GEOMETRIC DESIGN, ADDITIVE PRODUCTION AND 3D SCANNING OF A HELICAL GEAR PAIR

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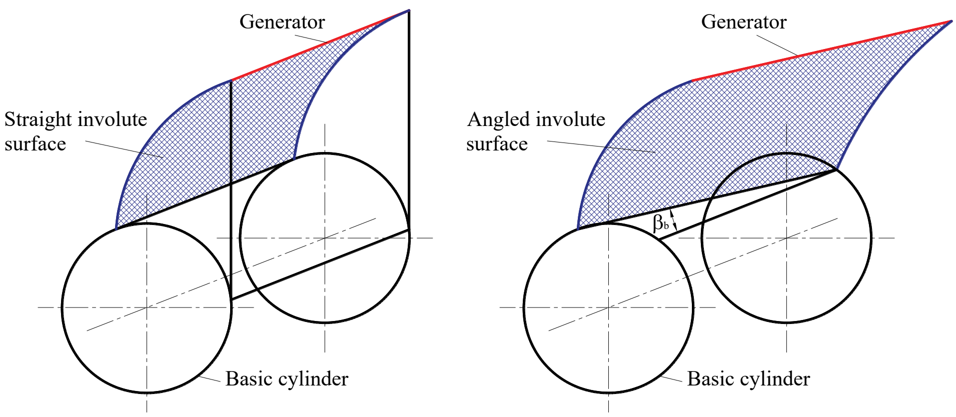
Abstract: *A helical gear pair was deisgned and CAD modelled by computational way. After the assembly simulation the models were produced by additive technology. The Fused Deposition Modeling (FDM) technology was selected for the 3D printing that is widely used for gear production with plastic material. The applied scanner can register the surface points of the workpiece with the projection of the structured light for the object and the usage of two calibrated cameras. Using of the 3D scanning we could inspect the geometric accuracy of the gear pair (pinion and gear) in comparison with the CAD models.*

Keywords: CAD, additive, manufacturing, 3D scanning, helical gear

1. INTRODUCTION

The involutes of tooth profiles of cylindrical gears can be generated from the basic circle. The theoretically usable tooth surface of the cylindrical gears can be generated from the basic cylinder [2, 3, 4].



a) spur gear b) helical gear

Figure 1. Generation of the involute surfaces

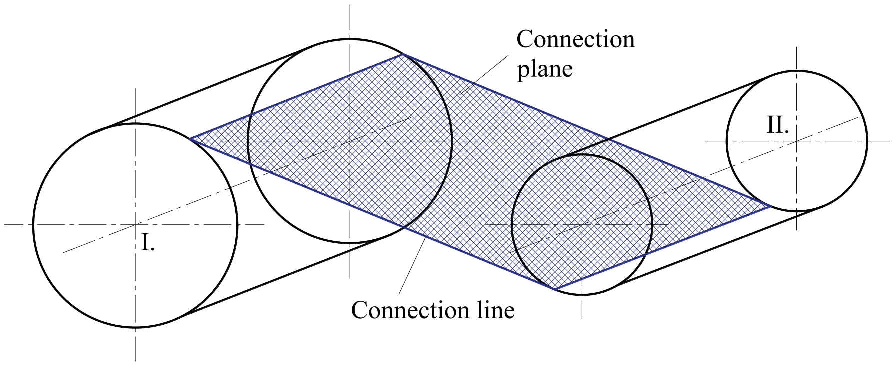


Figure 2. The connection plane of the involute cylindrical gears

The connection line of the theoretical connecting tooth surfaces is called generator. It can move along the tooth surface during the rotation of the gears. The generator is parallel with the centre line of the gear in case of spur gears (Figure 1.a). The generator is angled (β_b) in comparison with the centre line of the gear in case of helical gear (Figure 2.b) [2, 3, 4].

The angle between the generatix and the axis of rotation of the base cylinder is the helix angle on the base circle / cylinder (β_b). The connection surface of the connecting gears are a plane. This is the connection plane (Figure 2) [2, 3, 4].

