# Comparison of Geometrical Accuracy of a Component Manufactured Using Additive and Conventional Methods

**Witold Habrat, Maciej Zak, Jolanta Krolczyk and Pawel Turek**

**Abstract** This chapter describes three different methods of manufacturing a vacuum cleaner connector made of ABS and NECURON plastic material. Basically, the part is produced on an injection molding machine; however, with the help of manual laser scanner analysis, it is possible to compare two other methods: part manufactured by milling is 0.04 mm and part manufactured by injection molding machine is −0.15 mm and 3D-printed part is −0.20 mm. All the above-mentioned methods of producing the connector have their advantages and disadvantages. The fabrication time of all elements (under 1 min for injection molding machine, 1.5 h for milling machine and ca. 7 h for 3D printing) and costs of machines and tooling are decisive factors for manufacturing technique selection.

**Keywords** Manufacturing technology · Reverse engineering · 3D printing · 3D scanning

## 1 Introduction

The development of CAD and CAM software has become the basis of aiding engineering efforts. This technology has enabled achieving better quality products at lower manufacturing prices, thus contributing to production optimization [1–3]. More and more often finished products are being processed to electronic models. This method is known as reverse engineering. Rapid prototyping enables the creation of physical models and prototypes based on a 3D-CAD model. 3D profilometry as a method of surface geometry inspection enables the monitoring of

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metrological changes of machine parts or processes [4, 5]. The machine part defects are very often caused by the inappropriately selected input parameters and manufacturing processes [6–8]. Additive manufacturing of components becomes effective in single-piece production or low-volume production [9], and it eliminates the need to use specially designed tooling (e.g., dies or molds). It possesses a big advantage compared to conventional fabrication methods, as well as presents a particular advantage over machining processes [10]. Additive manufacturing methods, however, do not ensure adequate elements accuracy in case of small- and micro-sized components. Rapid prototyping methods in combination with reverse engineering make a good tool for producing prototypes.

Along with industry development, new machines and manufacturing methods being developed. Moreover, the significant increase of application of polymer plastics in production is being observed. The ability to adjust properties to user requirements in particular applications is the main feature of mass and common application in different areas of the economy. In the past decade, the global demand for plastics has grown by 62% while the manufacturing of steel shrunk by 21% [11]. Plastics are characterized by the ease of forming and coloring. Injection molding of plastics is commonly used for manufacturing household articles components, packaging, machine components, tools, prostheses and other models used for serial production. The general property of plastics is their lower density compared to metals, corrosion resistance, moisture resistance and very low heat conductivity as well as very good dielectric properties.

The purpose of this paper is to compare the geometrical accuracy of a selected component manufactured with the use of three basic fabrication methods: machining, injection molding and 3D printing (rapid prototyping). The geometry was verified using manual laser 3D scanner.

## 2 Materials and Methods

The model used for research is a connector used to join the suction nozzle with a telescopic tube of a Zelmer vacuum cleaner (Fig. 1). After creating the geometry in CAD software, it was vital to save the data in a neutral format enabling further data processing in rapid prototyping system.

The file was created in Creo Parametric 2.0 software in PRT format (Fig. 1). Additionally, the generated STL file was analyzed in 3D-Tool software. A relevant density of triangular mesh resembling the surface controls the exported model accuracy. The solid model was generated and described by a triangular mesh of 0.01 resolution (Fig. 2).

The verified model was sent to Insight Stratasys software responsible for preparing the STL model to be fabricated by the 3D printer. Optimum parameters in configurational option are shown below:

