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MODERN APPROACH FOR DESIGN AND MANUFACTURING OF PRODUCTS USING FDM PROCESS

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Abstract: *Rapid prototyping or additive manufacturing usually known as 3D printing or layer manufacturing is a very rapid direction of development regarding manufacturing technology. The article presents step by step methodology on the possibilities to use 3D printing technology for the production (fabrication and assembling) of prototype related to modern approach for engineering teaching methodology related to concept of circular economy. The main advantages of using 3D printing result in its abilities to obtain and produce directly needed components from CAD model, whose file is the information srealce for generating STL (Standard Triangulation Language) file, which is needed to start working on 3D printer.*

The paper presents an example of 3D printing using FDM (Fused Deposition Modeling) process and ABS plastic filament from which the component parts of the differential are made, preceded by the CAD phase in SolidWorks software and completed with the assembly phase of the differential transmission. It has been pointed out that the 3D printing process were developed with CAM software based on CAD model.

Key words: *3D printing, Circular economy, Computer Aided Design, Computer Aided Manufacturing, FDM process, Differential transmission.*

1. INTRODUCTION

The use of CAD/CAM (Computer Aided Design and Computer Aided Manufacturing) related to the design of manufacturing products dates back to the sixties of the last century. Thus, during the conceptual design of the product using CAD/CAM, the engineer must select and ensure the realization of the geometric parts respecting the quality and the tolerances of the surfaces, taking into account both the cost and the time required for the manufacture of the final product, and where appropriate, the possibility of assembling the parts in a functional assembly.

Nowadays, for the fabrication of complex shapes, the CAD/CAM technologies and systems are used very often and the newest trend in the developing manufacturing technologies is based on 3D printing and rapid prototyping [1,2].

Many varieties and production technologies have been created to provide the most common material for molding, such as SLS machines (methodical laser firing to sinter polymer-based powder particles to obtain layer by layer parts), on the other hand, FDM machines (melt and extrude polymer thread through the nozzle, laying it in a certain trajectory to obtain solid parts or bodies layer by layer) [1,3].

The paper describes and shows a sample of 3D printing with FDM (Fused Deposition Modeling) process and ABS plastic filament from which the component parts of the differential are made, preceded by the computer aided design phase in SolidWorks software and completed with the assembly phase of the differential transmission. It was noted that the 3D printing process were developed with CAD/CAM software based on designed 3D models.

The article presents a step-by-step methodology regarding the opportunities of 3D printing technology in fabrication (manufacturing and assembly) of a prototype, associated with a modern approach to the methodology of engineering education. The main advantages of using 3D printing result in its abilities to obtain and produce directly needed components from CAD path, whose information is the source for obtaining STL (Standard Triangulation Language) file, which is needed to start working on 3D printer.

2. CAD/CAM/CAE ASPECTS

It is hard to imagine and even inconceivable modern mechanical engineering without computer aided, manufacturing and engineering design CAD/CAM/CAE. A first step in mastering computer-aided design methods is learning basic computer graphics drawing procedures. Various software is known in this field that include drawing elements, dimensions, tolerances and adjustments, the properties of the used materials, like: AutoCAD, Solid Edge, SolidWorks, CATIA etc. The advantages offered by CAD/CAM/CAE software are described below [2]:

- Faster development of technical documentation;
- High precision of execution and assembly drawings;
- High speed of execution and assembly drawings;
- Possibility of editing the drawings or 3D models;
- Performing engineering calculation, constructive and functional optimization of the final product;
- Increase the Engineer's productivity;
- Rapid integration of the design process (CAD) with the manufacturing process (CAM), through STL file format, which is needed to start working on 3D printer.

For CAD process in this paper it used SOLIDWORKS™ 3D Mechanical CAD and/or Simulation Licensed Software Education Edition.

Computer aided design largely follows the same traditional methods and processes: select the drawing format, units of measurement, scale and then proceed to create the needed geometry for 3D parts of prototype or final product, in this case differential transmission, therefore by using graphical symbol as points, lines, curves, planes and different shapes will be obtained with detailed description about any designed component in a graphical form.

