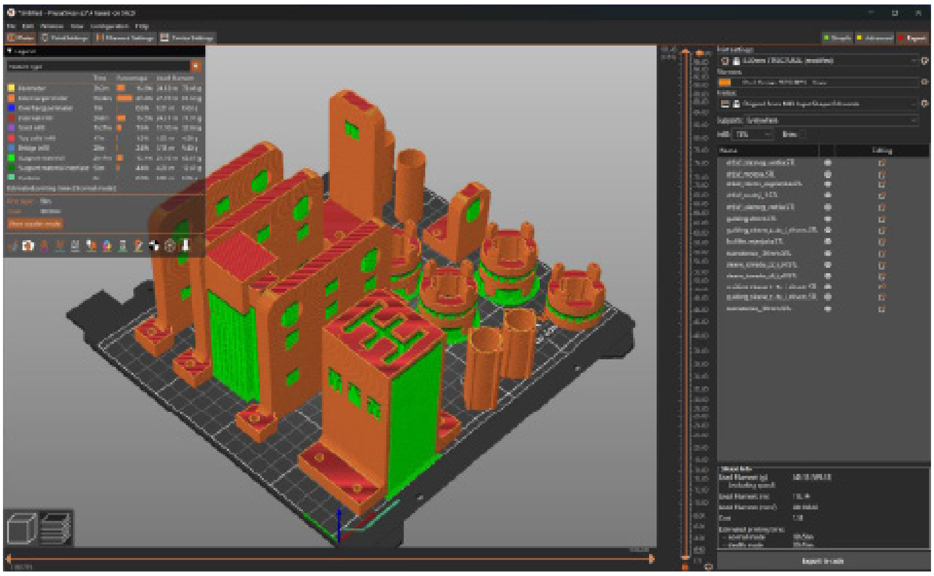


Slika 1 *Prikaz 3D ispisanih dijelova modela [1]*

Figure 1 *Representation of 3D printed model parts [1]*

Before the actual printing of the constructed parts, it is necessary to load the STL files into the software for preparing the print. The PrusaSlicer software slices parts into layers of specific dimensions and generates G-code that the 3D printer uses as printing instructions for each individual layer. The parts printing parameters for the gearbox model include a layer height of 0.2 mm, an infill density of 15% and three wall layers totalling 1.2mm to increase the strength of the parts with optimal material savings without compromising the integrity of the parts. The temperature of the working surface of the 3D printer for PETG material is 90˚C, while the temperature of the nozzle is 240˚C. Heating the working surface for this material is extremely important in order to avoid bending, and thus the peeling of the printed model due to sudden cooling of the material. [1]

When positioning parts on the working surface of the 3D printer, it is important to pay attention



***Slika 2** Prikaz dijelova u PrusaSlicer softveru [1]*

***Figure 2** Parts in PrusaSlicer software [1]*

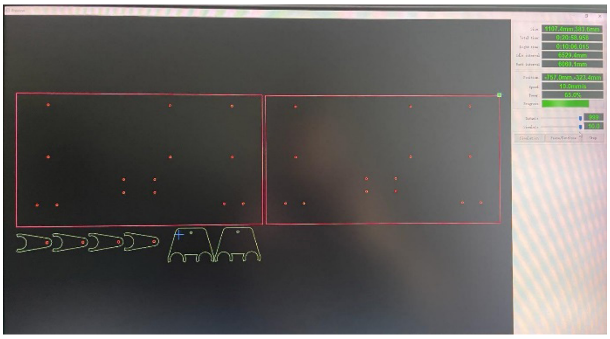
to their orientation in order to optimize material consumption with minimal use of the support structure (Figure 5). Shown in green in the picture is the support structure, which is necessary for parts that have horizontal segments without any support.

3. LASERSKA OBRADA MATERIJALA
3. LASER MATERIAL PROCESSING

Plexiglas parts were cut with the Bodor laser for non-metals. The parts are modelled using the SolidWorks CAD/CAM software, after which the cutting lines are defined in the RDWorksV8 software in such a way that we can choose which lines we want to process, in which order and also determine the processing power of the laser. In this case (Figure 6) the power is set to 65% to cut 4 mm thick plexiglass and the cutting speed is 10 mm/s. The power of the laser is 150 W, which is significant for laser processing of non-metals. The working dimensions of the laser are 1300x900 mm.

The laser-cut parts are the plate on which the entire gearbox is mounted, the forks and the double forks that are used to engage the claw clutches in the gears.

The laser works by amplifying the laser beam (electromagnetic radiation) with the help of a lens and focusing it on a very small surface of the workpiece. Given that the beam is monochromatic light, which means that the laser beam consists of only one colour, unlike ordinary light that is a mixture of all the colours of the rainbow spectrum, it can be focused on a very small area.