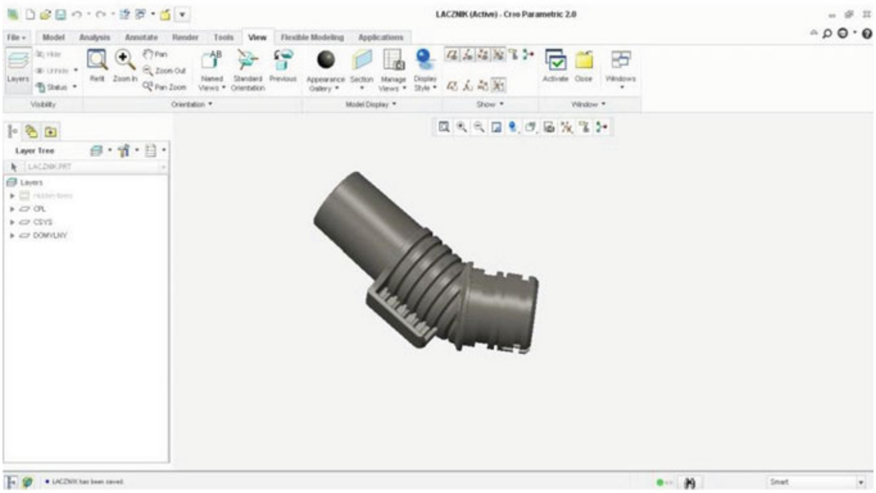


**Fig. 1** Surface CAD model of a connector for the vacuum cleaner

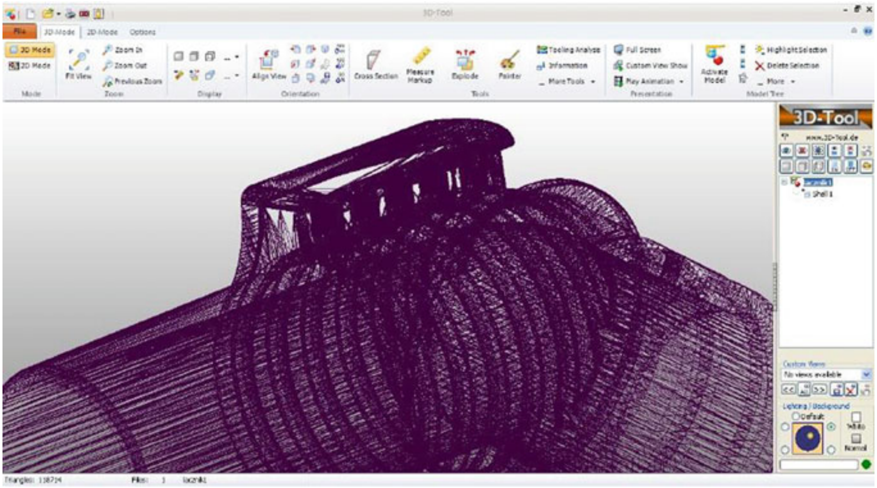


**Fig. 2** High-resolution triangular grid of STL model

- 3D printer model—Fortus 360mc Small,
- Single-layer height set to 0.254 mm,
- head model used to build the component—T16,
- modeling material—ABS-M30,
- head model used to build supports—T12,
- support material—SR30,
- interior design—solid—normal,

– visible surface—reinforced,
– support design—columns.

Subsequently, the program performed relevant calculations simulating the view of supports (gray), part (red) and approximate fabrication time. Different settings were selected aiming to achieve lower support material consumption, improved surface finish of the surface used to fit the telescopic tube of the vacuum machine and optimum printing time. Optimum model is depicted in Fig. 3. The verified model was transmitted to software synchronized with the 3D printer. The printer model is Fortus 360mc (Fig. 4), which utilizes the FDM technology to create the prototype. This method consists in applying "liquified" thermoplastic material onto a particular modeling support and self-hardening of the material.

The system is equipped with a 355 × 254 × 254 mm workspace, two heads and four material feeds—two for model material (ABS-M30) and two for the so-called support (T12SR30). Each layer is 0.254 mm thick. The material feeding nozzle is heated to material melting temperature in order to prevent solidification in the nozzle. Easily melting wax is used as a supporting material for the printing process to enable effortless disposal when the task is finished. It is an easy and safe method which does not damage the model. The supports were dissolved in PADT cleaning device, model SCA-1200. The final view of the printed connector is shown in Fig. 5.

