Research of manufactured devices for the automotive and medical industry using 3D printing

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Abstract.. This paper presents the methods of manufacturing devices used for the fabrication of parts in the automotive and medical industries, manufactured by 3D printing. In industrial drive technology, the automotive industry and other similar industries, it is necessary to use devices for orienting and fixing the parts to be manufactured in order to obtain the finished product.In the final stages of manufacturing and beyond, it is necessary that the devices are very reliable, to present a good condition of their surface so that there is no damage to the parts that will come into contact with them. In this respect, this paper presents devices for orientation and fixing of parts and finished products, devices that have been obtained by 3D printing, from recyclable materials, with low weight and surface condition and high dimensional accuracy. In order to improve the surface of the active part of the devices, after 3D printing, they were finished using CNC milling machines, thus achieving surface finishes of the order of those achieved by grinding operations. These devices were also validated by finite element analysis and then manufactured and introduced into the production line, and have been in use for about 2 years without any problems in use.

1.Introduction

In the automotive industry, the future direction requires the continuous development of new concepts and the optimization of all business processes [1]. Also, the growing globalization produces a growing distance from traditional business processes, both at the design, manufacturing, sales and logistics level, as well as convergence between information and communication technologies and process optimization [2].

Equipment and machinery manufacturing companies in fields such as automotive, medical, machine and equipment manufacturing [3], [4], [5] are looking for manufacturing methods that are useful both from an environmental point of view, sustainable, low resource consumption, high reliability, low production prices, increased productivity, increased performance, methods involving the use of new materials [6], [7], new machinery [8], [9], these being combined resulting in new technologies, namely hybrid manufacturing [10], [11], [12].

These new technologies combine additive and subtractive manufacturing operations [13], [14], and the quality of the obtained parts as well as the manufacturing time are considerably improved [15], [16].

In order to increase productivity, on CNC machines, orientation and clamping devices are used, automation, introduction of robots in the production line, combined tools [17], [18], thus the performance of the new products obtained is of a high level, which leads to the emergence of new automobiles, medical devices, of a complexity and quality far beyond those already known, this being achieved at a fairly high speed [19].

The newest manufacturing methods, in addition to those already known, are those of additive manufacturing [20], methods that involve the manufacture of parts from both plastics [21], and metallic materials [6], [22], materials with good properties in their exploitation, thus from them being manufactured both parts for different fields but especially the manufacture of devices [23], [24].

Devices make it possible to manufacture new parts, and considering that they are not mass-produced, 3D printing is a reliable technology from this point of view, fast, easy to make, and finally, it is possible to add machining operations to finish their active parts [25].

2. Device description

This paper presents two types of devices that are used in different industries, industrial drive technologies and medical industry, devices that are involved in the manufacturing process of motors in the two branches, both being manufactured by Fused Deposition Modeling (also known as FDM), the material used being Acrylonitrile Butadiene Styrene (ABS) [26], a material with good operating properties, the active part being finished by milling with a CNC machine [27].

2.1 Device used for automotive parts

In industrial drive technologies, industrial purpose equipment is used in simplified assembly increased system reliability, increased system lifetime, optimised thermal management improved handling during assembly and maintenance, thus the device shown in ***Figure 1***, is used for the proper labelling of an electric motor.

a) 3D model devices

b) Assembly device on the equipment

Figure 1 Device fixed in machine

In order to properly label the engine, it is necessary to label it to certain dimensions imposed by the project, so this device has a double role, both as a support and as a poka-yoke system, so the labeling is done properly.

Due to the complexity of the device, engine labelling will be performed in an optimal working position for the operator, and the reject rate in case of labelling (mislabelling) has decreased by 15%, initially the engine was labelled in a device without poka-yoke system. (***Figure 2***).

a) Labelling support (initial)

b) Labelling support (current)

Figure 2 Comparison between the old and new device

Also the ergonomics of its use in the production process by the operator is increased, so the barcode can be scanned while the motor is fixed in the device and not outside of it, as before. (***Figure 3***).

Figure 3 Scanning the part on the device

The 3D printer with the help of which this support was printed, is an industrial 3D printer Creator 3 [28], use of printing technology Fused Filament Fabrication (FFF), also known as fused deposition moulding (with the acronym FDM) or free filament fabrication, is a 3D printing process using a continuous filament of a thermoplastic material.

