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Manufacturing of new type curvilinear tooth profiled involute gears using 3D printing

Mahir UZUN[1*], Yılmaz GÜR[2], Üsame Ali USCA[3]

*[*1,3] Bingol University, Mechanical Engineering Department, Bingol, TURKEY*
[2.] Balıkesir University, Mechanical Engineering Department, Cagis Campus, Balıkesir, TURKEY

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Abstract

Curvilinear profiled involute gears have more favorable working conditions compared to spur gears and arrow profiled gears. However, these gears cannot be manufactured by conventional manufacturing methods. The use of curvilinear profiled gears was not widespread in the industry due to these difficulties encountered in the manufacturing. In this study, the existing manufacturing methods of current gears have been investigated. In addition to CNC manufacturing method, which eliminated the difficulties encountered in the present manufacturing methods, 3D printers were used to manufacture curvilinear involute gears and presented as an alternative manufacturing method.

Keywords: *Curvilinear involute profiled gears, 3D printers, gear manufacturing methods, nonstandard gears.*

Yeni tip eğrisel diş profilli dişlilerin 3 Boyutlu baskı metoduyla üretimi

Özet

Eğrisel evolvent profilli dişliler, düz dişliler ve ok profilli dişlilere kıyasla daha elverişli çalışma koşullarına sahiptir. Bununla birlikte, bu dişliler geleneksel üretim yöntemleriyle üretilemezler. Eğrisel profilli dişlilerin kullanımı, imalatta karşılaşılan bu zorluklardan ötürü endüstride kullanımları yaygın değildir. Bu çalışmada mevcut dişlilerin mevcut üretim yöntemleri incelenmiştir. Mevcut üretim yöntemlerinde karşılaşılan zorlukları ortadan kaldıran CNC üretim yöntemine ek olarak, eğrisel

[*] Mahir UZUN, muzun@bingol.edu.tr, https://orcid.org/0000-0002-0907-6875
Yılmaz GÜR, ygur@balikesir.edu.tr, http://orcid.org/0000-0003-1709-1298
Usame Ali USCA, ausca@bingol.edu.tr, https://orcid.org/0000-0001-5160-5526

evolvent profilli dişliler üretmek için 3D yazıcılar kullanılmış ve alternatif üretim yöntemi olarak sunulmuştur.

Anahtar kelimeler: *Eğrisel diş profilli dişliler, 3D yazıcılar, dişli imalat yöntemleri, standart dışı dişliler.*

1. Introduction

The manufacturing methods of non-standard curvilinear involute profiled cylindrical gears should be improved due to their advantages. If difficulties encountered during manufacturing can be overcome, use of these gears will become widespread in the industry because of their advantages compared to spur gear and herringbone gears. Since tooth profiles of these gears are convex-concave, they cannot be produced by standard manufacturing methods; however, they can be manufactured with special machined and methods. While manufacturing these gears with new methods, separate size of cutters and tool holders are needed for each gear module and radius of curvature. This situation causes both waste of time and higher costs. Successful manufacturing methods have been developed with CNC machines; however, having only one manufacturing methods to produce these gears is a disadvantage. Therefore, non-standard curvilinear involute profiled cylindrical gears are not widely used in industry. However, if more proper manufacturing methods can be developed to produce these gears, the usability of these gears will become widespread in industry. Because these gears have many advantages such as ability of carrying loads, balancing axial forces, quiet functioning and lubricating properties compared to spur and herringbone gears.