Helical gears are one type of cylindrical gears with slanted tooth trace. Compared to spur gears, they have the larger contact ratio and excel in quietness and less vibration and able to transmit large force. A pair of helical gears has the same helix angle but the helix hand is opposite. Helical gears are parallel shaft gears and their mesh is almost all rolling contact, thus their general efficiency is high, ranging from 90-99.5% [13].

2. GEOMETRIC DESIGN AND CAD MODELLING

Table 1. Calculated geometric parameters

General parameters		
Name	**Unit**	**Value**
Normal Diametral Pitch	mm	2.54
Diametral Pitch	mm	2.386819
Normal Modular Pitch	mm	10
Modular Pitch	mm	10.641778
Normal Pressure Angle	°	20
Pressure Angle	°	21.173
Helix Angle	°	20
Ratio, 1:x		0.625
Center Distance	mm	207.515

Name	Unit	Gear Value	Pinion Value
Lead	mm	2204.4965	1377.8103
Number of Teeth		24	15
Pitch Diameter	mm	255.403	159.627
Major Diameter	mm	275.403	179.627
Minor Diameter	mm	230.403	134.627
Addendum	mm	10	
Dedendum	mm	12.5	
Base Diameter	mm	238.162	148.851
Whole Depth	mm	22.5	
Circular Pitch	mm	33.432	
Circular Pitch, Normal	mm	31.416	
Fillet Radius	mm	3	3
Backlash	mm	0.5	0.5
Tooth Thickness	mm	16.2161	16.2161
Tooth Thickness, Normal	mm	15.2381	15.2381
Face Width	mm	70	70
Hand of Helix		Left_hand	Right_Hand

The geometric design was made by the GearTeq software that is a complex gear design software. After the adjustment of the initial parameters it can determine all of the output geometric parameters and create the CAD models for the SolidWorks software [1]. The calculated parameters can be seen on Table 1.

After the geometric design the CAD models can be generated and inserted into the SolidWorks software (Figure 3).

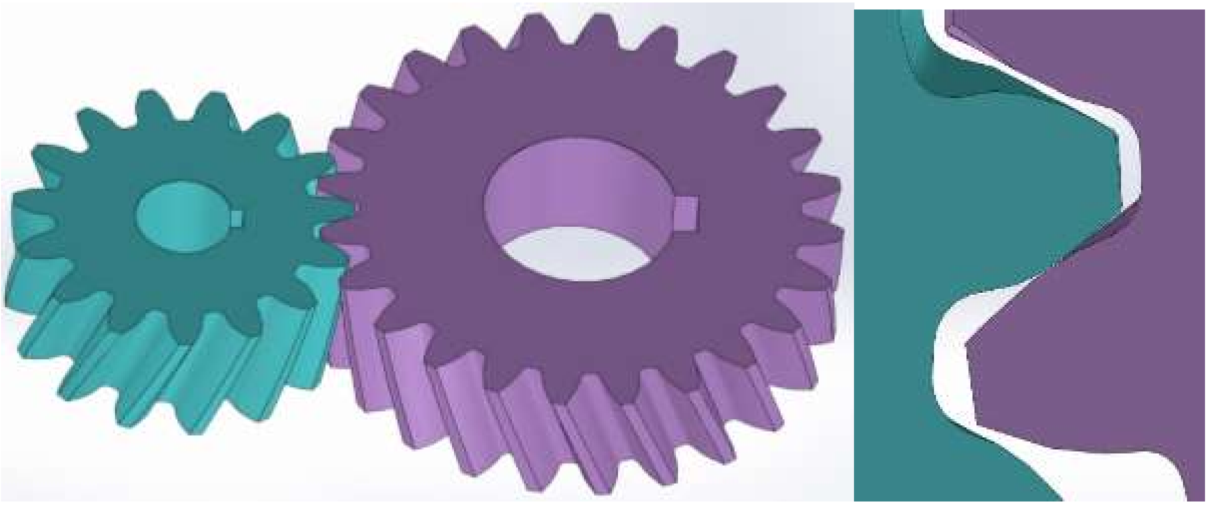


Figure 3. CAD models of the designed helical gear.