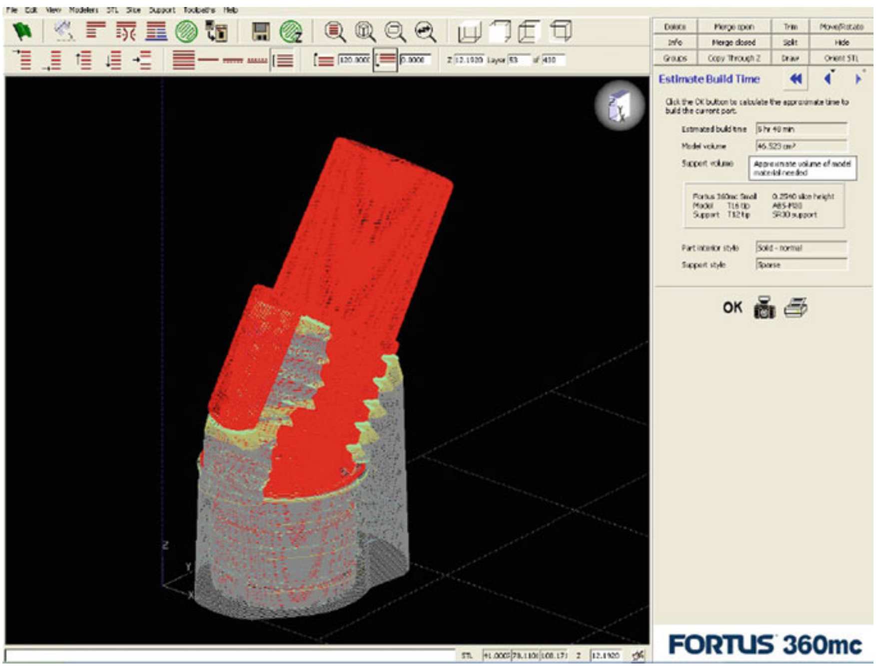


**Fig. 3** Model for 3D printing

**Fig. 4** 3D printer Fortus 360mc

**Fig. 5** Model of the connector performed on a 3D printer

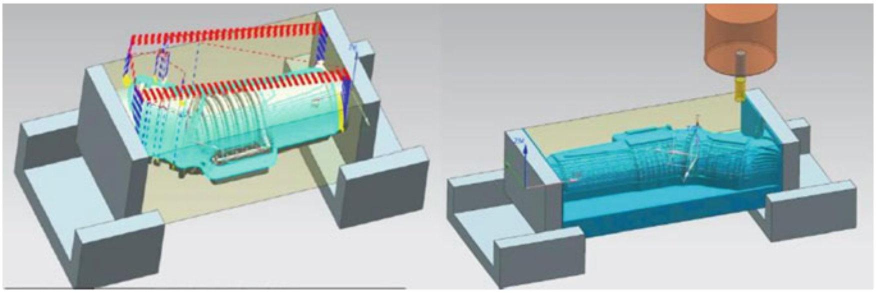

**Fig. 6** View of toolpaths and machined model

The second component used for comparative analysis was processed by machining. A 6-mm-diameter end mill with 40-mm holder length was used. The stock value at sidewalls was set to 0.2 mm, and tolerance values were set to 0.003 mm. Tool paths generated and the machined model are presented in Fig. 6.

Next, a 3-mm-diameter ball end mill with 40-mm holder length was utilized for semi-finish machining of the connector's cavity. The subsequent stock was set to 0, and inner and outer wall tolerances were set to 0.003 mm. Afterward, three other tools were added—12-mm-diameter and 6-mm-diameter end mills and a 3-mm-diameter ball end mill.

Machining was performed on a vertical machining center HAAS Mini Mill on a Necuron material workpiece. Necuron is a polyurethane material possessing a uniform structure and good machinability, taking into account its hardness and strength. The final stage of machining is depicted in Fig. 7.

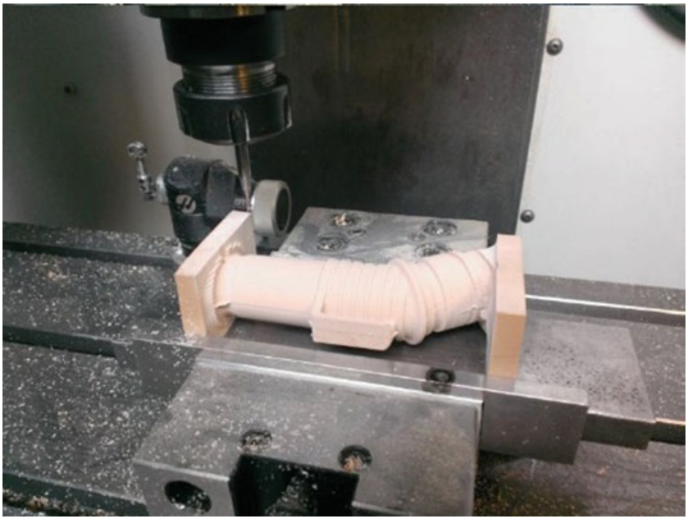

**Fig. 7** Final machining stage of the connector on the milling machine

**Fig. 8** Station for laser scanning

Last part has been manufactured using injection molding technology, and this is a manufacturing process for producing parts by injecting material into a mold.

