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TECHNICAL AND ECONOMIC ANALYSIS OF MANUFACTURING PROCESS FOR HIGH PRECISION CUSTOMIZED PART

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Abstract: This paper presents research results on optimum manufacturing process for prototyping high precision customized products parts and, therefore, products. The results would be applied to reduce research cost for development of new personalized devices used, for example, in prosthetics of missing limbs. These devices need high precision parts and, not the least, affordable costs. In order to obtain the prototype of these devices, several types of manufacturing processes have been analysed. As conclusion of the research results, we can state that the selection of the best manufacturing process type for obtaining high precision customized parts is a big challenge for engineers as they must get the best technique which ensures high precision (on one hand) and affordable costs (materials and equipment's, on the other hand). When the prototyped parts are components of a special product, as example, an upper limb prosthesis, high attention should be also focused on the reliability of prototyped parts. 3D printing technologies have developed and extremely evolved lately but still there are cases when their performances are limited (especially when small dimensions and tight tolerances are required for parts' geometry). Also, considering the component costs, an adequate analysis must be done in order to select the optimal variant of the production process. The research results presented in this paper are focused on the analysis of optimal cost for prototyping customized parts of personalized devices used for the upper limb prosthesis.
Key words: technical – economic analysis, manufacturing cost, customized part, high precision, 3D printing, CNC turning.

1. INTRODUCTION

In recent years, manufacturing technologies have a high evolution and additive technologies have been a challenge for many production/manufacturing companies in various fields, which manufacturing various components for products with a very high degree of precision. Usually, additive technologies are used to make customized products, prototypes or product / prototype components. However, additive technology increasingly used for the mass customization, production of any types of open-source designs in the field of agriculture, in healthcare, automotive industry, locomotive industry and aviation industries [1].
In the production processes, there is the problem of reducing the production costs, but without reducing the quality requirements that the obtained products must meet.
Thus, the question arises, if these new technologies that the world of product manufacturing is tempted to use only because they are new, are suitable to be used in the case of customizable products whose components must meet certain conditions regarding accuracy.
According with Mohsen Attaran [2] the five key benefits of Additive Manufacturing (AM) technologies versus traditional manufacturing are cost, speed, quality, innovation/transformation, and impact, but AM will not replace existing conventional production methods. Thus, using the AM technologies for healthcare customised product could be a greatest transformative potential [2].
The applications of AM in medical industry for manufacturing prosthesis [3, 4] - even human organs is becoming an increasingly standard implementation of the technology.
But for the moment, the technology must be improved because the accuracy of printed products is not all time according with prescription quality requirements and, sometime the cost of research could be a limit for research. So, the researchers do not expect that AM technologies to replace conventional manufacturing processes [2].
This paper presents research results on optimum manufacturing process for prototyping high precision customized products parts and, therefore, products.
The results would be applied to reduce cost for development of new personalized devices used, for example, in prosthetics of missing limbs. These devices need high precision parts and, not the least, affordable costs.

2. METHODOLOGY

The evaluation method, in this research, consists in according a weighted mark for the studied process, based on the importance of the parameters considered. Basically, the most important is to obtain a functional product so that geometric precision (GP) is weighted by the higher score. The manufacturing cost (MC) has high importance but is not decisive. The least considered to be relevant is the processing time PT). The values of weighted marks are: 0.55; 0.35 and, respectively, 0.10.

For each of the studied parameters, in calculation there is considered the coded value (see equation 1), which is not dimensional (to avoid different measurement units):

$$z = \frac{x - \frac{x_{min} + x_{max}}{2}}{\frac{x_{max} - x_{min}}{2}} \tag{1}$$

where x is real value of the parameters (GP, MC, PT) and z its coded value.

It results the process mark (PM), as result of the formula 2:

$$PM = 0.55 \cdot GP + 0.35 \cdot MC + 0.1 \cdot PT \tag{2}$$

where the higher value for PM is for the most adequate process.

The prototype intended to be manufactured (that stands as background for this study) is that of a hand prosthesis, Figure 1.

The basic mechanical component for finger motion transmission is the worm gear. Due to dimensions of the prototype and the motion accuracy required, the worm gear module is 0.6 mm. So, it should be a small dimension's part, with high precision and, thus, difficult to manufacture. This is why, the relevant criteria considered in this research is that of obtaining required geometric precision.

In order to obtain the prototype of these devices, several types of manufacturing processes have been analysed. An efficient process for obtaining customised parts is 3D printing, so that two printing process types have been considered (based on their characteristics and resources needed). Another process type studied has been conventional manufacturing (machining).