Forster has developed a machine named also Forster, and manufactured curvilinear involute profiled cylindrical gears [1]. Recently, there are some ongoing studies to manufacture these gears, developed a special cutting tool in order to produce these gears on conventional milling machines and suggested that these gears can be manufactured by laser sintering method in the relevant study [2]. Unlike the current cutters, a cylindrical head cutter was developed and plastic gears were manufactured by connecting this cutter with a mandrel. The optimization of geometry of the gear sides, effects of curvature radius on the sliding speed, effects of curvature radius on the gripping and performance of tooth profiles also was analyzed [3]. Than gears which manufactured with different geometry and shear rate were examined [4]. Non-standard gear geometry was simulated and investigated on their study [5]. In addition to all these studies, it is important to see that there are various studies being conducted on the designs of CNC milling machines and similar machines unlike traditional manufacturing methods to produce these gears with special tools and cutters lately in the industry. Epicycloid planet gear of cycloid drivers were designed and machined [6]. In another work, straight bevel gear was manufactured using end mill with CNC machine [7]. Spur gear in Ti-6Al-4V alloy was manufactured with electrical discharge method [8]. In a study, was suggested a new method for manufacturing curvilinear gears [9]. The investigation was made which on using the CNC milling machines to manufacture these gears and estimated production times [10]. Curvilinear gears were manufactured successfully using the CNC milling machines [11, 12].

Fused deposition modeling (FDM) is an Additive Manufacturing (AM) technology invented by Scott Crump and patented in 1990's as "an apparatus for creating three-dimensional objects by fused deposition modelling method". In this method a movable extrusion head moves along the "X" and "Y" directions in a predetermined pattern to form the three dimensional object while the building platform moves down in "Z" direction by the thickness of one layer [13,14]. When the extruded material that its temperature is controlled is discharged on the building platform, and it solidifies substantially instantaneously. The material extruded from the extrusion nozzle in multiple layers adhere to each other to produce the 3-dimensional object. (Fig. 1). Self-hardening any material such as waxes, thermoplastic resins, epoxies, foaming plastics, Acrylonitrile Butadiene Styrene (ABS) and Polylactic Acid (PLA), which adheres to the previous layer when solidified, can be used. Digital production process starts with the generating of 3D model of the gear. 3D Computer-Aided Design (CAD) model data then converted to StereoLithography (STL) file format in order to further process it in a slicing software which is MakerWare^{TM} in this case. 3D model of the gear are sliced into successive 2D layers. Both layers and travel movements of the extrusion head unit are calculated in MakerWare^{TM} slicing process. No support structure is needed for this gear model because there is no overhangs, cavities and bridges. All these slicing data are then exported to either "gcode" or "x3g" file format to print the gear model in a 3D FDM printer.

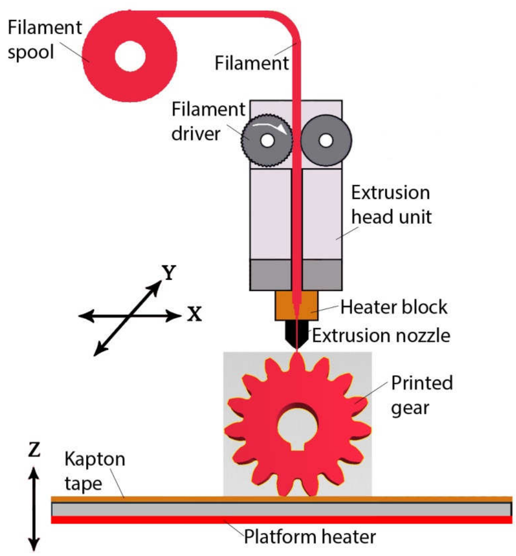

Figure 1. FDM digital fabrication method [15].

In this study, plastic curvilinear involute gears were manufactured using 3D FMD printer and their accuracy values were presented by performing geometric measurements with the aim of promoting the use of these gears in the industry. In this way, alternative manufacturing method is investigated for the production of a curvilinear tooth profiles gear.

2. Material and method

2.1. 3D modeling of the gear

In recent years, as a result of improvements in 3D printers, very complex and diverse parts can be manufactured. In this study, it has been investigated to see whether curvilinear involute profiled gears, which were proved to be useful in the literature and have only one successful manufacturing method, can be produced using 3D printers. Firstly, a involute gear which has a specially developed tooth profile is modeled in a CAD software as a 3D model (Fig.2). Generated of 3d model, the size of the gear is given in Table1. The outside diameter of the gear is 103.6 mm, the thickness is 20 mm and number of teeth is 15. When the modeling is completed, 3D model data is exported to "STL" file format in order to prepare the model for slicing process.