The models obtained were subject to dimensional verification using a digital contactless NIKON laser scanner, model K-scan MMD100 mounted on an MCA II measurement arm (Fig. 8) and using Focus Handheld software. The width of the laser beam equals 100 mm, measurement error is 10 μm and a number of scanned line points is 1000 at 33–150 Hz scanning frequency.

## 3 Results

Scanning was performed by adjusting the power of the laser beam to the character of the scanned object surface. For a white, brown and black connector, the power of the laser was consecutively set to 18, 36 and 98. This resulted in best possible resemblance of scanned surface of the model. The scanner enables precise and fast measurements when scanning shiny and polished surfaces. The Focus software ensures data processing with minimal involvement of the operator. The CAD model creation process consists in scanning the surface of the object with the laser beam followed by importing and preprocessing of a cloud of points or a triangular mesh in the program. Subsequently, curves surrounding the scanned component are created and then a mesh is created on the measured part. Before comparing the scanned model with the base CAD model of the connector, undesirable surfaces

**Table 1** Deviation data for model connector created with different processes

| | Milling machine | FDM printing in a 3D printer | Injection molding machine |
|---|---|---|---|
| Number of points | 82,271 | 71,698 | 51,399 |
| Maximum deviation (mm) | 1.59 | 1.63 | 1.39 |
| Minimum deviation (mm) | −1.10 | 0.79 | −1.87 |
| Range (mm) | 2.69 | 2.42 | 3.25 |
| Mean deviation (mm) | 0.04 | 0.20 | −0.15 |

that could interfere with the results of the measurements were cut off. Next both models were opened in Inspection software and overlaid onto each other with "Best Fit" option enabled along with 1-µm-fit tolerance. For each component, two reports were presented: a chromatic map of 3D deviations and surface inspection results achieved by cutting the model with a 2D plane. Analysis results are shown in Table 1 and graphically in Figs. 9, 10, 11 and 12. Measurement results are depicted with colors: red—the feature value of the measured component is above tolerance limit, green—the feature value of the measured component is within tolerance, and blue—the feature value of the measured component is below tolerance limit.

The highest number of points was managed to be collected on the machined part model, i.e., 82,271 points. The maximum positive deviation for all three connectors

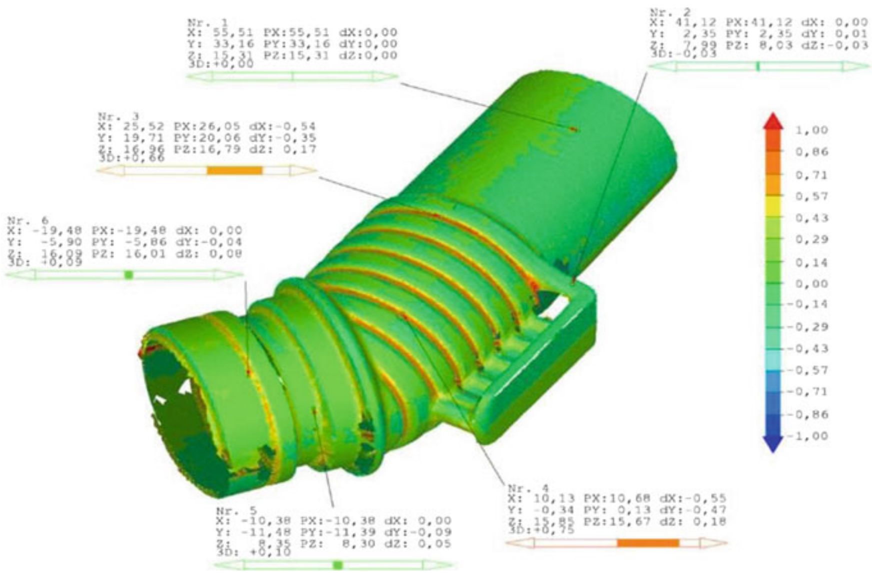


**Fig. 9** Chromatic map of deviations of the connector fabricated using machining on the milling machine, including 6 representative points