The motivation idea of this paper is not only to design something theoretically, but in the end bring to life real concept – a functional differential transmission.

As CAD greatly facilitates the process of manufacturing by conveying essential product information in an automated form that can be easily used by untrained or trained workers, more and more companies are choosing CAD/CAM/CAE to achieve the best accuracy, efficiency and economic growth through reduced time-to-market of their products. As a result, there is a big demand for CAD software and skilled personnel (engineers) who can use it.

Everything starts from the main advantages of a CAD drawing, that the editing process is faster than the manual method. Thus, CAD significantly reduces time design and allows for realistic simulations, rather than the creation and testing of real prototypes. The integration of CAD with CAM makes product development even faster and more efficient. As CAM stimulates and accelerates productivity, it has become an increasingly important visualization tool before the production process begins. This is why CAD is being used in almost every industry such as manufacturing, automotive, electronics, aerospace, and CAD training is becoming increasingly important.

In fact, instead of just creating blueprints, CAD has revolutionized the concept of design and the way it is implemented. Like manual sketching of technical and engineering drawings, CAD output conveys information such as tolerances, dimensions, technological processes and materials according to application-specific conventions in solid models. Instead of drawing on a solid form, designers use CAD to create product model forms (3D parts) with associated product data, and then create sketches (2D models) when needed [2].

It is important to remember when performing CAD teaching courses is to ensure that the student does not develop a dislike for CAD, or does not develop a feeling that its study is too difficult or complicated. Any good CAD training offers education in such a way that the student enjoys the journey through the course, while picking up the principles of CAD with pleasure and naturally.

It is also important to understand that CAD/CAM training is not complete without practical training.

Thereby the modern approach in CAD/CAM teaching and training is based on three pillars:

- CAD;
- CAM;
- Assembling process.

3. CIRCULAR ECONOMY

Creating practical device (differential transmission) for teaching purposes, starts with processes and components made to achieve the proposed objectives tended to be supported by several norms, namely: the criterion of sustainability, and circular economic model in concordance with sustainable development objectives proposed by the United Nations.

Sustainability or durability is system capacity to exist continuously. Lasting development involves ensuring the growing demands of humanity, without minimizing the possibility of future generations to obtain their own goals.

At the local and global level, generally the current economic model is a linear one, unsustainable, although the principles of sustainability are beginning to be applied in economically developed countries. The life cycle of most products includes:

- exploitation and extraction stages (raw material);
- production (objects);
- use (products);
- disposal (waste).

This process is characterized by two important effects: overuse exploitation of natural resources and pollution.

The solution for replacement the linear economy is the model for circular economy presented conceptually in figure 1. The model assumes reuse, repair and recycling of products considered waste. Recycling eliminates, at least partially, the need to exploit new natural resources, implicitly reducing the generated amount of waste. The circular economy requires the appropriate design of the product, which implies a long life and a construction that facilitates replacement and recycling components.

It is recommended to constantly evaluate the product life cycle, which comes to determine the impact on the environment associated with each stage product of, process or service generated by a social/industrial entity. The concepts of sustainability and circular economy are thoroughly analyzed by Geissdoerfer et. all [4].

In September 2015, the United Nation General Assembly adopted the 2030 Agenda for Sustainable Development that includes 17 Sustainable Development Goals (SDGs). Building on the principle of "*leaving no one behind*", the new Agenda emphasizes a holistic approach to achieving sustainable development for all. Based on these, several actions are developed to solve them especially global problems of humanity. For example, objective number 7 *Affordable and clean energy* have to solve the energy problem that must be clean and available to everyone. Objective 12 *Responsible Consumption and Production* involve sustainable production and consumption. Thus, by 2030, achieve the sustainable management and efficient use of natural resources, substantially reduce waste generation through prevention, reduction, recycling and reuse, everywhere people have the relevant information for sustainable development and lifestyles in harmony with nature. Objective 13 *Climate Action* needs the urgent involvement in the fight regarding climate change [5].

