PARAMETRIC DESIGN AND RAPID PROTOTYPING OF SPUR GEAR

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ABSTRACT: Competitive economy in the current stage requires the development of rapid prototype of a particular product. Reducing the time needed with prototype design and construction is doing by concurrent engineering so as to achieve integration between the stages of product development. Parametric design is of interest to design pieces families, each family member being able to be designed by changing initial parameters. Making physical prototype most often involves high costs, even in case of a properly project. The paper presents a method of parametric design of wheels that make up a gear and the physical realization of the gear prototype using rapid prototyping technique.
KEY WORDS: parametric design, rapid prototyping, cylindrical gear

1. INTRODUCTION

Considering the current progress of design and manufacturing techniques, engineers have at their disposal a short time for the development of a prototype of a new product in accordance with market requirements.

In a competitive economic environment, rapid development of the concept of the product is essential in order to create a product of good quality, cheaper and adapted to customers' needs.

Therefore, a product must be the result of concurrent engineering of activities which contribute to it, such as the study of customer needs, conception phase, constructive design, manufacturing process design, prototyping, launch of manufacture of the product.

Virtual manufacturing integrates the computer aided design (CAD) with computer aided engineering (CAE) and computer aided manufacturing (CAM) in the same environment that assures flexibility and facilitates the collaboration between all departments which develop the product.

The traditional methods mean achieving the prototype of the product in order to be tested. Most often physical realization of prototype requires a long time and high costs, even where there is a good design, which is a shortcoming in the process of obtaining the final product.

One of the current methods of making prototypes is represented by rapid prototyping technique.

Currently new virtual manufacturing technologies and rapid prototyping have revolutionized the way for the development of a new product .

The rapid prototyping technique is used in a wide variety of fields and means a rapid manufacturing process of parts of a product before its market launches.

The rapid prototyping technique can be used to create physical prototypes quickly, which together with the virtual prototype allows testing, study and correction behavior of the model and can accelerate rapid development of the final product, without the need to carry out the tooling for processing

Regarding the parametric design, it presents a major interest for the design of families of parts.

The parameterization involves a geometric model in a CAD application and realizing constraints between geometric designed model, so that by changing the initial parameters, the entire model is updated automatically.

The paper presents a method of parameterized design of spur gears and achieving them through rapid prototyping. They were used computational relationships known from the literature, it was done a computer program that provided geometrical parameter values which were used to achieve the dimensional constraints to obtain 3D model.

Physical realization of the designed model was achieved by rapid prototyping, on equipments that used FDM technique.

Studied bibliography, websites, showed that there are concerns of different researcher and materialized in articles, master theses which address both designing parameterized gears as well as their realization through rapid prototyping [1], [3], [4], [5], [7], [8].

2. THEORETICAL ASPECTS

At the cylindrical external gears with straight teeth, the teeth of the two wheels are arranged parallel to the wheel axles. The curve of intersection of the tooth flank with a frontal plane defines the gear tooth profile.

As tooth profile are used more curves:

- involute;
- cycloid
- circular arc

Of all these curves, the most used is involute.

Involute is the curve described by a point M of a line t, which rolls without sliding on a fixed circle of radius r, called the base circle (Figure 1).

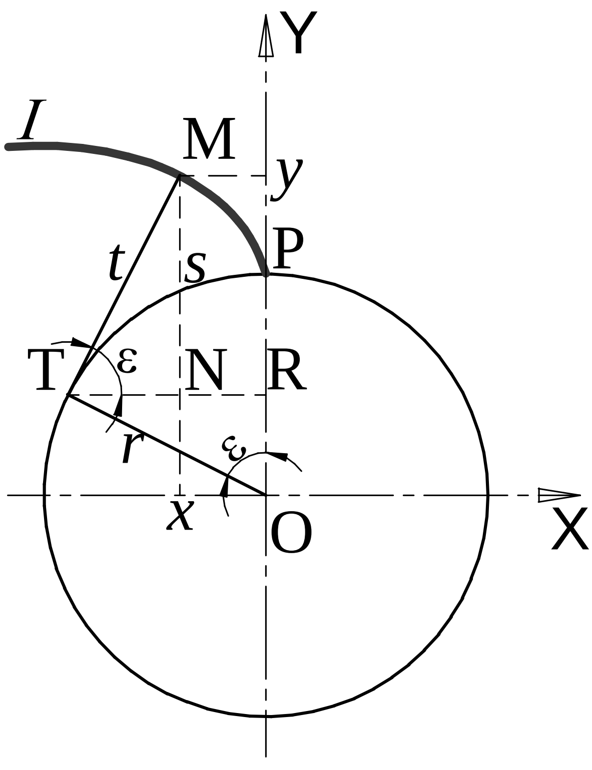

Figure 1. The involute.