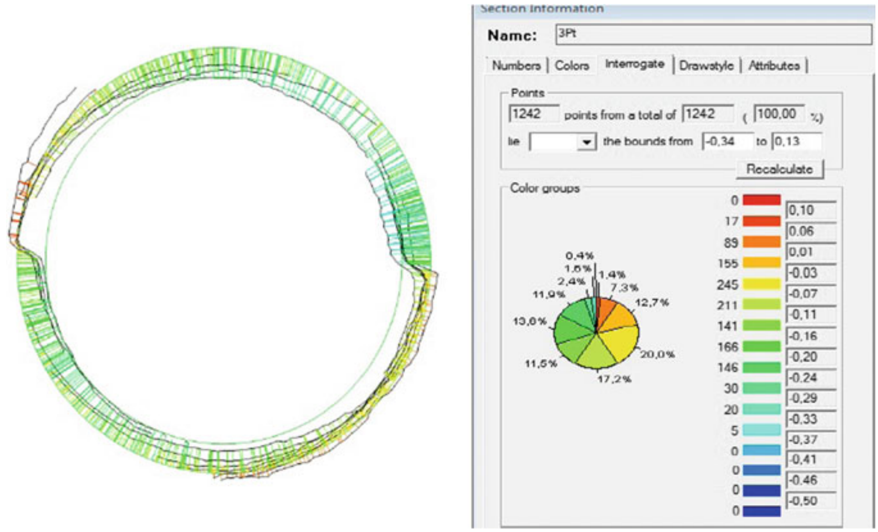


**Fig. 10** Cross-section and chromatic deviation map including the number of points within the given range for the connector fabricated using machining on the milling machine

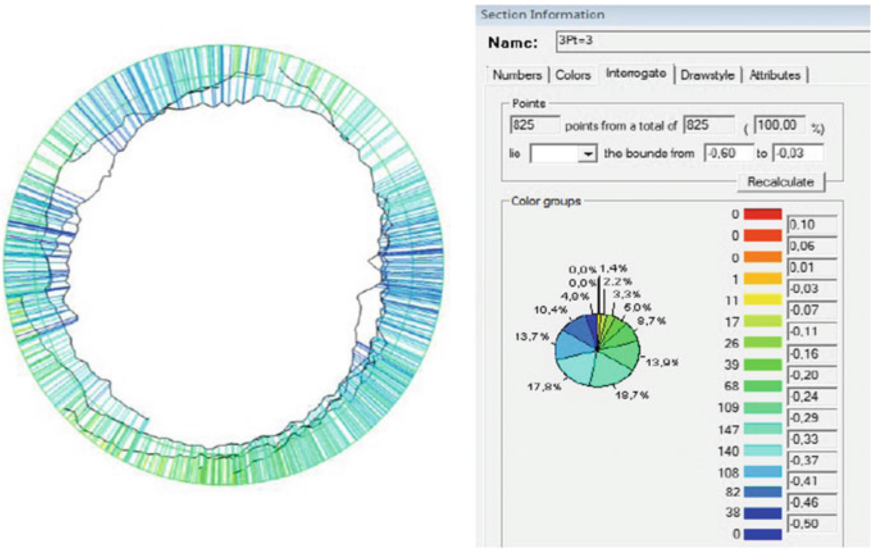


**Fig. 11** Chromatic map of deviations of the connector fabricated using FDM method on the 3D printer, including 5 representative points

