APPLICATION OF MODERN TECHNOLOGIES IN PRODUCTION DESIGN OF CAR COMPONENT PROTOTYPE

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An article deals with a design and production of a prototype component for an automotive industry. A theoretical part defines a technology of plastics injection from the point of view of selection, preparation and use of appropriate materials for plastic components fabrication. There is also defined a basic principle of activities of an injection moulding machine with a subsequent description of an issue of design and construction of injection moulds. A practical part of the article deals with a 3D model formation of the car component prototype (PC modelling in a parametric CAD software Autodesk Inventor, a control of entry data) and its production using an additive technology of Rapid Prototyping (a method of Fused Deposition Modelling – a 3D Printer uPrint). The practical part also focuses on production of the real prototype casts of the car component casted from a special binary resin. The final prototype casts are casted to a silicon mould that is made using a vacuum casting system. The article also includes a metrological measurement of the prototype components (components made using an injection moulding machine, the 3D printer and the silicon mould) using the 3D measuring device in order to evaluate of production tolerances to a given technical documentation. The article ends with evaluation of production of the prototype component with recommendations and an analysis of the most economical solution (modern technological procedures versus the aluminium mould), including final summarization of costs on the car component production.

KEYWORDS

plastics injection, prototype component, rapid prototyping, silicon mould, resin, 3D printer, 3D measuring device

1 INTRODUCTION

Nowadays, most of plastic products are made by plastic injecting technology. It is a fast process used for production of a huge number of identic objects of various dimensions and difficulties. The injection process requires the use of a plastic material, injection moulding machine and injection mould [Bachorik 2016][CustomPartNet 2009].

There exist many types of materials that may be used for the injection process. They are mostly polymers, including thermoplastics, some thermosets and elastomers. When those materials are used in the injection process, its raw form is in small granules (pellets) or a soft powder whereas each material has different qualities. They may influence not only solidity and a function of the moulding, but also the parameters of the production process. For their improvement additives are added to the material before injecting. They are added by mixing or kneading [Bachorik 2016][Ragan 2008][Zeman 2009].

An inseparable part of this process are injecting moulding machines, modern machines enabling full automatization of the injecting process. They consist of an injection unit, closing unit and injection mould. A work principle of those machines lies in dispensing of the material in a form of small pellets from a feeding hopper to a heat cylinder. In the cylinder, there is the material further heated up to its firing to a melted metal. Subsequently, the melted metal is transferred to a mould cavity under high pressure by a gate system. There it hardens. After hardening, the mould opens and the moulding is removed along with the whole gate system by bouncers. Finally, the mould closes and the whole cycle repeats [Bachorik 2016][Lenfeld 2010][Ryan 2002].

The injection mould is a replaceable part of the closing unit. Its main function is to transport the polymer melted metal to the mould cavity, which gives the product the final shape and keeps it until it freezes. Then, it is cooled to the temperature at which a significant deformation does not occur. The mould is very often made of cheaper and less-quality material (e.g. aluminium). The prototype components are made by using the mould to verify a shape and dimension of components or to verify an accuracy of the mould design itself. After accuracy verification the mould is made of the steel and serves for serial production of the plastic components [Bachorik 2016][Zeman 2009][Bobek 2015].

The article deals with production of prototype plastic components using the modern technological processes in order to prevent production of the aluminium mould, which would lead to financial and time savings.

2 MODEL FORMATION

Before production of the prototype component using the additive method of Fused Deposition Modelling, it is necessary to form its model. It is constructed in 3D parametrical software Autodesk Invetor. Individual shapes and dimensions along with their given tolerances proceeded from a part of drawing documentation are shown in Fig. 1a and Fig. 1b. This component is used in the automotive industry [Bachorik 2016].