3. MANUFACTURING BY ADDITIVE TECHNOLOGY

FDM technology was used for the 3D printing. This technology is also known as fused filament fabrication (FFF), that is an additive manufacturing (AM) process. FDM builds parts layer by layer by selectively depositing melted material in a predetermined path. It uses thermoplastic polymers that come in filaments to form the final physical objects [5, 6, 8]. Ultimaker 3 Printer was used for the execution of the technology, which parameters are in Table 2.

Table 2. The parameters of the Ultimaker 3 Printer

Denomination	**Value**
Nozzle diameter [mm]	0,4
Heating of the printing core [°C]	180-280
Resolutions of the *X, Y, Z* positions [µm]	6,9; 6,9; 2,5
Layer resolution by 0.4 nozzle [mm]	0,2-0,06
Material of the printer tray	glass
Heating of the printer tray [°C]	20-140
Printing volume [mm]	230 x 190 x 200

The type of the applied material is an ABS filament that's brand is Ultimaker. This material has high expansion that is why it is especially sensitive for buckle. In spite of this property, it is widely used due to its frictional and static properties. The preparation of the printing process was made by the Ultimaker Cura sliceing software. There are a lot of printing adjustments in this software which have pre-set values. The Ultimaker company could make an overall 3D printing ecosystem where the hardware, the software and the basic material can work together optimal to provide the best part quality. The applied setting parameters can be seen on Table 3. The printing strategy and the material structure can be seen on Figure 4. The technological process can be seen on Figure 5.

Table 3. The applied setting parameters for the additive manufacturing

Denomination	**Value**
Layer thickness [mm]	0.1
Dimension of filling [%]	40
Type of filling	Cubic
Basic material	ABS
Printing temperature [°C]	230
Temperature of printer tray[°C]	80
Printing speed [mm/s]	55
Adhesion of printing tray	enabled