Figure.2. 3D modeling of an involute gear in a CAD software.

2.2. Slicing of the involute gear into layers

MakerWare™ version 3.4.1.48 slicing software is used for calculation both for the movements of the extrusion nozzle along the "X" and "Y" axes and also for the number of layers to process. Inıtially 3D model of the gear is placed onto the building platform and orientated. The orientation of the model not only affects the dimensional accuracy and the surface quality but also whether support structures are needed or not. The thicknesses of the layers also play an important role on the surface quality. As a rule "The thinner the layer is the higher the surface smoothness". In the slicing process, 3D model of the involute gear is sliced into successive 2D layers. The number of layers was 161 (Fig.3) and the height of a layer was 125 µm. The estimated time to complete the printing was calculated as 26 hours and material used during the printing process as 126 grams by the slicing software.

Table.1. Size of the gear.

Magnitudes	**Symbol**	**Application**
Module	m	*6*
Number of teeth	Z	*15*
Outside diameter	Da	*103,6 mm*
Tooth width	b	*20 mm*

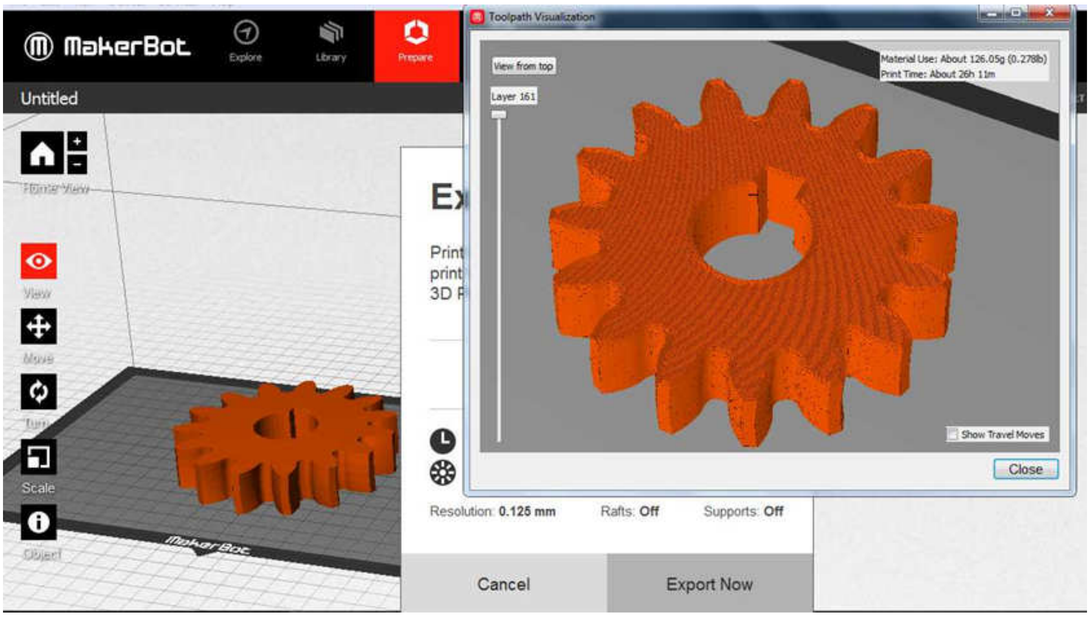

Figure.3.Slicing of the 3D gear model into layers and calculation of the head unit movements.

2.3. 3D printing of the involute gear

Flashforge Creator 3D FDM printer showed in (Fig.4) was used for printing of the involute gear. When gear is manufactured, Consumable material is ABS (Acrylonitrile butadiene styrene) plastic is used. It's chemical formula $(C_8H_8)_x$•$(C_4H_6)_y$•$(C_3H_3N)_z$) and properties are given in Table2. The diameter of the ABS plastic filament was 1.75 mm. Building platform of the 3D printer both was preheated to 110 ^oC and also was covered with heat resistant kapton tape in order to ensure that the involute gear sticks well to the platform. The temperature of the platform was held constant during the printing process at 110 ^oC.