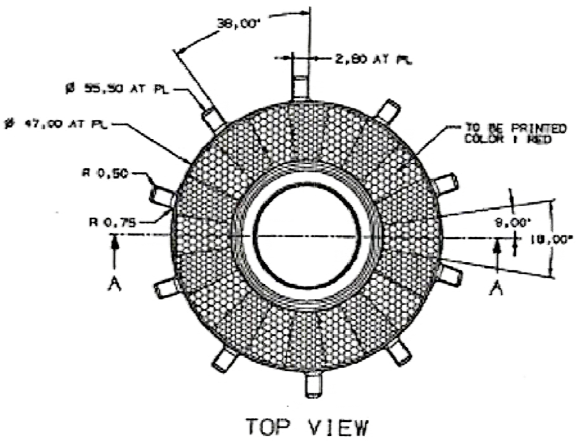

Figure 1a. Part of Drawing Documentation of Prototype Component – TOP VIEW

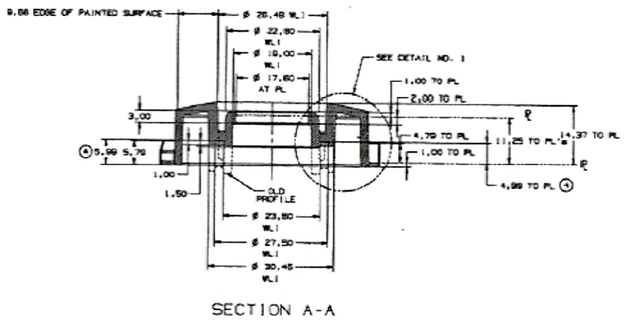

Figure 1b. Part of Drawing Documentation of Prototype Component – SECTION A-A

3 MODEL PRINTING BY USING 3D PRINTER UPRINT

After forming of the final model illustrated in Fig. 2, the model is printed by 3D printer [Bachorik 2016].

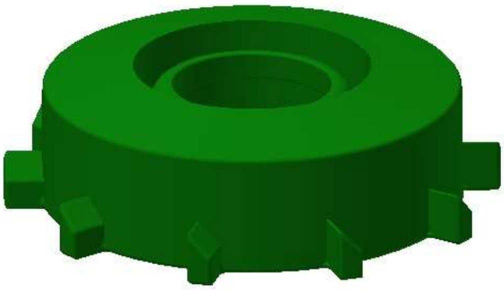

Figure 2. Prototype Model of Component

3.1 Model Export to STL Format

Firstly, it is needed to export the model to STL format supported by the 3D printer. This is done directly in software Autodesk Inventor, in which individual parameters for this export are set [Bachorik 2016].

3.2 Model Preparation for Printing in Software CatalystEX

The software CatalystEX is a software designed for communication with 3D printers. It enables to open the 3D model quickly and easily, prepare it for the print and send to the device [Bachorik 2016][Drapela 2010][Chua 2010][Piska 2009].

During the model preparation, the model exported to the STL format, is opened in software MiniMagic and GOM Inspect. Software guarantees that the model is correct without any discontinuities and other errors that would interfere during the printing. After accuracy verification, it is loaded in CatalystEX software, where the basic printing parameters are set (e.g. a width of a layer, way of model filling, support setting, number of copies, units and sizes). Then, the prepared model is sent to the device. Subsequently, it is printed by the printer called Dimension. For the printing of the master model, the material ABSplus is used, whereas a depth of one layer is 0.178 mm[Bachorik 2016][Drapela 2010][Chua 2010][Piska 2009][Sedlak 2013][Sedlak 2015].

3.3 Surface Modification of Master Model

After the master model printing by the 3D printer, there stay spots on the model surface (in form of dapples) after the layers that are gradually applied on the model during the printing. Therefore, before production of the silicone mould, the surface modification of the model is necessary (see Fig. 3) to prevent the printing of those dapples in the shape cavity of the mould [Bachorik 2016][Drapela 2010][Chua 2010][Piska 2009][Sedlak 2013][Sedlak 2015].

Figure 3. Filled Prototype Model

4 PRODUCTION OF SILICONE MOULD

Mould production consists of frame construction from glass plates in shape of a rectangular of approximately the same dimension. They are stuck on the edges using a fuse pistol in dimension corresponding to the size of the component boarding [Bachorik 2016][Drapela 2010].

Then, a joint face among two parts of the silicon mould is formed by a heated modelling clay. One half of the mould is filled with it. Subsequently, there is put the filled model. The silicone preparation follows. It consists of a mixture of a non-oil hardening mix and a binary silicone, approximately at rate 1:10 [Bachorik 2016][Drapela 2010].

To prevent the emerge of undesirable air bubbles in the silicone, which would harm the cast, the prepared material is put to a pre-pressurized vacuum chamber. The bubbles are removed from the silicone in the chamber. Finally, the first part of the mould is casted by the silicone see Fig. 4 [Bachorik 2016][Drapela 2010].