- x, y - coordinates of point P;
- R - point of intersection of the perpendicular from the point T with OX.
- N – intersection point of the perpendicular from the point M on TR.

Parametric equations of the involute curve, generated by the movement of the point M on the right, under the terms indicated above, requires that the x and y coordinates of the point M, to be expressed depending on the parameters which determine this movement, namely:

- r - circle radius„r"
- ε – rotation angle of the right line
- s – length of arc TP
- t – length of right segment TM

Because the right line "*t*" rolls without sliding on the circle of radius *"r"* the length of the segment TM is equal with the arc length TP.

The length of arc TP is determined by:

$$t = s = r \cdot \varepsilon \qquad (1)$$

where *ε* is expressed in radians

From the Figure 1 can be easily shown that parametric equations of involute "*I"* are expressed through:

$$\begin{cases} x = -r \sin\varepsilon + r \times \varepsilon \cos \varepsilon \\ y = r \cos \varepsilon + r \times \varepsilon \sin \varepsilon \end{cases} \qquad (2)$$

The main geometric parameters of the wheels and their gear result from Figure 2 [2].

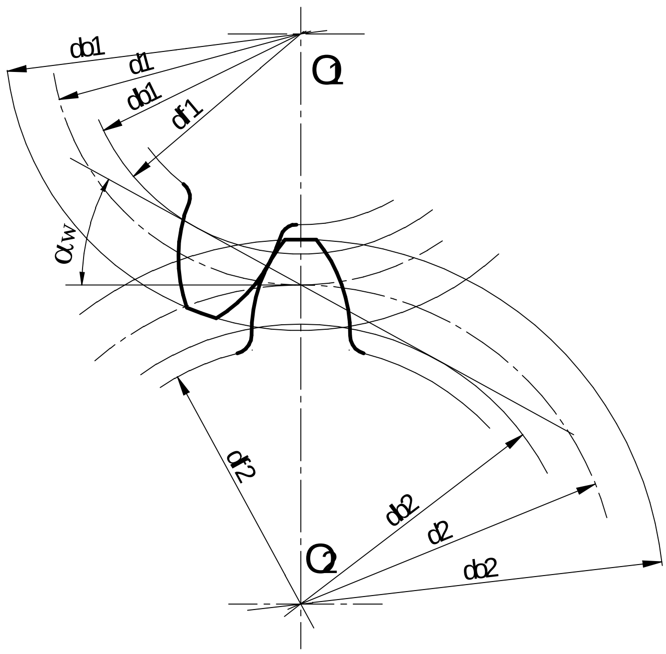

Figure 2. The basic parameters of spur gears.

Basic parameters of spur gears and their calculation relationships are:

Number of teeth - z_1, z_2

Module - m

Addendum - h_a = 1

Clearance - c = 0.25

Root fillet - r_f

Pressure Angle - α= 20o

Center Distance - a_w

Product Center Distance - a

Operating Pressure Angle - α_w

$$\alpha_w = \arccos\left(\frac{a}{a_w}\cos\alpha\right) \tag{3}$$

Unit correction x_1, x_2;

Pitch diameters - $d_{1,2}$;

$$d_{1,2} = m \cdot z_{1,2} \tag{4}$$

Base circle diameters d_{b1}; d_{b2};

$$d_{b_{1,2}} = d_{1,2}\cos\alpha \tag{5}$$

Work pitch diameters - d_{w1}; d_{w2};

$$d_{w_{1,2}} = d_{1,2} \cdot \frac{\cos\alpha}{\cos\alpha_w} \tag{6}$$

Root diameters, d_{f1}; d_{f2},

$$d_{f_{1,2}} = m[z_{1,2} - 2(h_a + c - x_{1,2})] \tag{7}$$

Outside diameters; d_{o1}; d_{o2},

$$d_{a1} = \pm 2a_w \mp m\left(z_2 \mp 2h_a^* + 2x_2\right) \tag{8}$$

$$d_{a2} = 2a_w \mp m\left(z_1 - 2h_a^* + 2x_1\right) \tag{9}$$

Circular Pitch – p;

$$p = \pi \cdot m \tag{10}$$

Base Circular Pitch - p_{tb}

$$p_{tb} = p \cos \alpha \tag{11}$$

Tooth thickness measured normally on the pitch diameter

$$s_{1,2} = \frac{p}{2} + 2mx_{1,2}tg\alpha \tag{12}$$

Theoretical center distance

$$a = \frac{d_1 + d_2}{2} \tag{13}$$

Real center distance

$$a_w = a\frac{\cos\alpha_t}{\cos\alpha_{tw}} \tag{14}$$

3. NUMERICAL STUDY

The relationships of geometric calculation of wheels and their cylindrical external gear and involute relationships were used in a program in MATLAB, which allows, based on initial determination involute points, the outside diameters, root diameter and pitch diameter, the number of teeth of the wheel and also the gear assembly data.