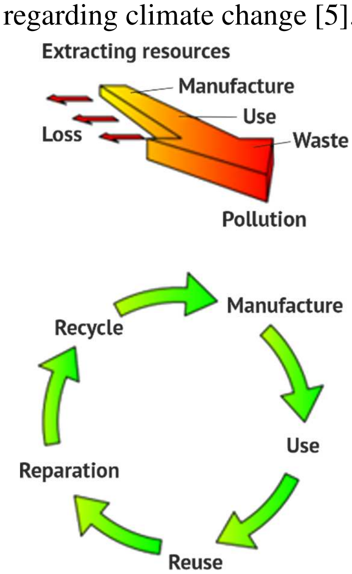

Fig.1. The linear and circular economic model [6]

Related to UN #Envision 2030, sustainable and circular economy [4,5] we start look up for device or part of them which can be recycled or reused for the manufacture or fabrication of new products. Because at our department exist a quite imposing number of work station (notebook) for CAD/CAM and printer EPSON or CANON from which year by year about 2-3% are scrapped, so it was decided to dismantle them and reuse the electric motors, belt transmissions, toothed wheel transmissions and other component parts which can be used for the design of other mechanical devices.

This is how was born the idea to combine the sustainable economy and the circular economy with the CAD design process and the CAM manufacturing process through 3D printing: some parts will be reused and some parts will be manufactured. Figure 2 present a dismembered EPSON L100 printer, from which it was reused electrical motor and belt transmission, to design new differential transmission. The main problem at this stage, the most important aspect that we have to establish are the dimensions Lxlxh of the assembly.

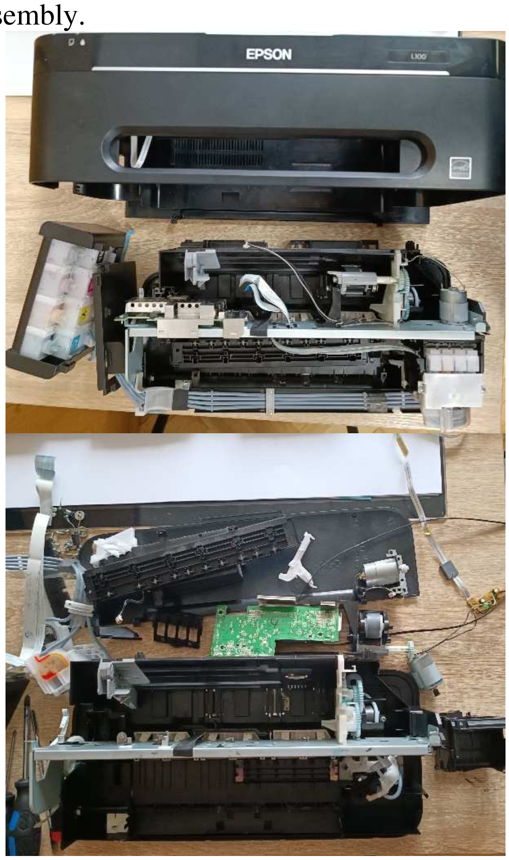

Fig.2. Dismembered EPSON L100 printer

4. CAD PROCESS

The CAD/CAM process stars from reused parts that was dismembered from EPSON L100 printer: electrical driver and belt transmission. Start from these two components it was established the main dimensions Lxlxh of future differential transmission according figure 3 main preliminary dimension for whole device will be 295x190x144 and for differential transmission will remain about 120x120x140.