After approximately 8 hours that are needed for the silicone hardening, the glass frame is dismantled and the first emerged part of the mould is cleared from the modelling clay. The cleared casted part of the mould is subsequently settled to the glass frame. The filled model is put to the shape part, on which two rollers made of the modelling clay are placed see Fig. 5. Soon after the casting, they serve as the gate opening for the casting mix. Their correct placing on the model is very important, because they are very important for the mix casting to all parts of shape cavity of the mould [Bachorik 2016][Drapela 2010].

During the formation of the second part of the mould the silicone is modified the same way as during the preparation of the first part. Subsequently, the mould is casted by the silicone again. After its hardening and removing of the glass frame, the complete mould consisting of two parts formed by the same method, is made [Bachorik 2016][Drapela 2010].

Production of the silicone mould is not important only for prototype components production. It may verify accuracy of designed placing of the joint face and the gate opening in practice. Verification of its correct location may significantly relieve a design and production of the regular steel mould and save time [Bachorik 2016][Drapela 2010].

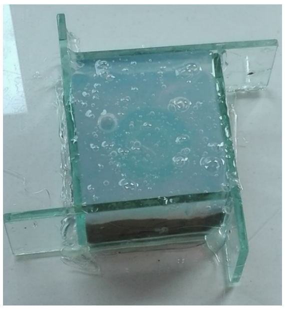

Figure 4. Filling of First Part of Mould

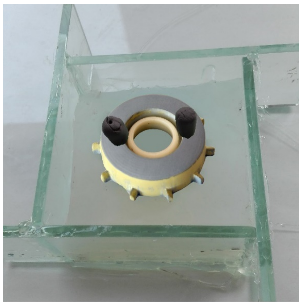

Figure 5. Choice of Running System

5 COMPONENT CASTING TO SILICONE MOULD

At first, it is necessary to clear both parts from rests of the modelling clay. Full leaking of the mix in the form cavity of the mould is not influenced only by an appropriate design of the gates as it is mentioned above, but it is also influenced a lot by their correct and sufficient bleeding. Therefore, it is necessary to form so-called air ducts in the cavity of the mould and especially in the area of tooth at the circumference of the component (they were regarded as the most critical places for full leaking of the mix). Those ducts are made by a jumper. They should improve better air sinking from a mould, so there are no air bubbles to which a plastic would not leak [Bachorik 2016][Drapela 2010].

After the cleaning and bleeding of both mould parts, they are connected to one unit by pins and put to the heated oven. Better leaking of the mix during the castling is reached by heating of the mould in the oven up to the demanded temperature. The so-modified mould is ready for the casting itself. Before, it is necessary to form a mix consisting from a bitumen and hardener in proportion 1:1. Both components of the mix are mixed very precisely with each other. The prepared mix along with the heated silicon mould are put into the vacuum chamber. The chamber is closed, pressured and then the mould is filled there. After its filling, the pressure is released from the vacuum chamber, which causes partial sucking of air from the mould [Bachorik 2016][Drapela 2010].

During the filling of the cavity it is necessary to control the speed of the mixture filling in order to protect it from the hardening, which comes very quickly at this kind of the mix. When the cavity is filled, the mix is hardened in 60 minutes. Subsequently, the mould is dismantled. The cast is removed from it see Fig. 6. The mould is cleaned and then it is connected again by pins to prepare it for the next casting. The five prototype components are produced this way, according to a producer [Bachorik 2016][Drapela 2010].

Figure 6. Final Prototype Cast

6 METROLOGICAL MEASURING

In a metrological section, geometrical parameters of individual components, specifically, the one made by the injection moulding machine, the one printed by the 3D printer, the masticated one and the one made by moulding into the silicon mould, are measured with the use of a 3D coordinate measuring machine.

It is the 3D portal type of the coordinate machine with a fixed table. Its main parts are the following, a working table, a portal and a Pinole made of a black granite which ensures equal thermal expansion to all axes. The machine measures with expanded uncertainty “U” that is expressed by a formula (1) [Bachorik 2016][Petrkovska 2012][BRT servis 2008]:

$$U_{(x,y,z)} = \pm(2 + L/330)\,[\mu m] \tag{1}$$

Where: $U_{(x,y,z)}$ [μm] - expanded measurement uncertainty in axes x, y, z,

L [mm] - length of measured parameter in axes x, y, z.