The first 3D printing technique used was FDM (fused deposition modelling) with biodegradable thermoplastic polymer (PLA), material and by Creality Ender 3-Pro equipment. The second prototyping technique considered was the one from EnvisionTEC that is based on 3SP (Scan, Spin and Selectively Photocure) technology. This technique enables to fast 3D print customized parts with complex shapes and tight tolerances. The printing equipment was Envisiontec ULTRA 3SP while the material was special resin, EnvisionTEC's premium E-Model Light (commonly used for orthodontic purposes). The third analysed prototyping process was turning - on CNC lathe (machining).

As mentioned before, the main purpose of this analysis was to obtain high-precision parts at a moderate cost for prototyping the hand prosthesis.

First, there was considered the FDM (fused deposition modelling) technique, with biodegradable thermoplastic polymer, PLA, and the equipment Creality Ender 3-Pro [5], Figure 2.

The second prototyping technique considered was the one from EnvisionTEC, Figure 3. It is based on "3SP (Scan, Spin and Selectively Photocure) technology and enables fast printing of accurate parts from STL files, no matter what the geometric complexity is. The printing equipment is Envisiontec ULTRA 3SP and the resin is a special one, EnvisionTEC's premium E-Model Light [6] (commonly used for orthodontic purposes).

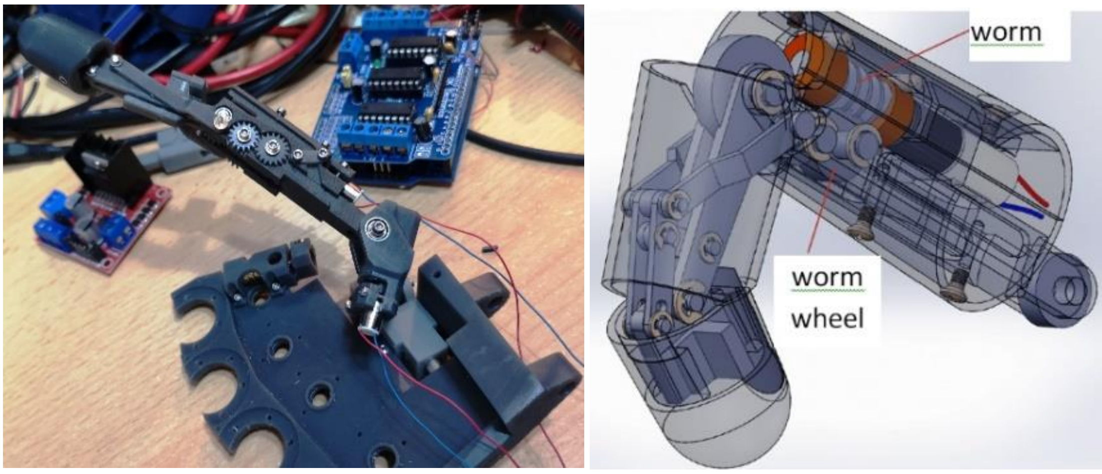
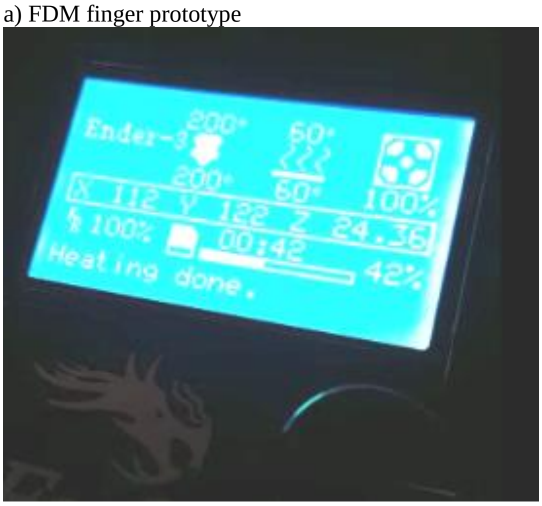


Fig. 1. Hand prosthesis – thumb prototype

a) FDM finger prototype



b) FDM equipment

Fig. 2. FDM prototyping

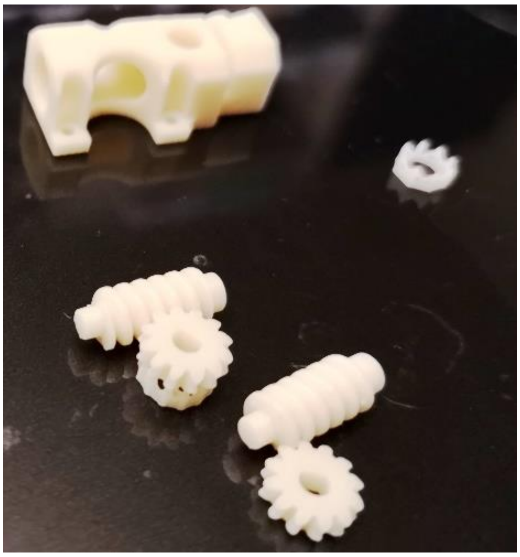


Fig. 3. 3SP printed parts

Fig. 4. Turning the worm prototype

The third technique studied for obtaining the parts prototype was that of conventional machining, meaning turning on CNC lathe, Figure 4. The worm was machined from brass, rod as raw material.