The dimensional accuracy of this support is of the order of tenths of millimetres, so there is no need for subsequent sharpening to tolerate the hole (active area) where the motor is to be positioned. Due to the fact that ABS is a material with good elasticity properties compared to another filament such as polylactic acid (PLA), which is a stiffer material with good friction properties, ABS is chosen as the material to be used for the ABS backing.

The 3D printed device was chosen because the delivery time of a new device manufactured by a supplier was 12 weeks, and in order to validate a new device to be produced by 3D printing (in 8 hours), a finite element analysis was applied to it, taking into account the following guidelines:

- Material to be made of: ABS
- Number of parts produced using this device: approximately 600 parts/day
- Motor weight: about 1kg
- Temperature at which it will work: 10ºC - 40ºC (50 ºF - 104 ºF)
- Relative humidity: ≤ 85%
- Atmospheric pressure : 700hPa - 1060hPa

Following analysis and manufacturing, the device was measured and then introduced into the production line, monitored by the process engineer responsible for that product, and finally validated as an OK device.

2.2 Device used for medical parts

The best possible supply requires the best possible technology. Using state-of-the-art pump technology significantly improves operational procedures, both in terms of quality and speed.

These systems and equipment use a range of pump drives from ebm-papst. It is crucial that these drives are quiet, have a high power density and provide precise power dosing for the conveyed substances. As a renowned engineering partner and manufacturer of pump drives, ebm-papst products are used in numerous medical technology and industrial applications [29].

Figure 4 Medical products which containing EBM engines [29]

There is a very high demand for these devices in the medical industry, due to the fact that many people suffer from this condition (chronic kidney failure on hemodialysis) [30], so due in part to increasing risk factors such as obesity and diabetes, the number of CKD patients has also increased, affecting approximately 843.6 million people worldwide in 2017 [31], [32].

Chronic kidney disease (CKD) is an important public and medical problem in the world due to the high burden on healthcare systems, so it is estimated that the number of dialysis patients will reach 5.5 million in 2030.[33].

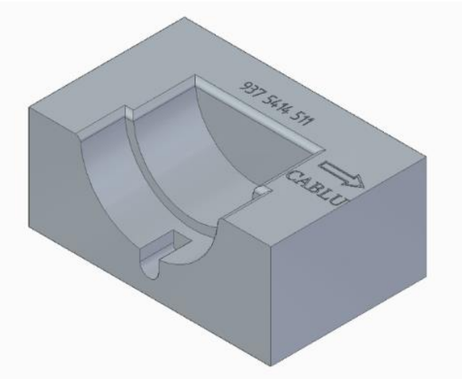
Figure 5 shows the characteristics of patients in Romania who started dialysis in the period 2015-2020, so it can be seen a high demand for the manufacture of such devices.

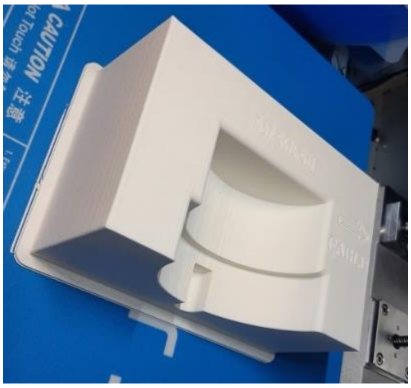
	2015	2016	2017	2018	2019	2020
Number	2885	2977	2930	3060	3097	2426
Median age (years)	63.3	64.8	64.7	64.9	65	64
Age >75 years (%)	18%	20%	19%	18%	19%	17%
Male (%)	59%	57%	58%	58%	59%	60%
Primary kidney disease (%)						
Diabetic cronic kidney disease	11%	10%	12%	11%	12%	12%
• Glomerular nephropathies	13%	11%	8%	9%	9%	11%
• Tubulo-interstitial nephropathies	6%	6%	6%	5%	8%	10%
• High blood pressure	6%	6%	7%	6%	8%	7%
• Vascular nephropathies	3%	3%	3%	2%	2%	1%
• Renal polycysticercosis	4%	4%	3%	3%	3%	3%
• Another	12%	11%	10%	11%	9%	11%
• Unknown	45%	49%	51%	52%	49%	45%