Before the measuring itself it is necessary to fix the measured component on the table of the machine to prevent any unintentional moving during the contact of a probe. The extent of fixation is chosen based on the need to measure as many parameters as possible. Subsequently, the parameters that are not measured by the machine due to fixation are determined by a calliper rule[Bachorik 2016][Petrkovska 2012][BRT servis 2008].

After this step and studying the mechanical drawings, the model is uploaded to software CALYPSO. Then follow adjusting the model by means of the setting of delicate contours and depicting edges for better visibility of the measured objects [Bachorik 2016][Petrkovska 2012][BRT servis 2008].

The next step is determining the model in this software. At first, adjusting of the component has to be carried out, which means that its position in the coordinate system is defined. In order to adjust it correctly, it is necessary to subtract six degrees of freedom. This is achieved by defining so called RPS points (a system of reference measuring points according to which a mutual position of the components is checked) from which it is proceeded during parametric controls, see Fig. 7 [Bachorik 2016][Petrkovska 2012][BRT servis 2008].

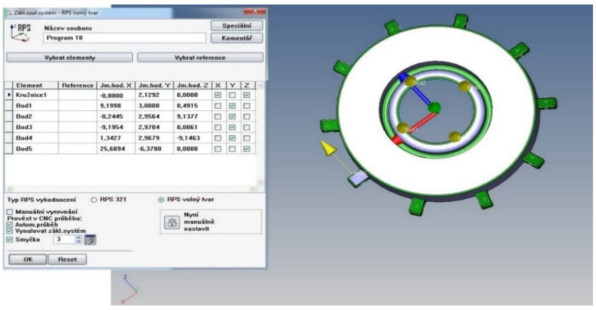

Figure 7. RPS Points Definition

Subsequently, the security cylinder is created, see Fig. 8. It forms boundaries in space, where the measuring probe moves at a very slow rate preventing from a collision with an object being measured. Beyond this space, the probe moves at a higher velocity. Areas of the security cylinder define safety groups. These groups identify direction in which the touch of the probe moves perpendicularly to the measured area or point [Bachorik 2016][Petrkovska 2012][BRT servis 2008].

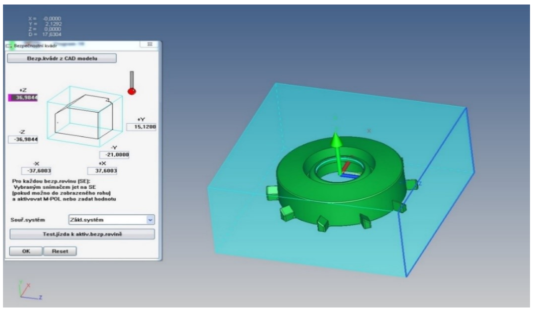

Figure 8. Security Cylinder Forming

The last step of the component setting is manual determining of above mentioned RPS points. After defining the points in this way, the real coordinates of the component are recalculated from the system of the machine into coordinates in software. By this, the component is prepared for measuring. At first, specific geometric parameters that are about to be measured, such as the circle diameter, width, position of teeth, etc. are marked. Tolerances are prescribed to the parameters based on the mechanical drawings, so that after the measuring, the machine is able to evaluate whether the real parameters are in the range of tolerances or not. After that, the elements are defined and the strategy of measuring is selected. During the measuring of diameters of individual circles, the scanning method is chosen because of higher accuracy [Bachorik 2016][Petrkovska 2012][BRT servis 2008].

During the measuring, the tooth width and bevelled angle of its upper part and planes are created by four points. Then, distance between two parallel planes and angle between upper and lateral plane of the teeth are determined. Due to the fact that radiuses are smaller than the diameter of the ruby ball (in our case 1.5 mm), they are not measured. The height of the tooth as well as the height of the whole component have to be measured by the calliper rule, because of component fixation on the table. Afterwards, other forms of the component may be measured [Bachorik 2016][Petrkovska 2012][BRT servis 2008].

At the end of the metrological measuring, laboratory reports are written. They include information about geometric parameters of all the forms of the component based on the production process. The reports confirm that the geometric parameters of the particular forms are within the range of tolerances given by the mechanical drawings. After this measuring, a conclusion is drawn that it is possible to replace the verification method connected with production of the aluminium mould by this selected modern technological advance of production [Bachorik 2016].