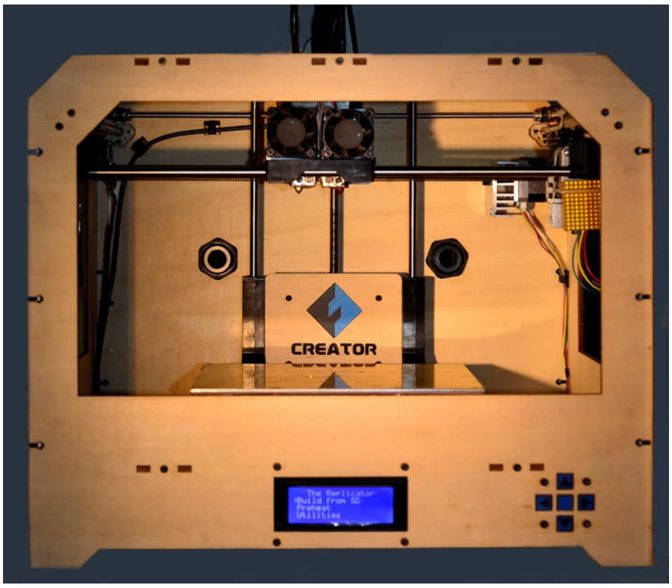

Figure. 4. Flashforge Creator 3D FDM printer.

Table.2. Properties of ABS Plastic materials.

Properties	Magnitude
Density (g/cc) Melt Flow 18 - 23 g/10 min	1.04
Melt Flow (g/10 min.)	18-23
Hardness, Rockwell R	103-112
Tensile Strength, Yield(MPa)	42.5-44.5
Maximum Service Temperature, Air(^{0}C)	89
Softening Point, (^{0}C)	89

ABS filament plastic was heated up to 226 ^{o}C inside the extrusion head unit in order to melt it. 3D fabrication took about 26 hours and approximately 126 grams ABS filament is consumed during the process. The printed involute gear is showed in (Fig.5).

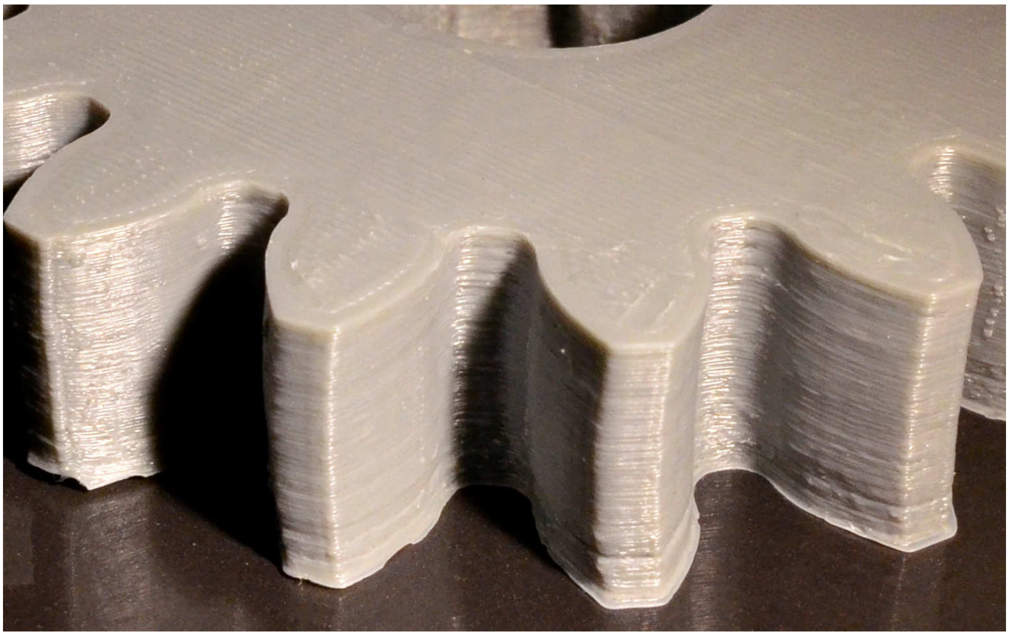

Figure.5. 3D printed involute gear in a FDM printer.