Figure 5 Characteristics of patients who started dialysis between 2015-2020 [34]

With this in mind, companies such as Ebm Papst and others, have the challenge, together with mechanical engineers, electronics engineers, etc., to manufacture such devices capable of treating these conditions, and in this case, at EBM, we use the combination of 3D printing processes with chipping methods, thus leading to the manufacture of equipment that is ultimately used to produce medical devices. [28],

The figure below (Figure 6) shows the 3D model of a brushless DC motor mount from EBM Papst Oradea, which is used in the production process of an electric motor [3]. The motor bracket is a device required to be made of plastic (ABS) to prevent scratching of the motor housing during the assembly process.



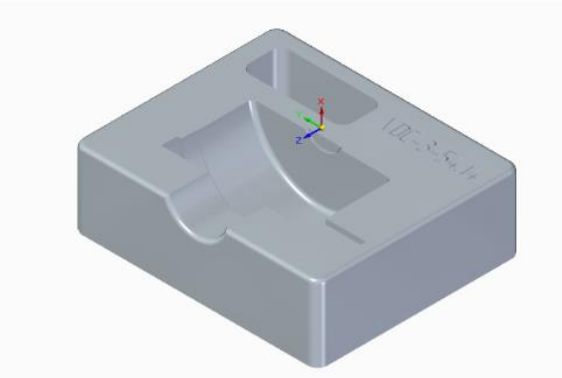


a) 3D model, Brushless support

b) 3D printed, Brushless support

Figure 6 Brushless motor support 1

Another case, similar to the one presented above, is the manufacture of another engine mount, the "poka-yoke" mount, which is designed to facilitate engine labelling and testing in the engine manufacturing process. (**Figure *7***).



a) 3D model, Brushless support

b) 3D printed, Brushless support

Figure 7 Brushless motor support 2

As mentioned in the previous chapters, in order to improve the quality of the surface of the device (**Figure *7***)., it was subjected to machining operations, namely of its active area (the location where the motor is to be fixed), due to the high roughness values favouring the appearance of degradation of the motor paint in the area of contact with it (**Figure 8**).

The roughness of the surfaces obtained from the printing of the substrate is shown in **Figure 9**, a roughness generally characteristic of rough machining. [35].

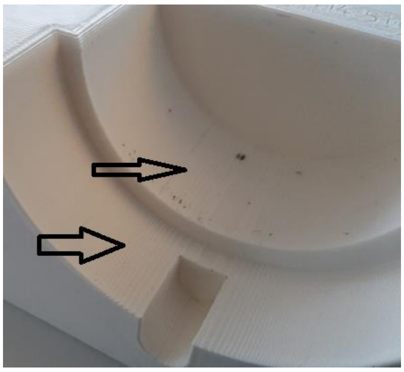


Figure 8 Motor support 3D printing

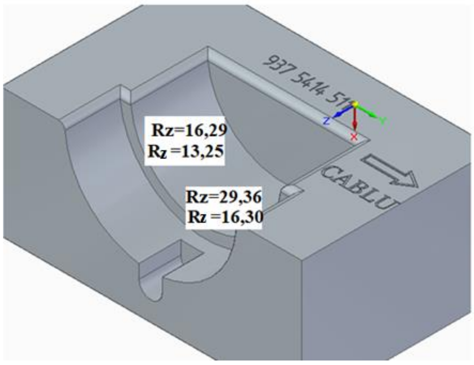
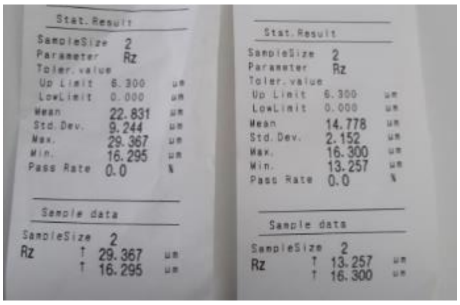