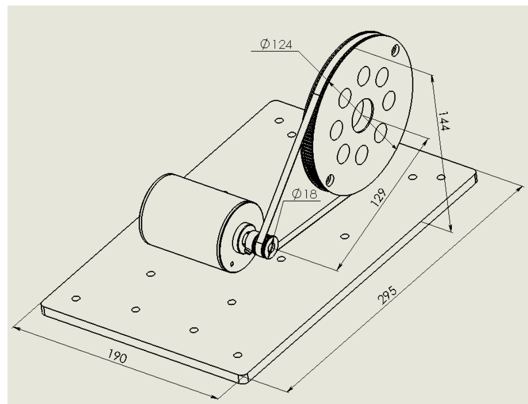

Fig.3. Preliminary dimensions 295 x 190 x 144

Belt transmissions or friction transmissions serve to transmit the rotational movement and torque from the driven (belt wheel $D_1=18\ mm$) shaft to the driving one (belt wheel $D_2=124\ mm$), in a certain ratio $i \approx 6.88$ and at a certain distance *129 mm* in this case:

$$i = \frac{D_2}{D_1} = \frac{124mm}{18mm} \cong 6.88. \tag{1}$$

Fig.4. Reused toothed belt

The reused toothed belt (figure 4), permit us to maintain strictly constant transmission ratio and these belts have a high traction capacity, silent operation. They can be used for power transmission up to 2 [kN] with velocities between 5 … 25 [m/s].

To design differential transmission 2K-H(-) Type according Yu and Beachley made from bevel wheels [7]. For satellite wheel $z = 17$ and for central wheels $z_a=z_b=24$.

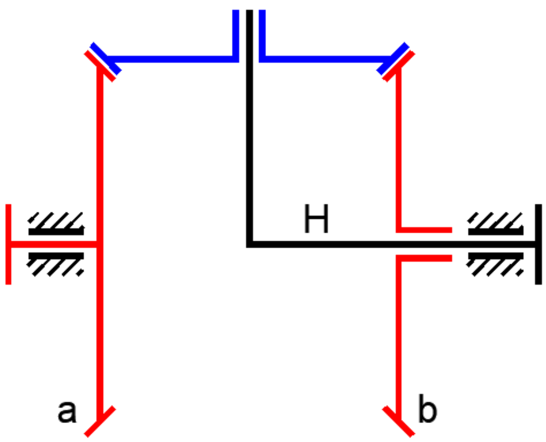

Fig.5. 2K-H(-) Type of differential [5]

CAD process was made within licensed software SOLIDWORKS [8]. In figure 6 and figure 7 we present process for design satellite wheel:

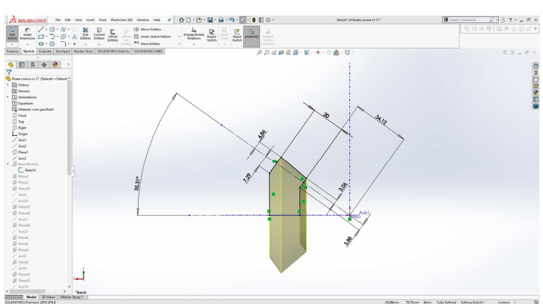

Fig.6. 2D Sketch of satellite wheel

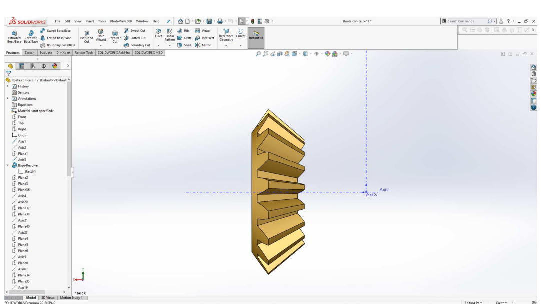

Fig.7. Final 3D model of satellite wheel

CAD process take about 5 working days, in which was designed whole parts of the entire final device. Figure 8 shows the final version of the whole assembly: differential transmission, belt transmission, electrical driver that can be used as a generator and tumbler to change driver rotation direction and switch ON/OFF electricity.

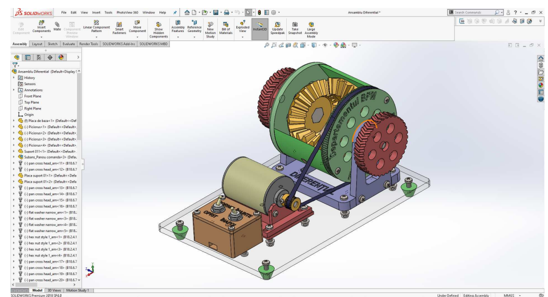

Fig.8. Final CAD assembly of designed device

In addition to reused and designed parts, standardized elements such as bearings or threaded assemblies (bolts, nuts, washers) were also used. Whole parts can be better visualized in exploded view of final device.