***Slika 3** Priprema dijelova za lasersku obradu materijala [1]*

***Figure 3** Preparation of parts for laser material processing [1]*

The laser consists of 3 basic parts: an energy source, gain medium and an optical resonator. The source of energy can be different, and in this case, it is a laser. The task of the laser as an energy source is to introduce enough energy into the gain medium to reach the excited state of the particles. The gain medium can be a gas, liquid or solid that has the ability to excite particles to a higher energy level. The optical resonator consists of two mirrors between which there is a gain medium. Photons of the correct wavelength, phase, and direction are reflected back and forth between these mirrors, and each time they pass through the gain medium, they emit other photons of the same phase, frequency, polarization, and direction—a process known as stimulated emission. This amplifies the light inside the resonator for further amplification. [2]

In short, a laser works by feeding energy into a gain medium to excite particles, using an optical resonator to amplify light through stimulated emission and emit a coherent beam of light through a partially transparent mirror.

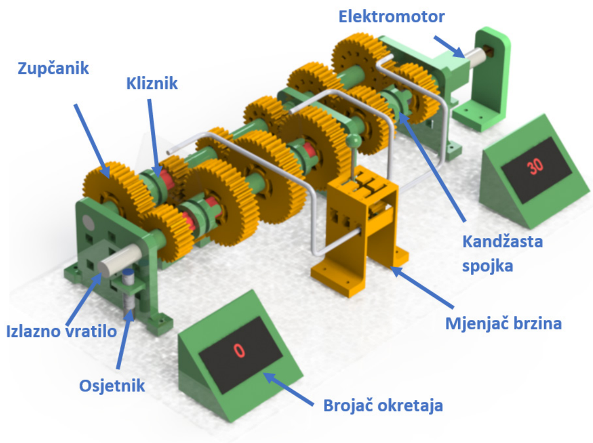
Slika 4 *Postupak laserske obrade materijala [1];*

Figure 4 *The laser material processing procedure [1]*

4. KONSTRUKCIJA MODELA MJENJAČKE KUTIJE

4. DESIGN OF GEARBOX MODEL

The design idea of the gearbox is based on a gearbox where the gears are in constant engagement. The advantage of such a gearbox is that the gears do not have to constantly re-engage with each other, which is why they wear out significantly less. This model consists of 13 gears, of which 10 are used as forward gears, a total of 5 forward speeds, and 3 are used for reverse, one reverse speed. The gear change mechanism is the same as what we can find in a car. For the sake of simplicity of 3D printing and construction, this model has no synchromeshes between the gears, which in a gearbox have the role of reducing the wear of machine parts and sudden loads in such a way as to equalize the revolutions of the input and output shafts with their conical construction. Instead of a synchromesh, this model engages the specific speed using a claw clutch which works very well in this simplified model considering the rotational speed of the electric motor that drives the gearbox is very low, only 30 revolutions per minute. A 12 V DC electric motor is used to drive the educational model, while sensors positioned under the input and output shafts are used to measure the rotational speed. The sensors are powered by 12V and are connected to screens that display the current number of shaft revolutions. Sensors, using a magnet built into the shaft, can read the rotational speed of the shaft or magnet and transmit this information to the screen. The measurement of the speed on the input and output shaft serves to better display the ratios of different enmeshed gears.



Slika 5 *Prikaz modela mjenjačke kutije [1]*

Figure 5 *Representation of the gearbox [1]*

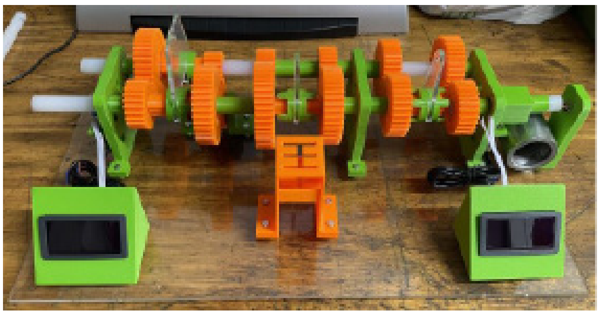
This model (Figure 1) consists of 4 shafts. One is the input shaft which, regardless of the speed or neutral position, is in constant engagement by way of one of the gears with the other shaft. The second shaft has 6 gears on it, 5 of which have an interference fit the shaft, and one gear has a clearance fit with the shaft. The third shaft, i.e., the output shaft is in constant enmeshment with the other by way of 5 gears, and it has 5 gears on it, 4 of which are in the interference fit with the shaft, and one is in the clearance fit. The fourth shaft carries a gear that has the purpose of changing the direction of rotation of the output shaft and is in constant enmeshment with the second and third shafts via this gear.

By engaging any of the speeds, power and torque are transmitted to the output shaft via a slide that is in interference fit with the shaft. The model also consists of 4 supports, for the shafts and the electric motor, 4 claw clutches, 4 slides on which the claw clutches are located, 12 spacers that keep the distance between the gears and the rack, 3 housings for the screens and the gear shift itself, 3 forks that transmit the shift from the manual transmission to the claw clutch and 3 rods that transmit the shift from the manual transmission to the forks. From the finished semi-finished products, this model consists of two screens, two Hall sensors, an electric motor and an adapter.