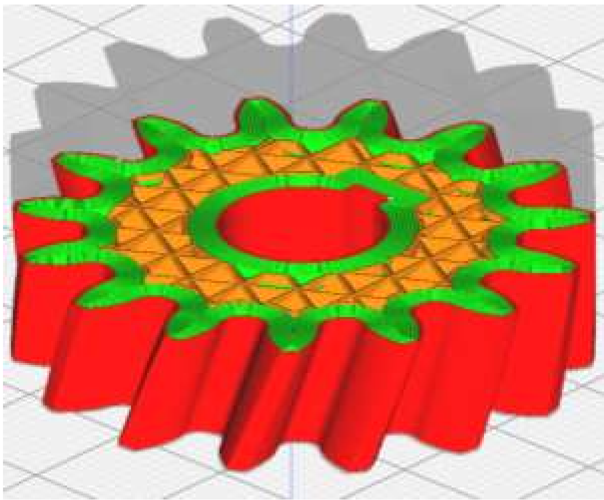


Figure 4. The printing strategy and the material structure by slicing method

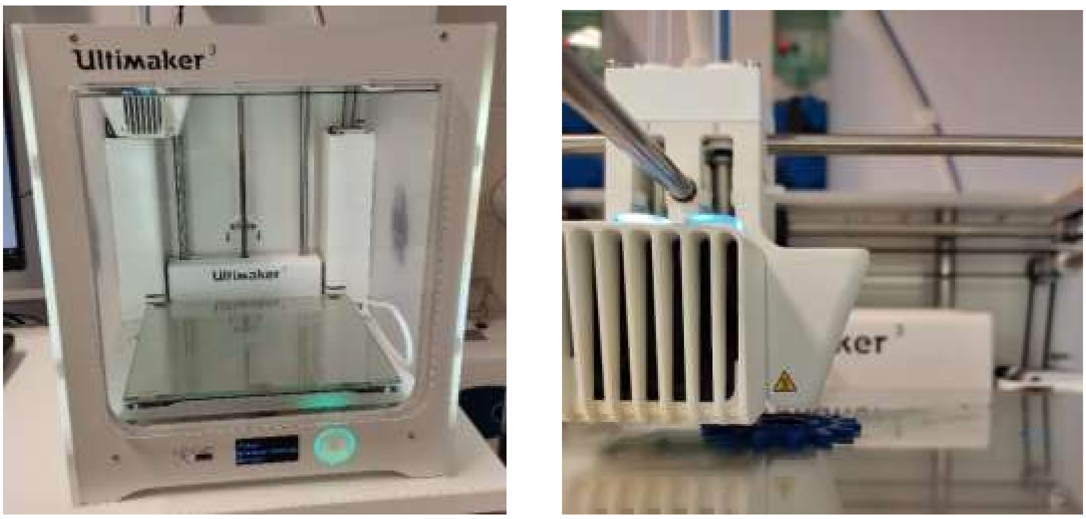


Figure 5. The additive manufacturing process of the gears by the Ultimaker 3 printer

4. GEOMETRIC INSPECTION BY 3D SCANNING

The applied scanner is the Atos Core 200 scanner that was developed for small and medium enterprises and educational institutions. The main parameters of the scanner is on Table 4.

Table 4. The main parameters of the AtosCore 200 scanner

Denomination	Value
Measuring area [mm]	200 x 150
Measuring distance [mm]	250
Resolution (point spacing) [mm]	0.08

The hardware contains a blue coloured projector and two high resolution cameras on the left and right sights from the same distances. Positioning is not needed since the positions of the cameras and the projector are constant. There is a possibility to measure the surface points of the workpieces by triangular method from arbitrary view point of the three different units. This method is officially called Triple Scan method (Figure 6) [10, 11, 12].

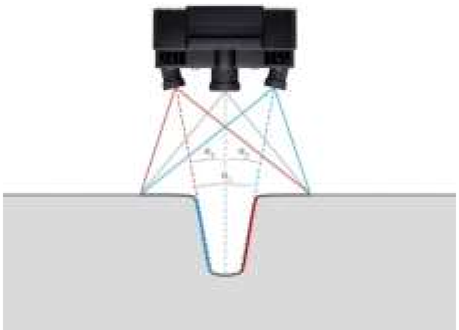


Figure 6. Triple Scan method [7]

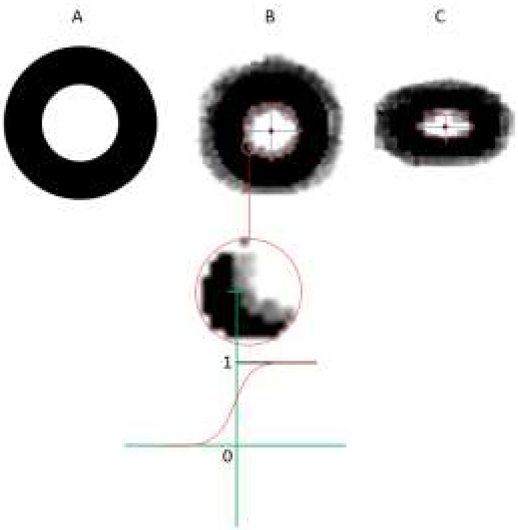


Figure 7. The detection of the reference point

The structured light of the scanner is necessary for the identification of the different surface points of the workpiece. Because of the interpretation of the process, we suppose the projected light is not blue – dark parallel lines, it is just one point. Such point is particularly the reference points that can identify the position of the model. Those points are self-adhesive sheets with dark outline. They also have special reflective coating and a determined circular shape. The thickness of this outline is also prescribed that is dark – white transition. The software of the scanner can identify this transition via the camera view. The process can be seen on Figure 7. The *A* figure section is the theoretical shape but *B* figure section will be forwarded that made from pixels due to the digital image processing of the cameras.

The position of the gears on the table of the 3D scanner can be seen on Figure 8.