Figure 9 Roughness (Rz) after 3D printing

3. Machining of motor supports

Following the 3D printing of the supports , they were checked in terms of surface condition, thus the results presented in Table 1 show the roughness Ra and Rz of the areas/surfaces in contact with the engine.,

Table 1 Roughness Ra and Rz after printing and milling

Operation type	Area	Rz[μm]	Ra[μm]	
After 3D printing	Lower	29,367	8,633	
	Lateral	16,295	4,624	
After milling operation	Lower	16,300	4,625	
	Lateral	13,257	3,715	

These surfaces, resulting from the combination of additive and subtractive-milling processing (**Figure 10**), exhibit mechanical, dimensional and surface condition characteristics (**Figure 11**), that are suitable for optimal operation, and the engine can be fixed into the substrate without damaging the paint (**Figure 12**).

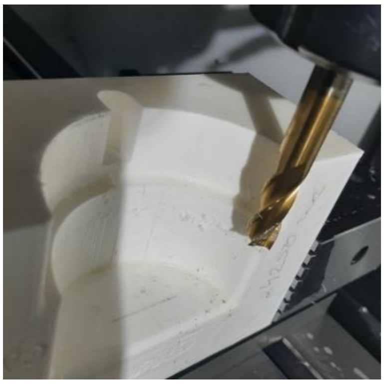


Figure 10 Milling of the active area of the support

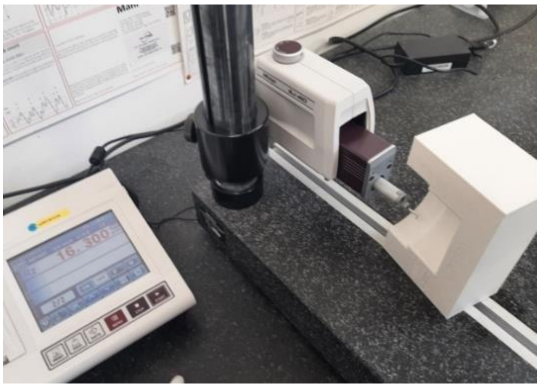
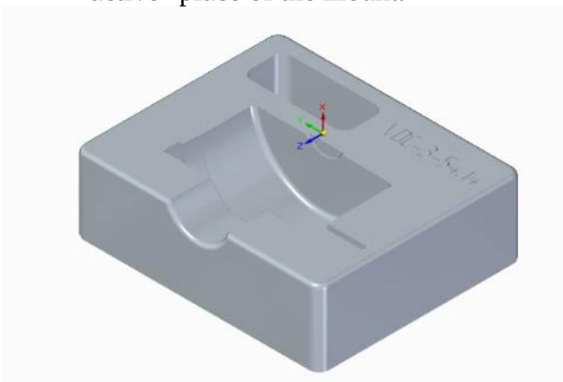


Figure 11 Surface area analysis

Figure 12 Engine positioned in the support

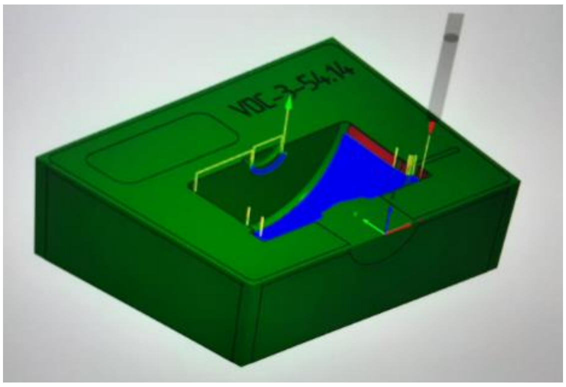
As steps of machining these surfaces, in the figures below (**Figure 13**), the stages through which a part goes by combining additive and subtractive machining and also the motor mount are shown, as follows:

- **Step 1 -** 3D model the substrate according to the project requirements using Solid Edge 2023,
- **Step 2-** 3D print the motor mount with an off-set = 0,5 mm/ contour, to leave enough material for the chipping,
- **Step 3 -** creation of the part program for the CNC machine, using Esprit TNG software,
- **Step 4-** after 3D printing, the part was clamped in a vice and machined on the active part using a Bullnose milling cutter with diameter = 4mm, as the CNC machine was a MiniMill2,
- **Step 5-** the motor mount is presented after the milling, and the workpiece (motor) is fixed in the "active" place of the mount.