The transmission ratios of this gearbox model depend on the gear it is in. Thus, in first gear it has a transmission ratio of 1:0.3535, in second gear 1:0.4667, in third gear 1:0.7778, in fourth gear 1:1, in fifth gear 1:1.2963 and in reverse 1:0.3111. Given that the system is driven by an electric motor that rotates at a speed of 30 revolutions per minute, this means that the input shaft will also constantly rotate at the same speed regardless of the selected gear, i.e., 30 revolutions per minute. The output shaft will rotate in the first gear at 10.6 rpm, in second gear 14 rpm, in third gear 23.3 rpm, in fourth gear 30 rpm, in fifth gear 38.9 rpm and in reverse 9.3 revolutions per minute. [1]

This gearbox model is most often used in cars where, depending on the manufacturer, the gear ratios are different in order to make the best use of the power and torque of the internal combustion engine in such a way that it is constantly kept at the optimal rotational speed via the gearbox.

From these data on speed ratios, we can conclude that by reducing the number of revolutions, we get more torque, which is very important during the initial movement of the vehicle. The smallest ratio is in reverse gear and first gear, which confirms this claim. On the other hand, in fifth gear we have the lowest available torque.



Slika 6 *Sastavljeni model mjenjačke kutije [1]*

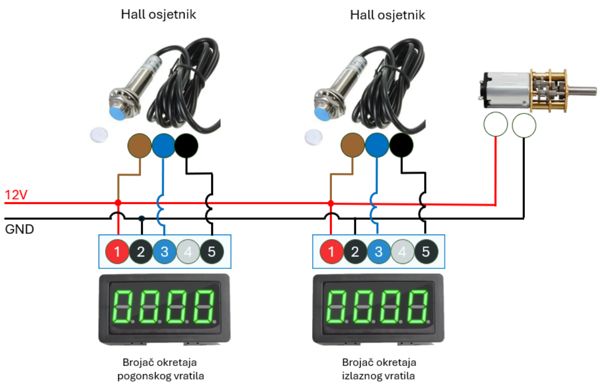
Figure 6 *Gearbox assembly [1]*

The assembly of the finished parts begins with grinding the parts to remove the support structures created during 3D printing and to obtain interference fits between the 3D printed parts and the shaft. Grooves and claw clutch teeth were also ground for better and smoother gear engagement.

After grinding, the assembly of the parts on the shafts commences. Since there are many parts in the interference fit with the shafts, a manual hydraulic press is used, without which it would not be possible to assembly the parts. The manual hydraulic press also enables interference fits to be made and to ensure that the parts themselves do not slip during transmission of power and torque and therefore the gearbox malfunctions. [1]

5. ELEKTRIČNA SHEMA SPAJANJA KOMPONENTI

5. ELECTRICAL DIAGRAM OF COMPONENT CONNECTIONS



Slika 7 *Shema spajanja motora, zaslona i osjetnika [1], [3], [4]*

Figure 7 *Wiring diagram for the motor, display, and sensor [1], [3], [4]*

The electronic assembly (Figure 3) consists of two Hall sensors that are connected to a screen that has the ability to count signals from these sensors. There are magnets on the input and output shafts that are used to excite the Hall sensor and send the same signal through the blue conductor to port number 3 of the revolution counter, which displays the current number of revolutions per minute on the screen. Sensors, motor and shaft revolution counter are powered by 12 V DC voltage. The motor rotates at a speed of 30 revolutions per minute when supplied with 12 V and this is the reference input speed of the shaft of the educational model of the gearbox.

6. ZAKLJUČAK
6. CONCLUSION

This paper shows the development of an educational model of a gearbox integrating in the process the disciplines of mechanical engineering and electrical engineering. Through the creation of the gearbox, the emphasis was placed on familiarizing students with the production process as well as the functionality of the gearbox used in various transport vehicles and machines. The creation of the model included all stages from modelling in SolidWorks CAD software, 3D parts printing, laser processing of materials to assembling and connecting the electronic components.

Using additive technologies such as 3D printing and modern laser cutting methods, this work taps into practical knowledge of modern production processes. The electric motor and Hall sensors enabled a demonstration of the operation of the gearbox, providing useful visual and measurement data on speed ratios and power and torque transmission.

This model not only serves as an educational tool for a better understanding of the mechanical and electrical aspects of the gearbox, but also encourages the development of practical skills in the design and manufacture of complex technical systems. Working on this model encourages interdisciplinary cooperation, which is a key component of modern engineering work.

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7. REFERENCES

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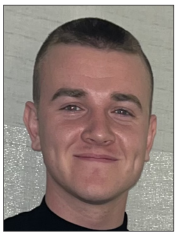

• **Neven Krulić** - Rođen je 2001. godine u Koprivnici te završio srednjoškolsko obrazovanje 2020. godine u I. tehničkoj školi Tesla, smjer strojarski tehničar. 2021. godine upisuje preddiplomski studij na Tehničkom veleučilištu u Zagrebu, smjer strojarstvo. Trenutno student zadnje godine preddiplomskog studija na Tehničkom veleučilištu u Zagrebu gdje namjerava upisati diplomski studij.

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