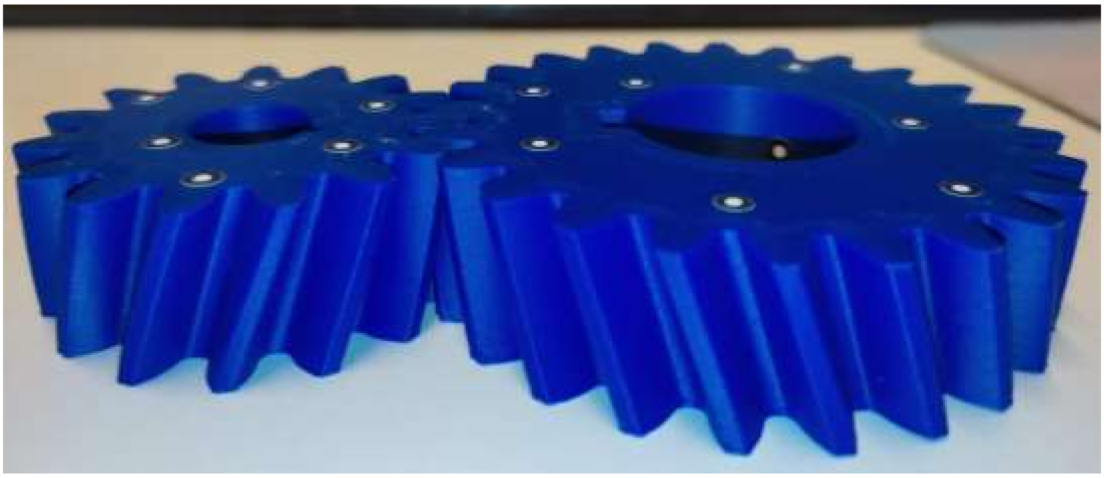
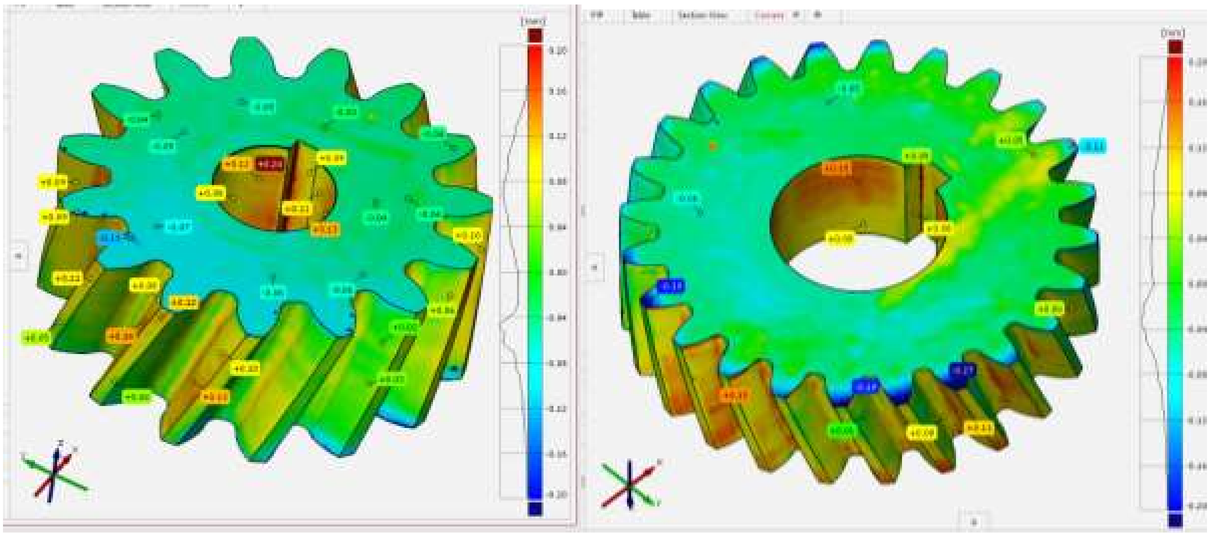