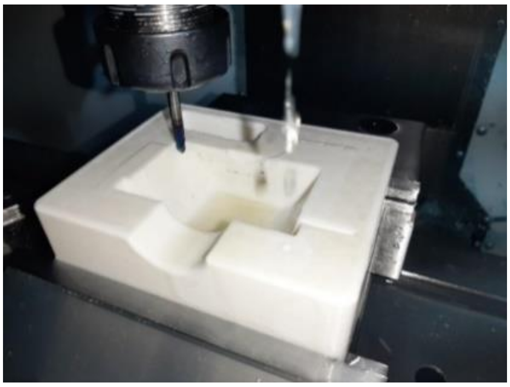


1. 3D design of the motor support

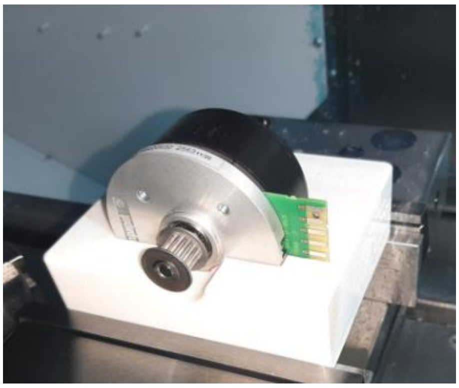
2. 3D printing of the motor support



3. Prepare of part program for milling



4. Support milling after 3D printing



5. Fixing the motor in the milled support

Figure 13 Steps required to manufacture an engine support

4. FEA analysis of engine support

The essence of finite element stress analysis is the replacement of the deformable body, i.e. the real continuum, by an articulated structural system whose sub-regions are called finite elements and which are in fact component parts of that body. We can therefore speak of a finite element structure that replaces the real structure.

An element is therefore a well-defined region of the body, but not only that, it is necessary that the properties of the element be adequately formulated so that it has a functionality dependent on the constraints imposed by the behaviour of the whole of which it is part. The correct formulation of these properties is done by means of matrix methods.

The formulation of the finite element properties, as part of a whole, is the starting point in solving the problem and is based on the precise knowledge of the geometrical and mechanical characteristics of each element, as well as on the evaluation of the nodal forces (forces, pressures and moments, impulses, energies, etc.) for each element, also by separate calculation.

The nodal forces are composed of two types of forces: concentrated forces taken up by the nodes and transmitted to the element, and forces transmitted to the nodes by the element itself. The latter are caused by loads distributed along the element and stresses due to temperature, inaccuracies in the assembly, etc. In short, nodal forces are expressed either directly through their components or indirectly through nodal displacements (arrows and bending moments, for example).

The procedure of the Finite Element Analysis Method can be briefly represented in a scheme like the one shown below:

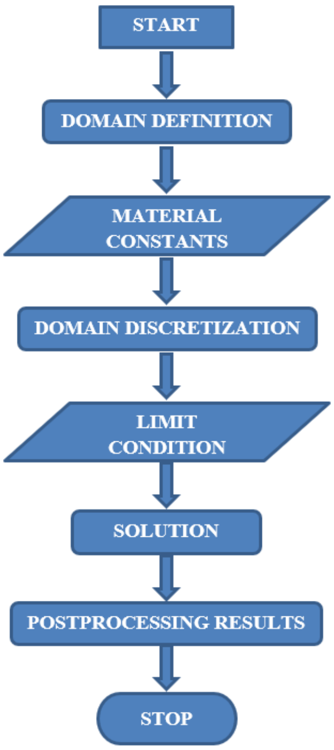


Figure 14 Finite Element Analysis Method Procedure

This device (motor support) is used in the production line, with a usage rate of 600 parts per day, which translates into 1200 cycles/day. The motors that are moulded using this device have a weight of about 900 grams, so finite element analysis is necessary to determine its strength in the production line.