The achieved program allows drawing the involute profile of the flanks of pinion and wheel, and the outside diameter, root diameter and base diameter also (Figure 3).

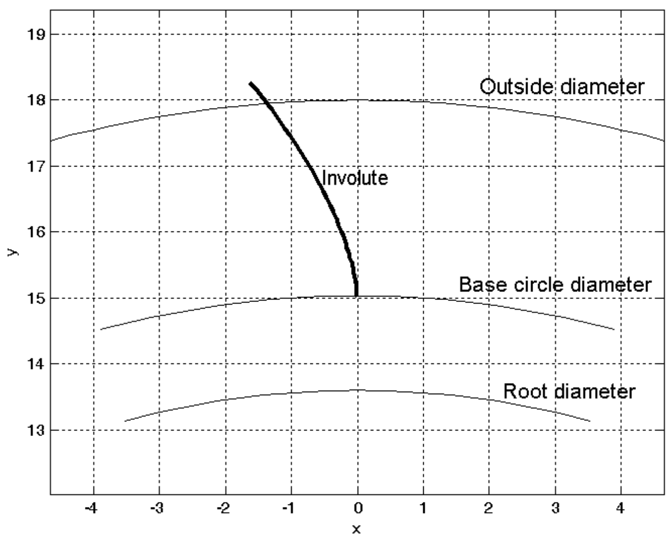

Figure 3. The involute flank of the wheel.

After calculations, all the data are saved in matrices and exported in .xls format, in order to be opened with Excel (Figure 4 and Figure 5).

Pinion.xls

	A	B	C
1	0	15.03508	0
2	-2.7E-05	15.03737	0
3	-0.00021	15.04424	0
4	-0.00072	15.05568	0
5	-0.0017	15.07168	0
6	-0.00333	15.09222	0
7	-0.00575	15.1173	0
8	-0.00913	15.14687	0
9	-0.01362	15.18093	0
10	-0.01938	15.21943	0
11	-0.02656	15.26234	0
12	-0.03533	15.30962	0
13	-0.04584	15.36123	0
14	-0.05824	15.41712	0
15	-0.07268	15.47724	0

Figure 4. The coordinate of point of involute profile.

Geometrical Data_Pinion.xls

	A	B
1	z1	16
2	m	2
3	Re1	18
4	Ra1	13.6
5	R1	16
6	r	0.38
7	l1	10
8	De1	36
9	Da1	27.2
10	D1	32
11	Db1	30.07016387
12	p	6.283185307
13	pbt	5.904262868
14	s	4.597473591
15	a	40

Figure 5. The basic parameters of the pinion.

4. PARAMETRIC DESIGN OF THE GEARS

Previously saved matrices are used to obtain the CAD model of pinion and wheel. For this, we used Solid Edge application, which has a working interface with Excel. Creating involute flank is done by importing points determined by a calculation and saved in matrices and then by using „Curve by table" command. After specifying the plane in which it will place the curve, (Figure 6) it is obtained the involute profile arranged in the selected plane.

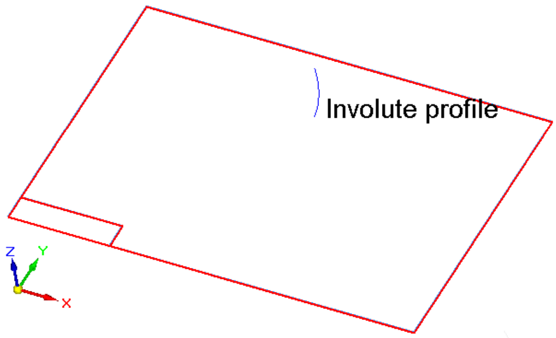

Figure 6. Involute profile placed on x-y plane.