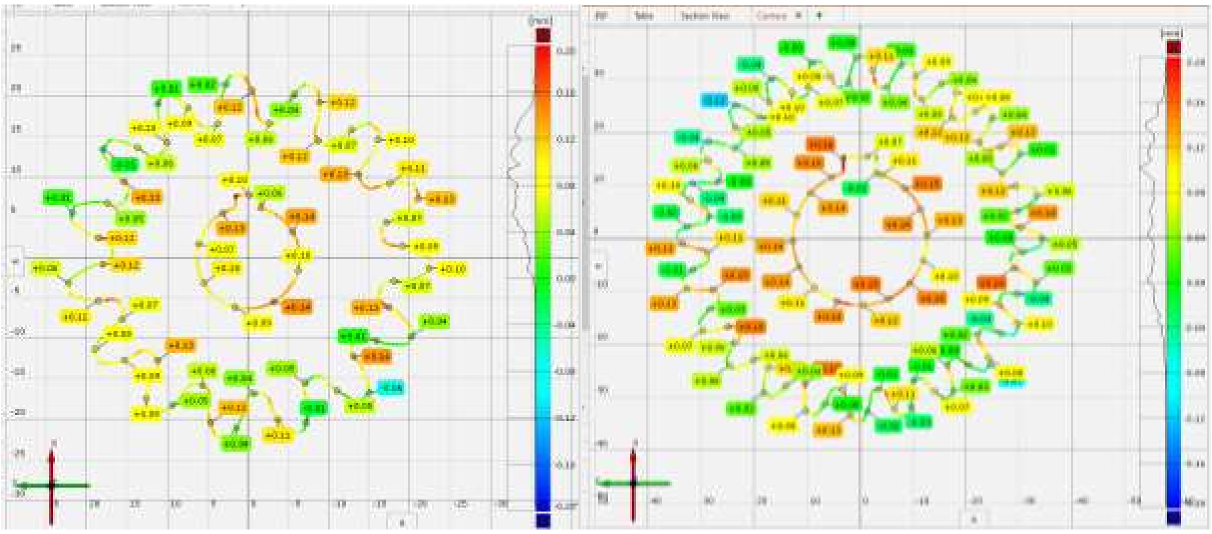
Figure 8. The position of the gear in the measuring table of the 3D scanner

During the analysis from pixel to pixel the white is 1 and the dark is 0 value. If the camera can not see the circular reference point, its view is an ellipse. If we insert an ellipse for the inflexion points, its middle point stays constant based on the angular transformations.



a) pinion b) gears

Figure 9. The comparison of the CAD models and the scanned models



a) pinion b) gears

Figure 10. The comparison of the CAD models and the scanned models in the middle section

After the execution of the 3D scanning we compiled the proper CAD models (pinion and gear) and the received models by scanning. The diversions can be seen on the whole bodies on Figure 9. The diversions can be seen on the middle section of the gears on Figure 10. The distribution charts of the accuracy are next to the figures.

5. CONCLUSION

Our department has a big investments that means we bought an Ultimaker 3 Printer and an Atos Core 200 3D scanner. The main scope of this study is the usage and the harmonization of the 3D modelling, additive manufacturing technology and the 3D scanning for gear design, manufacturing and accuracy analysis in our department.

We designed a helical gear pair with the GearTeq gear designer software. After that, the CAD models of the elements could be generated into the SolidWorks software where the assembly and the collision analyses could be done.

We designed additive manufacturing technology for the manufacturing of the gears. In this case we could get real physical models from plastic.

One of the scope of this publication was the comparison of the CAD models and the received virtual models after the 3D scanning to determine the accuracy of the modelling and the scanning process. The 3D scanning process was executed with Triple Scan method. Based on the evaluation of the results that we got after the compilation of the models the differences are within 0 – 0.15 mm interval.

Based on this 3D scanning method the received surface roughness could be also estimated after a gear cutting technology thus the gears could be classified based on the geometric accuracy.

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