Basically, the proposed methodology is intended to support the purpose of this research which is to identify the optimal manufacturing process for obtaining the parts with high precision for customized products.

The obtained result could be used to reduce the research cost of developing new devices used especially in medical fields.

3. RESULTS AND DISCUSSIONS

Basically, none of the FDM printed worm gears were good enough for finger motion, as the worm and the wheel could not get in contact. It is assumed that this prototyping technique does not enable very small and accurate dimensions of parts, such as 0.6 mm module and 0.005 mm tolerances. The second tested technique, 3SP, resulted in, relatively good geometric precision of parts. Still, for the worm gear, there was not a perfect contact of the worm and the wheel, especially when assembled with the micro-motor for motion transmission, Figure 5.

The third applied technique, that of worm turning was the one that ensured the geometric precision required for worm gear, Figure 6. This is the case when the 0.6 mm module was checked and was right, as well as when a correct finger motion was generated.

The manufacturing components of the studied product - customized device, hand prosthesis, was conditioned by high geometric precision required. Thus, there was the problem of obtaining components that meet the prescribed conditions, but with a moderate cost.

For example, the manufacture of the worm gear caused some problems during manufacturing process. For the accuracy (tolerances and surface shape) obtained in the manufacturing process, there has been allocated grades between 1 to 10 were, for a high precision, the grade is 10 and for an inadequate precision, the grade is 1.

Analysing the final part (worm gear) obtained by each of the three proposed manufacturing methods, the parameters of operative programming of the production results (time and cost) reported on the obtained precision are presented in Table 1.

Even if in the case of using the FDM method the production cost is minimum, the precision of the part is very low so, basically, the functional role of the part could not be fulfilled. Also, the processing time is very high comparing with processing time in machining process.

The final part (worm gear components), obtained after manufacturing by each of the studied methods are presented in Figure 7.

Finally, one can notice that additive manufacturing technologies are very versatile and efficient in current manufacturing processes but, for parts with small dimension and tight tolerances they cannot be used, because their real performances are limited.

Fig. 5. Test the worm gear 3SP prototype

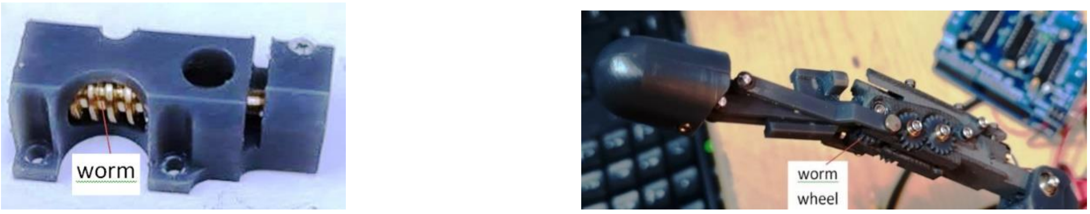


Fig. 6. Test the worm gear machined prototype

Table 1. Manufacturing process analyses results

Method	Processing time, PT	Manufacturing cost, MC	Geometric precision, GP	Process mark, PM	Result
FDM	360 [min]	1 [Euro]	2	-0.800	Inadequate process
	1 (coded)	-1 (coded)	-1		
3SP	84 [min]	2.8 [Euro]	6	0.285	Adequate process
	-0.65 (coded)	1 (coded)	0		
Machining (turning on CNC lathe)	25 [min]	1.6 [Euro]	10	0.333	**Most adequate process**

FDM method prototyping 3SP prototyping Machining

Fig.7. Final studied part (worm – worm wheel)

4. CONCLUSIONS

Analysing the above-mentioned results, we can state that choosing of manufacturing process for customized part is a big challenge for engineers because they must find an optimum between quality and manufacturing cost, especially when we discuss about customized products like prothesis.

Usually, the additive technologies are used for manufacturing prototypes, although lately they are found even in large series and mass productions, but in the case of manufacturing prosthetic products, used in the medical field, they must be customized according to the characteristics of the person who will wear the prosthesis. Thus, there is the problem of an efficient analysis regarding the way of manufacturing parts of the final product because it must fulfill the functional role established in the conception and design phase. Thus, even if the cost of such personalised products is very important, its functional role prevails, because the operation falls within the established parameters, the component parts of the product must fully comply with the prescribed tolerances.

Also, considering the component costs, an adequate analysis must be done to select the optimal variant of the production process. The research results presented in this paper are focused on the analysis of optimal cost for prototyping customized parts of customized hand prosthesis.

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