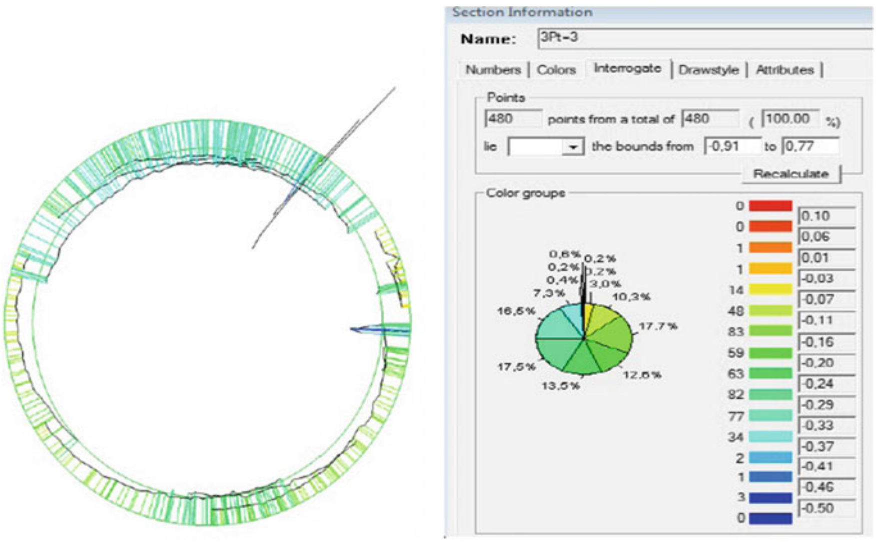


**Fig. 12** Cross-section and chromatic deviation map including the number of points within the given range for the connector fabricated using injection molding

equaled approximately the same reaching, and the highest value for 3D-printed part is +1.63 mm, for machined part, the value is +1.59 and the injection molded part has the value of +1.39 mm. The negative deviation was the biggest for injection molded component −1.87 mm, for the machined component, it is −1.10 mm and for the 3D printer, it is −0.79 mm. The most precisely manufactured component was the part with smallest mean deviation of all points measured compared to the base model, i.e., the machined part of 0.04 mm, followed by injection molded part of −0.15 mm and 3D-printed part of −0.20 mm. The injection molded part achieved the highest range of cross-section deviation of 1.68 mm based on 480 points, followed by 3D-printed part with 0.63 mm based on 825 points and the machined part proved again to be the most precisely fabricated part with deviation range of 0.37 mm based on 1242 points.

## 4 Conclusions

1. Model fabricated using 3D printing showed the lowest manufacturing accuracy with a mean deviation of −0.20 mm. However, one has to consider that the print was performed with high accuracy available for the machine, i.e., 0.25 mm, which is in agreement with the result received. In order to achieve more precise results, it is necessary to use a more accurate machine.

2. The connector fabricated on injection molding machine was black with a shiny surface, which was an obstacle in the precise scanning of the model and resulted in a low number of points collected in comparison with other methods i.e., 51,399, about 1/3 points less. It effected in the fact that the injection molding method appeared to be the second least effective with a mean deviation of −0.15 mm. Additionally, the manufacturing inaccuracy could result from problems present during forming, i.e., contaminated mold, too high/too low injection speed, moist granulate.
3. The machined model turned out to be fabricated with the highest quality and a mean deviation of only 0.04 mm. The result could be even better if tools with smaller diameters were utilized—unfortunately, they were not available in the storage room. The color of the printed part (brown and matt) was favorable for laser scanning. This resulted in the collection of a highest number of points and a low number of scanning repetitions which aided achieving trustworthy results for further analysis.
4. All presented methods have their strengths and weaknesses. The connector fabricated on the molding machine presented an average manufacturing precision, and it is adequate, however, for household equipment. Additionally, its main advantage was short-cycle time (under 1 min) for producing a single part. The disadvantage of this method is the cost of injection molding machine and the mold. The connector manufactured with the use of FDM proved to be the less accurate and its time of fabrication reached approximately 7 h, which is disqualifying for high-volume production. The advantage of 3D printing is the low cost of the machine and project preparation and relatively fast fabrication of a prototype. An additional strength of RP technology is the ability to manufacture parts of complex geometry and free surface shapes which cannot be produced using other techniques. The surface of the machined model was the most precise. The fabrication time reached about 1.5 h which is a result by far worse than achieved by injection molding but better than the result presented by the FDM method. Manufacturing of the part involves the purchase of an expensive machine, specialized tooling and preparation of a program to machine the part. Fabrication of a wide spectrum of shapes depends on available cutting tools, fixturing and collision-free access to the machining area which is usually hindered by design complexity.

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