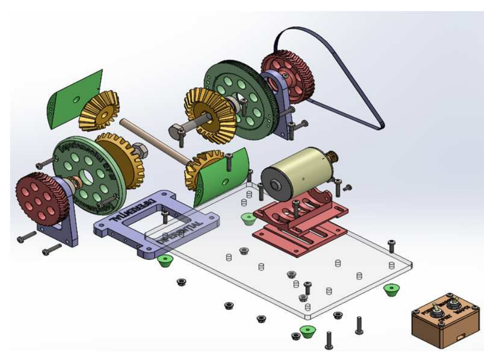

Fig.9. Exploded view of final device

5. MANUFACTURING AND ASSEMBLY PROCESS

Classic manufacturing techniques which include e.g. turning, milling or drilling are known as "Subtractive Manufacturing" and consists in removing excess material from preformed block. This type of process generates a lot of waste because the cut material cannot be reused. Moreover, scrap in the form of chips resulting from the machining process, due to its small thickness, is also a problematic metallurgical material.

In order to make it possible to use sustainable and circular economy, additive manufacturing was used to make the samples. This technology in contrast to subtractive processing, consists in the production of a part built of successively overlapping layers in the form of cross-sections.

3D printing as one of the additive technologies has various advantages and limitations. Its main advantages include the universality of this technology, which allows you to make products of any complex shape. In addition, thanks to the use of layer-by-layer production characteristics, it is possible to make parts that have not been possible to make using traditional manufacturing methods. Examples of such elements can be all kinds of complicated cooling or heating channels inside the elements. 3D printing significantly accelerates the design and prototyping process [9], reducing the time necessary for the implementation of new products from months to days or weeks, while the production of parts usually takes from minutes to several hours. Thanks to the fact that the price of 3D printers has fallen over the years, some devices are now within the financial reach of the average consumer or small business. Unfortunately, the 3D printing technology also has its limitations. One of the main problems with 3D printing is the ability to properly get the customer's design for the needs of 3D printing process. Very good knowledge of CAD (Computer Aided Desing) software alone is not enough at this stage. Another disadvantage is the cost of the professional equipment. While consumer printers can be purchased at affordable prices, the use of equipment and material from leading manufacturers such as Stratasys or 3D Systems involves a noticeable investment. The 3D printing technology is not the answer to every type of production method; however, its sophistication helps speed up design and engineering more than ever before.

In Fig. 10 was presented the CAD-CAM system used in presented example to prepare the design and G-code for it produce using 3D printer. Used material to obtain 3D printed pieces was an ABS filament of 1.75 mm diameter from Gembird® company, with melt point about 225 °C – 240 °C and density at 21.5 °C: 1.01 g/cm^3 [10].

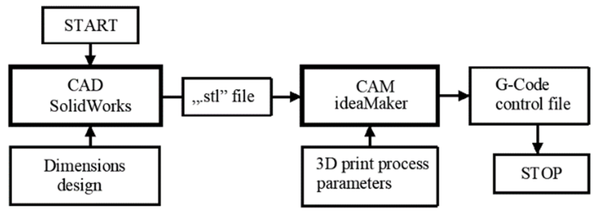

Fig.10. CAD/CAM principles for 3D printing

In this case, as CAD software SolidWorks was used [8]. As CAM component, the popular software ideaMaker was used, us slicer software for RAISE 3D E2 desktop 3D printer (Fig. 11). This desktop 3D printer can print with a variety of different materials called filaments, and its unique extruder gear design enables it to use flexible 3D printing materials, such as ABS, more reliably and with better results [9].