The finite element analysis was done using SolidEdge 2023, more detailed results of this analysis are available on request, the steps of the analysis are presented below:

- Setting the material type and its characteristics

The material used for this piece was ABS, printed by FDM process with a professional Creator 3 printer, a durable, flexible and high temperature resistant material

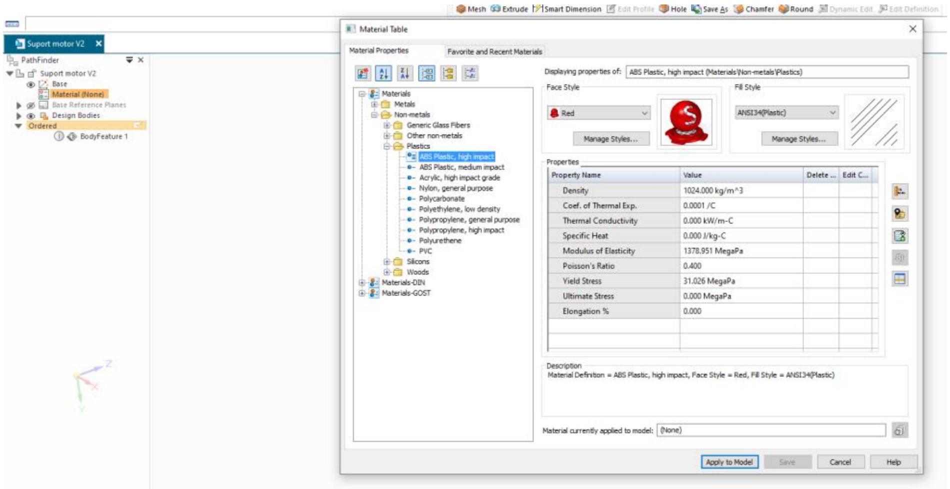


Figure 15 Setting the material type and its characteristics

- Inserting boundary conditions

The boundary conditions for performing a finite element analysis are the determination of the fictitious supports and the forces, pressures, moments.. acting on the part to be analyzed. For this part the conditions shown in figure X have been established, and the force acting on the surface of the inner walls of this support is 100N.

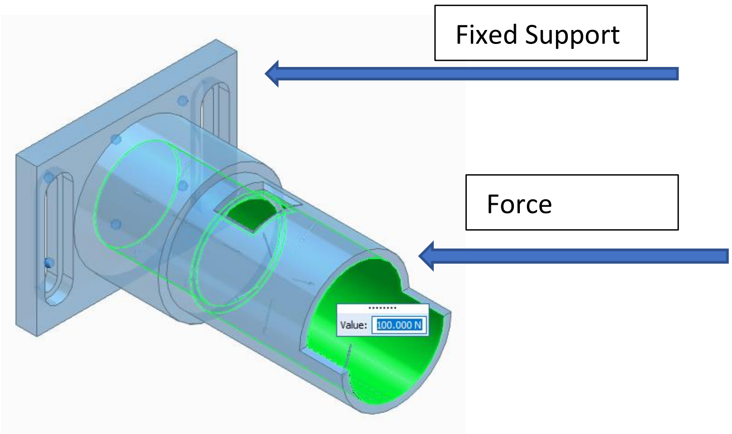
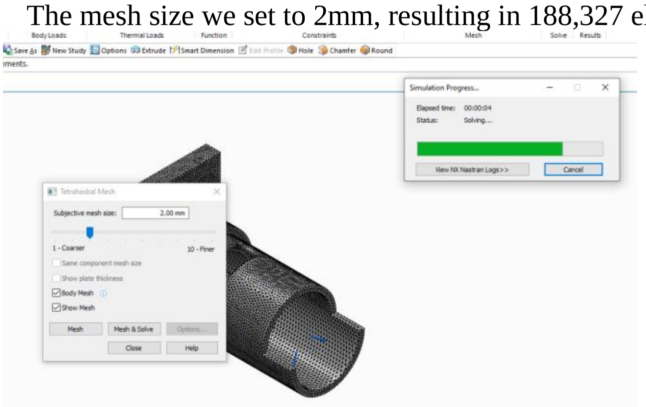


Figure 16 Inserting boundary conditions

- Discretization of surfaces, Mesh

Grids are a crucial step in design analysis. The software automatically creates a mixed mesh of solid, shell and beam elements. The accuracy of the solution depends on the quality of the mesh. In general, the finer the mesh, the better the accuracy.