The manufactured gears have been subjected to experimental measurements for the purpose of proving the geometric accuracy by using 3D scanning method with a precision value of 0.001 mm. 3D model of the manufactured gear was created by using 3D scanning model. Measurements were performed on 8 different points of 3D models obtained both after manufacturing and during the design phase over their starting, mid and endings across sides of the gears (Fig.6). The values measured were comparatively presented (Fig.7).

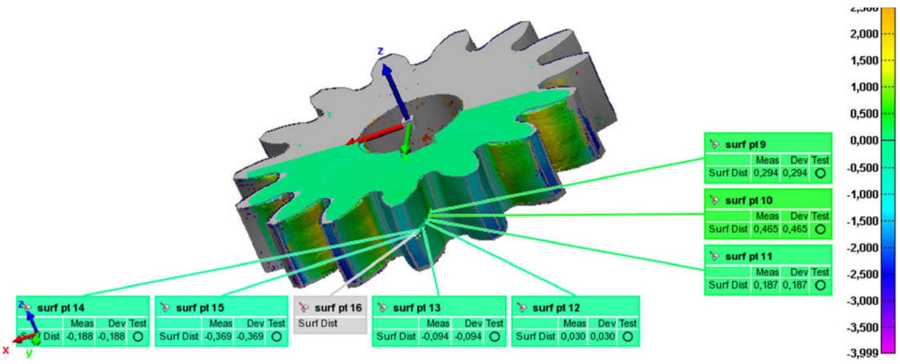

Figure.6. Experimental measurements on 3D model and scanning model.

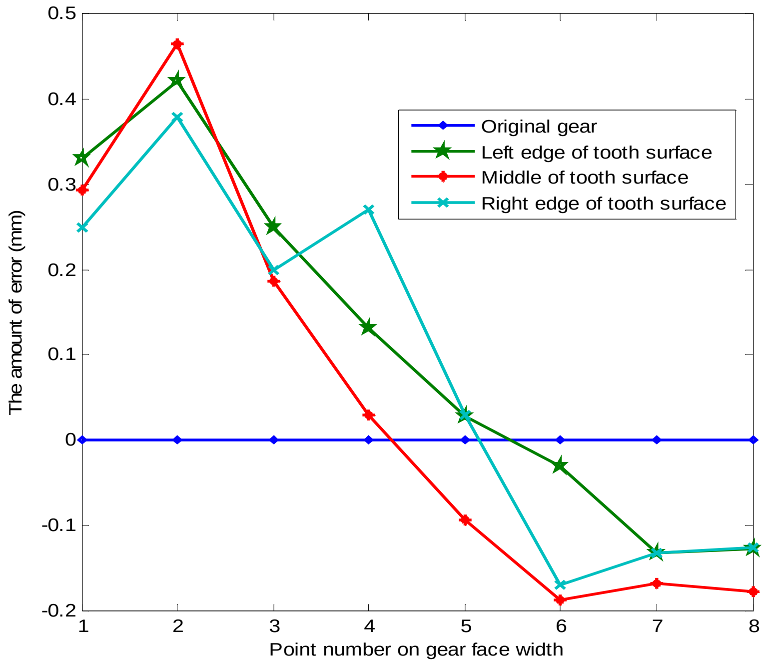

Figure.7. The comparatively measured values of gear.