In the Tab. 1, there are mentioned 8 average deviations of the measured values calculated from 10 measurements (see Fig. 9a and Fig. 9b). Overall, 57 parameters are defined on each component by the measuring process and each one of them is within the geometric tolerances given by mechanical drawings.

Table 1. Measured Geometric Deviations of Component

Component Type based on Production	Geometric Deviations of Particular Component Parameters [mm]							
	$\varnothing c_1$	$\varnothing c_2$	$\varnothing c_3$	$\varnothing c_4$	$\varnothing c_5$	$\varnothing c_6$	Tooth Height h	Tooth Width w
Moulding	-0.1161	0.1257	-0.0747	-0.0390	-0.1494	-0.0795	-0.0700	0.1234
3D Printer Printout	-0.0405	-0.0069	0.0241	-0.1170	-0.1473	0.0143	0.0200	0.0852
Filled Printout	0.1143	-0.0592	0.0860	-0.0829	-0.1186	0.0825	0.1100	-0.1342
Casting	0.1490	0.0138	0.1401	0.1229	-0.0195	0.1005	0.1300	0.0581

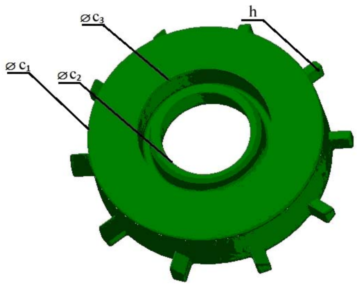

Figure 9a. Illustration of Measured Parameters on Prototype Component Mentioned in Tab. 1 ($\varnothing c_1$, $\varnothing c_2$, $\varnothing c_3$, h)

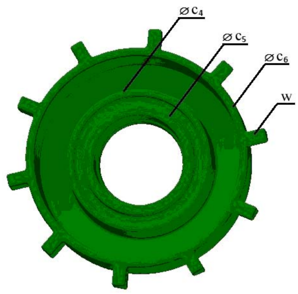

Figure 9b. Illustration of Measured Parameters on Prototype Component Mentioned in Tab. 1 ($\varnothing c_4$, $\varnothing c_5$, $\varnothing c_6$, w)

7 ECONOMIC ANALYSIS

The economic analysis of prototype components production using modern technologies consists of a financial assessment of specific working processes. By summing up expenses of all the processes, the overall costs of the final automobile prototype are 440 euros. In practise, at first the aluminium mould is used in production of plastic prototype components. Due to the softer material of the mould, it serves for production of only several mouldings. If the moulded pieces made this way are correct, based on the aluminium mould, the more expensive steel mould is constructed for serial production [Bachorik 2016].

For economic comparison of expenses, a Chinese company is asked for drawing up a quotation on production of the aluminium mould based on the shape and parameters of our prototype component. The quotation for production of the prototype component is calculated to the price of 4,000 Euros. However, this amount does not include expenses coupled with hour-rate of a worker and energy during the production process. Despite of this fact, the sum confirms that because of the modern technological advances, it is possible to save expenses up to 10 times. This is illustrated in the dependency chart in Fig. 10 [Bachorik 2016].

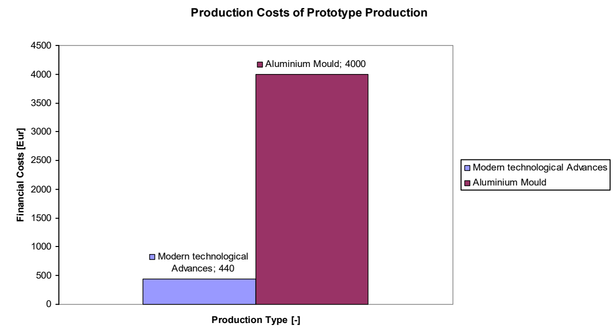

Figure 10. Comparison of Expenses on Prototype Components Production

8 CONCLUSION

This article analyses working processes in production of prototype components using modern technologies that reduce production of the aluminium mould. This mould serves as the verification method before the use of the proper steel mould for serial production. The metrological measuring confirms that the parameters of the prototype components made this way comply to the mechanical drawing documentation. This fact proves the usability of this specific production method in practise. At the same time, production of the prototype components using these modern technologies not only saves time, but also financial expenses which are in comparison with the aluminium mould roughly 10%.

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