To obtain the CAD model of the wheel is drawn a sketch arranged in the same plane of involute curve, which is then extruded. To achieve tooth profile with involute profile, the curve obtained before should be mirrored about the symmetry axis of the tooth and intersecting with outside and base circles. After completing the basis sketch and applying dimensional relationships, they are constraining using variable table (Figure 7) and the data from the matrix with values of geometrical parameters

The sketch used to 3D model of the wheel is shown in Figure 8.

distance

Type	Name	Value	Rule	Formula	Range	Expo...	Exposed N
D...	V687	27.20 mm	Paste Link	@'F:\...		☐	
D...	V688	30.07 mm	Paste Link	@'F:\...		☐	
D...	V689	32.00 mm	Paste Link	@'F:\...		☐	
D...	V690	36.00 mm	Paste Link	@'F:\...		☐	

Figure 8. Variables table for geometrical parameters of wheel.

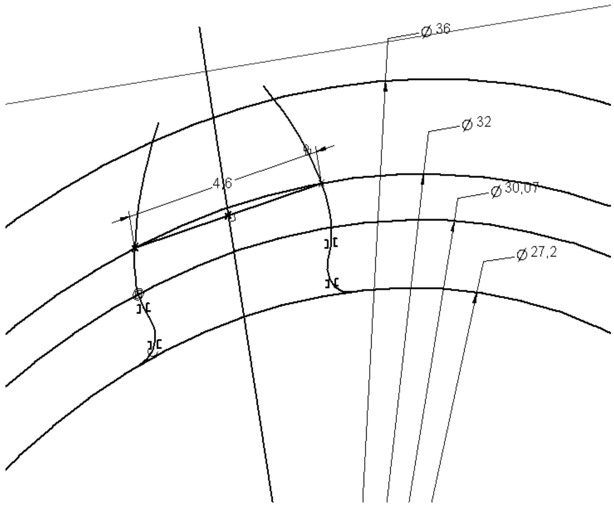

Figure 8. Constrained sketch used for 3D model of the wheel.

Using extrusion command is obtained the body of the wheel and a tooth with involute profile (Figure 9) [6].

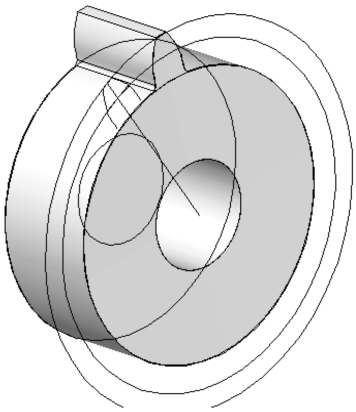

Figure 9. Body of the wheel.

In order to obtain teeth on your entire circumference it will use the multiplication command, resulting in the end of the wheel CAD model (Figure 10).

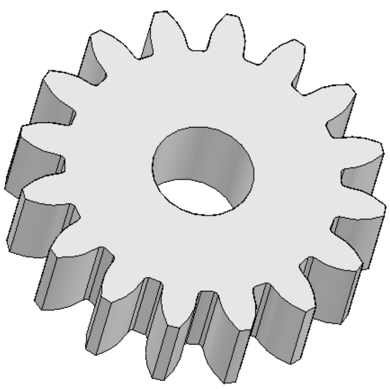

Figure 10. The 3d model of the wheel.

By proceeding in a similar manner is achieved 3D model of the sprocket (Figure 11).

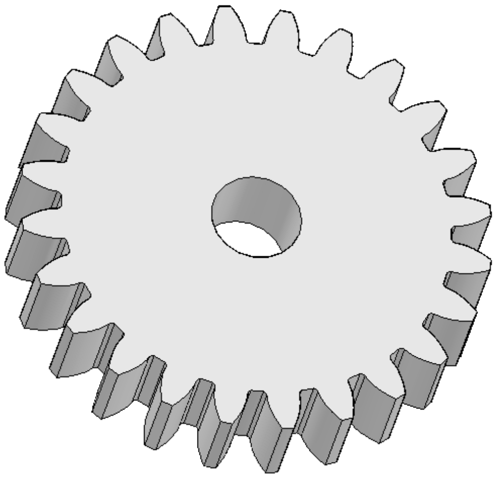

Figure 11. The 3d model of pinion.

Knowing fitting details, having established the positional relationships, after the applying the constraints according to elements previously determined, is obtained the gear presented in Figure 12.

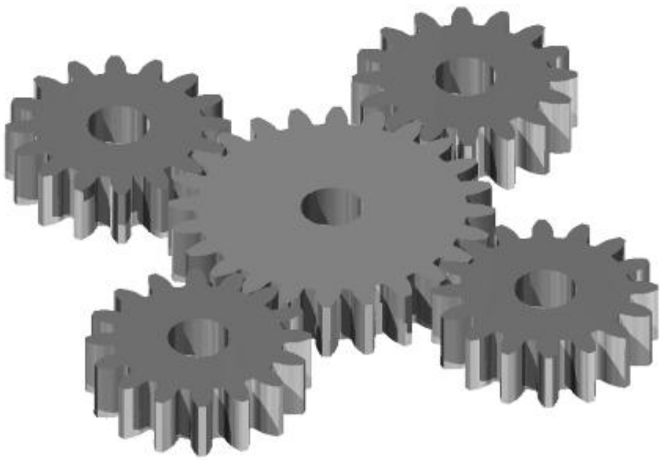

Figure 12. The 3d model of the gear.