3. Result and discussion

In this study, the current methods used or manufacturing of curvilinear involute profiled gears were investigated and it has been seen that these gears can be produced with a full accurate geometry by using spherical and flat-fronted finger cutters on at least four axial CNC machines. In addition to this method, curvilinear involute profiled gears were produced by using 3D printer in order to have an alternative method. The models of current gears were created by 3D scanning method in order to determine the geometrical accuracy of the manufactured gears. Measurements were taken on one tooth of the gear and deviation values are removed. In the measurements performed on the tooth profile of the gear manufactured by a 3D printer, a little positive deviation was seen in the areas close to root of the tooth, while negative deviation was seen at the points close to the top of tooth compared to the actual models. It has been also seen that this negative situation was caused by rapid cooling of the plastic material used to manufacture gears with a 3D printer. In addition, on the side profile of the tooth, it has been seen that lines created by each layer during manufacturing has caused surface roughness. In addition, the production of the gear took about 26 hours, which can be considered as a long time. If this manufacturing method developed for plastic material can be applied on metal materials successfully and resulting surface roughness can be eliminated by developing a suitable grinding method, and manufacturing time can be reduced to reasonable values; a successful manufacturing method would be achieved in addition to the limited manufacturing methods, which are obstacles for widespread use of curvilinear involute profiled gears, which were proven to be advantageous, in the industry. Thus, an alternative method for the manufacture of these gears will be developed.

References

[1] İleri, H., **Machine elements**, İstanbul Technical University Library, 721, 793-795, (1963).

[2] Bryan, N.V, Douglas, W., Laurentia, A., Gabriel, A., Non-standard cylindrical gears, International Conference on Gears, Germany, VDI report 1665, 1, 311-326, (2002).

[3] Laurantia, A., Gabriel, A., Alexandru, E., Iulian, G.B., Synthesis and Analysis of Plastic Curved Face width Spur Gears, The Annals of University of Galati Fascicle VIII, ISSN1221-4590, TRIBOLOGY, (2005).

[4] Laurantia, A., Gabriel, A., Douglas, W., Optimization of The Tooth Flank Geometry for Non-Standard Spur Gear, The Annals of University of Galati Fascicle VIII, ISSN1221-4590,TRIBOLOGY, (2006).

[5] Laurantia, A., Douglas, W., Gabriel, A., Influence of Non-Standard Geometry of Plastic Gear on Sliding Velocities, The Annals of University of Galati Fascicle VIII, ISSN1221-4590, TRIBOLOGY., (2004).

[6] Laurantia, A., Gabriel, A., Epureanu, A., Oancea, N., Walton, D., Numerical simulation and generation of curved face width gears. **International Journal of Machine Tools and Manufacture**, 42 (1), 1-6, (2002).

[7] Lai, TS., Design and machining of epicycloid planet gear of cycloid drives. **The International Journal of Advanced Manufacturing Technology**, 28 (7-8), 665-670, (2006).

[8] Ozel, C., İnan, A., Ozler, L., An investigation on manufacturing of the straight bevel gear using end mill by CNC milling machine. **Journal of Manufacturing Science and Engineering, Transaction of the ASME**., 127, 503-511, (2005).

[9] Talon, J.L.H., Ortega, J.C.C., Gomez, C.L., Sancho, E.R. and Olmos, E.F., Manufacture of a spur tooth gear in Ti-6Al-4V alloy by electrical discharge. **Computer-Aided Design**, 42, 221-230, (2010).

[10] Uzun, M., Ozel, C., İnan, A., Investigation of Manufacturing Possibilities of Non-standard Curve Linear Profiled Cylindrical Involute Gears With CNC Milling Machine, MATIT, 125-133, (2011).

[11] Uzun, M., The investigation on manufacturing time of a new type concave-convex gear by a CNC milling machine. **The International Journal of Advanced Manufacturing Technology**, 77(5-8), 1275-1280, (2015).

[12] Uzun, M., İnan, A., Manufacturing the new type concave-convex profile involute gears modeled by CAD-CAM in CNC milling machines. **Journal of the**

Brazilian Society of Mechanical Sciences and Engineering, 37(1), 255-261, (2015).

[13] Crump, S.S., U.S. Patent 5, 121, 329, Apparatus and method for creating three-dimensional objects, U.S.Class: 364/468, ASSIGNEES: Stratasys, Inc., Minneapolis, MN, (Date of Patent), (1992).

[14] MakerBot® MakerWare™, 3D printing software, Retrieved from http://www.makerbot.com/support/makerware/documentation/slicer/ 23.02.2015), (2014).

[15] Gur, Y., Additive manufacturing of anatomical models from computed tomography scan data. **MCB: Molecular & Cellular Biomechanics**, 11(4), 249-258, (2014).