The mesh size we set to 2mm, resulting in 188,327 elements and 291,153 nodes.

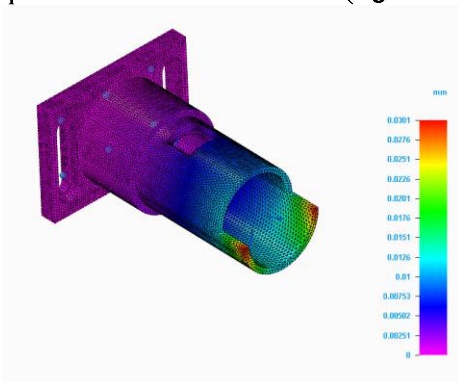


Mesh type	Tetrahedral
Mesher	Body Mesh
Total number of bodies meshed	1
Total number of elements	188,327
Total number of nodes	291,153
Subjective mesh size (1-10)	3

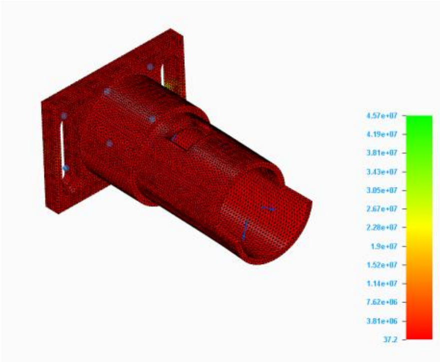
Figure 17 Discretization of surfaces, Mesh

- - Results

  The results of this analysis system were directed to the analytical determination of the total deformation of the areas affected by the contact between the part and the support (**Figure *18 a***), of the factor of safety (**Figure *18 b***), respectively to the calculation and evaluation of the equivalent von Misses tension (**Figure *18 c***).

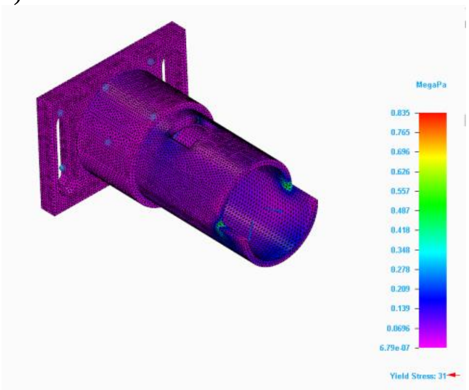


a)Total deformation



b)Safety factor

Total deformation: 0.03 mm
Safety factor: minimum 37,2, maximum $4.57x10^7$
Von Misses: minimum 6.79e-07 MegaPa, maximum, 0.835 MegaPa



c)Tensiunea echivalenta Von Misses

Figure 18 Discretization of surfaces, Mesh

Following the results of these analyses, and also from a practical point of view, this device corresponds to the requirements imposed by the project, being used in the production line with positive results.

6. Conclusion

- Manufacturing devices using 3D printing is successful for prototype parts as well as for complex profile parts;
- Combining 3D printing with chipping results in devices with the same high precision as those produced by traditional methods (milling, turning, injection moulding, moulding...);
- Medical problems require engineering solutions, thus the benefits of both fields lead to a better coexistence of people;
- The price and manufacturing time for certain parts by combining 3D printing with chipping operations is decreased;
- The raw material being in filament form, and printing being carried out with little additional processing, results in low material loss;
- - The chipping parameters used for milling correspond to a finishing chipping parameters, since roughing is no longer necessary, thus the machining time is reduced;
- - The machining of such a device involves only chipping the active area, areas which do not have a high dimensional accuracy or a surface quality superior to that obtained by embossing need not be chipped;

- - Chipping only the active areas of a part requires fewer workpiece fixtures for machining, simpler part program, fewer chipping tools used.
- - Using FEA it is possible to optimise projects to be launched later on the production line, respecting the operating parameters and duration imposed by the project.
- - Combining 3D printing with FEA analysis results in optimised and sustainable products.

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Acknowledgments
This research was developed under financing of ebm-papst Automotive & Drives Romania SRL Oradea,