5. RAPID PROTOTYPING OF GEAR WHEELS

Current rapid prototyping systems allows easily manufacturing the parts with complex shapes and adequate conditions of precision.

To achieve the pinion and the wheel was used INSPIRE S200 printer, that uses the ABS material for work. Printer is working by the fused deposition modeling method, which consists in deposition of layers of molten material and their solidification. The working head is equipped with heated nozzles that are able to move in a horizontal plane, and the table on which is realized the part is moving in the vertical direction [9].

The main stages of work are:

- Import the CAD model of the part in the printer software;
- setting up the working parameters
- Achieving physical model by depositing layers of support and the layers which will determine the part geometry (Figure 13)

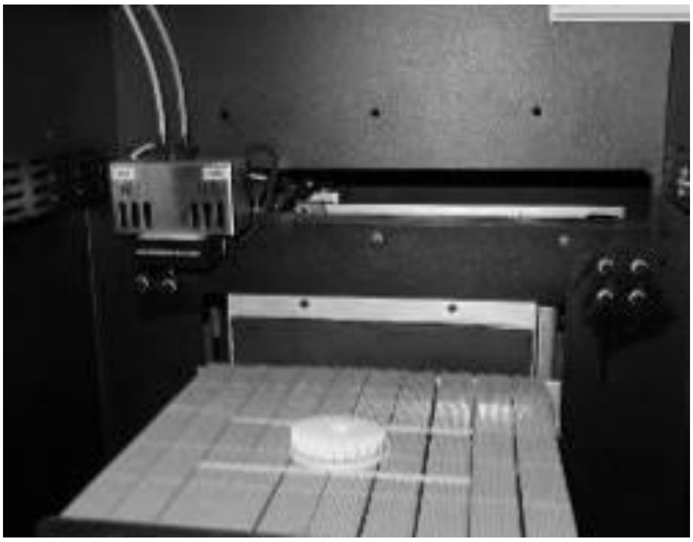

Figure 13. The real model of pinion.

Similarly, are obtained the real models of the gear wheels. In Figure 14 is shown the designed gear manufactured through rapid prototyping technique.

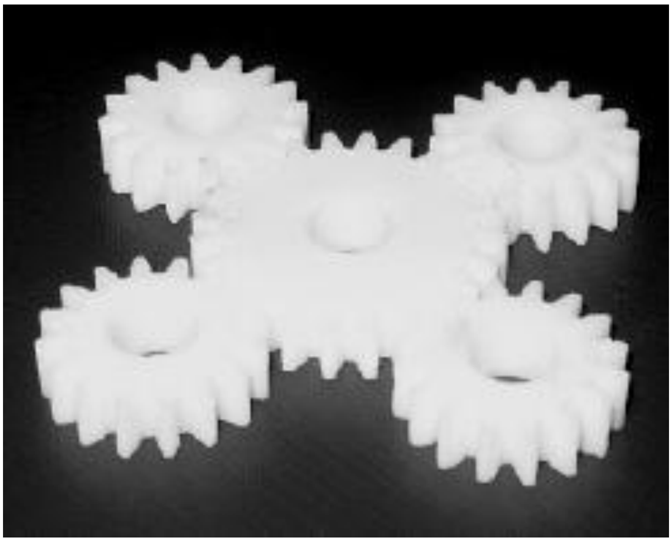

Figure 14. The real model of the gear.

6. CONCLUSIONS

The proposed method has the advantage that once realized the calculation program it can be "generated" any cylindrical gear. The 3D models of the pinion, the wheels and the gear are possible in a very short time.

Tooth profile is drawn through a large number of points, which contribute to achieve accurate involute.

Accuracy of the obtained product by rapid prototyping depends on finesse network of triangles obtained by converting CAD model in STL format.

The printer settings regarding on the number of layers influence the accuracy of obtained prototype.

The rapid prototyping technique enables obtaining of complex shapes products in short time, without requiring tools or other machining operations.

The method allows to obtain cylindrical gears for certain transmissions to different devices, as spare parts without the need for design and development of special molds or cutting tools for processing the gears.

7. ACKNOWLEDGEMENTS

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