Fig.11. The desktop 3D printer (RAISE 3D E2) used in this work

The first stage of 3D printing process is a design of the part in CAD software. The bridge between 3D designed parts and real manufactured parts is STL format, that help us quickly and comfortably transfer the information to the 3D printer.The STL format describes a 3D model's surface by using an array of linked triangles to recreate the surface geometry, the greater the number of mentioned triangles, the more precise and smoother quality of the geometry. The STL format is universal and compatible with almost all 3D printers, which is why it is so popular over others like VRML, AMF, 3MF, OBJ, etc. Figure 12 present the 3D process to obtain bevel satellite wheel and obtained wheel.

Fig.12. The desktop 3D printer (RAISE 3D E2) used in this work

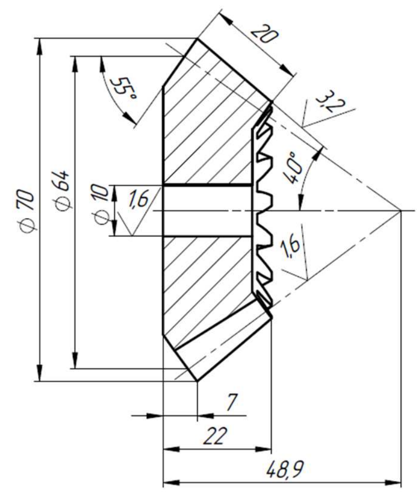

Fig.13. Technical draw for satellite bevel wheel

Table 1

Theoretical and practical dimension of 3D printing.

Dimension type	*Theoretical dimension*	*Measured dimension*	*Deviation*
Inner hole	⌀10	⌀10.2	+0.2
Inner hole	Ra 1,6	Ra 2.3	+0.7
Inner tooth	Ra 1,6	Ra 2.6	+1.0
Outer tooth	Ra 3.2	Ra 2.7	-0.5

The dimension's accuracy of the printing parts (dimensions in the drawing - figure 13) and the real size of the printed wheel can be visualized in Table 1. The roughness of the surfaces was measured with Taylor Hobson Instrument for measuring surface accuracy. The dimension's accuracy of the obtained parts was acceptable and permit to mount them and assemble differential transmission as shown in figure 14.

Fig.14. Final working assembled differential transmission

6. CONCLUSION

The 3D printing and rapid prototyping is denied for the development of manufacturing technologies, especially suitable for the tasks of prototyping, unique solutions and education. This provided high accuracy in the assembly of elements to obtain a proper working device.

Integration of circular economy principles in the educational process is very important. The high schools and universities can become a pole of excellence for the dissemination of information and in the case of circular economy objectives - of information that presupposes the adoption of environmentally friendly behavior and the dissemination of good practices, primarily at home which will also have an impact at the local and global level. Thereby, teachers and professors are obliged to educate a generation that will knows and applies at work or in everyday life the principles of the circular economy. Regarding mechanical engineering students especially those who was involved in CAD process it is possible to introduce a new terminology or change CAD in to GCAD (Green Computer Aided Design) – where specialist not only increase engineer`s productivity when they are performing engineering calculation and design, constructive and functional optimization but also take into account the principles of the circular economy.

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[10] ABS plastic filament for 3D printers, 1.75 mm diameter from gembird® company. https://gembird.com/products.aspx?sg=285

Abordarea modernă pentru proiectarea și fabricația produselor utilizând procesul de prototipare rapidă

Prototiparea rapidă sau fabricarea aditivă cunoscută de obicei sub numele de imprimare 3D sau fabricare în straturi este o direcție care se dezvoltă rapid cu aplicații directe în tehnologia de fabricație. Articolul prezintă metodologia legată de posibilitățile de utilizare a tehnologiei de imprimare 3D pentru producerea prototipurilor sau modelelor reale (mecanismul diferențial în articolul dat) combinat cu abordarea modernă a metodologiei de predare în mediul ingineresc bazată pe conceptul economiei circulare. Principalele avantaje ale utilizării imprimării 3D rezultă în abilitățile sale de a obține și produce componentele necesare direct din modelul CAD, al cărui fișier este sursa de informații pentru generarea fișierului FTL, care este necesar pentru a începe lucrul la imprimanta 3D.

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