

# Creation of gear geometry by CAD applications

Silvia Maláková<sup>1</sup>  
Samuel Sivák<sup>2</sup>

<sup>1</sup> Technical University of Košice, Faculty of Mechanical Engineering; Letná 9, Košice, Slovensko; email: silvia.malakova@tuke.sk

<sup>2</sup> Technical University of Košice, Faculty of Mechanical Engineering; Letná 9, Košice, Slovensko; email: samuel.sivak@tuke.sk

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**Abstract** The rapid development of science in the field of computer technology makes it possible to solve even more demanding engineering problems using modern calculation methods. These include numerical methods of mathematics. The finite element method (FEM) is one of the most widespread numerical methods. FEM is a method used to solve a wide range of engineering problems, such as flexibility and strength problems, heat transfer issues, as well as a wide range of gear solutions. In this area, the FEM is used mainly to solve deformation and stress tasks in the examined gears. There are many programs for solving problems using FEM, but one of the conditions for successful solving of deformation and stress analysis of gearing using this method is the most accurate determination of the computer model of the examined gearing. The article is aimed at the issue of creating gear geometry in the environment of CAD applications.

**Keywords** Spur gear, involute gearing, parametric, CAD

## 1. INTRODUCTION

Gears are the basic element for the transmission and transformation of mechanical energy and movement from one place to another. They have been known and used by humanity before our era. This is also evidenced by the findings in the work of Aristotle (384 - 322 BC), who knew the gears by using gear wheels. The mathematician and physicist Archimedes (287 - 212 BC) used gears for water pumping. A number of gears used today were found in the schemes of Leonardo da Vinci (1452 - 1519) [1]. It can be said that gears have become a symbol of engineering.

Nowadays, the design and construction of gears are greatly simplified and accelerated by various computer programs for construction engineering. They enable the precise production of the desired body shape with the required accuracy [2]. The computer-modeled gears can then be used for production (as production drawings) or for other uses, for example in solving problems of elasticity and strength, such as solving static deformation and stress analysis of gears using the finite element method [3].

The first step to successfully manage the problem of solving the deformation analysis of spur gears with straight teeth using the finite element method is to model as accurately as possible the shape of the investigated object, in this case the shape of the spur gear.

Creating geometry is the first step in creating a computational model of the investigated object [4]. There are several CAD systems for creating involute gear geometry, such as AutoCAD, Bentley, Pro/Engineer, I-DEAS, Solid Works, NX and the like.

## 2. CONDITIONS FOR MODELING OF THE INVOLUTE TOOTH SHAPE FOR SPUR GEAR

For modeling of spur gears made by a rack tool without protuberance, it should be noted that the side of the involute tooth consists of the involute and dedendum transition curve of the side of the tooth. Only the involute part of the tooth flank may act as the active part of the tooth flank during operation of the gear wheel. The task of the transition curve is to create a smooth rounded transition between the involute part of the gearing and the dedendum circle. Therefore, when creating a geometric model of spur gearing, it is necessary to focus on the most accurate constructions of the involute, such as the transition part of the side of the involute tooth. The involute part of the tooth is formed by the straight part of the rack tool in the direction from the addendum to the dedendum [5]. It is known that the profile normal is passing through the instantaneous center of rolling is a tangent to the base circle. The line of action, which for the involute profile is identical to the profile normal line (the common normal of the two contacting flanks of the teeth at their points of contact), thus always passes through the instantaneous center of rolling. The production meshing angle of gearing is equal to the angle of the tool profile. From a geometric point of view, an involute is a planar curve that intersects all tangents perpendicular to the circle. This circle is its evolute i.e., by the set (geometric points) of the centers of curvature of the involute. For gearing, it is called base circle. The involute is unambiguously determined by one parameter - the radius of the basic circle. According to the trochoid construction method, the involute arises as a trajectory of a point firmly connected to the forming line, which rolls along the base circle, its evolute. The starting point of the involute lies on the base circle (Figure 1).

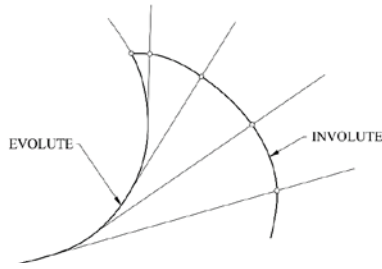


Fig. 1. Involute, evolute

Dedendum transition - the transmission curve is the area between the involute surface of the gear and the dedendum circle. The task of the transition curve is to create a smooth transition between the involute part of the gear and the bottom land. Dedendum transmission curve of the tooth made by the rack tool is produced by gradually rolling the rack tool along the pitch circle of the gear wheel [6]. The radius of curvature of the transition curve at its individual points is variable. Construction of the transition curve is therefore made as an envelope of roundings of the positions of the rack tool, which rolls along the pitch circle of the gear wheel. By connecting the involute and the transition part the tooth shape is constructed [7]. To build one complete tooth shape, the additional data are needed, such as the dimensions of the addendum and dedendum circle, which will limit the height of the tooth. To construct one tooth, the necessary values of the width of the teeth on a radius (for example, on the pitch radius), or the corresponding size of the chord are needed.

In practice, there are also corrected spur gears. Two basic types of corrections are used for involute gearing. A necessary correction that removes the undercut of the gear tooth and a preferred correction that is made in order to obtain the specific properties of the gear profile. When creating a geometric model of a corrected spur gear, it is essential to start from the relations for the basic dimensions of these corrected gears.

### 3. APPLICATION OF MIXED CAD MODELING OF SPUR GEARING

One of the methods for gear generation is simulation of the whole or just a part of the machining process. Such CAD model generation consists of solid modeling of semi-finished product, which will become gear wheel, and the tool, which is used in the machining process. These two models have to be aligned into a correct position. In the next step the simulation is proceeded by given movement steps for tool, or in some cases for both tool and workpiece as well. The gearing is made as subtraction of one volume against another, i.e., tool volume is subtracted from workpiece volume wherever they intersect. Disadvantage of this method (Figure 2) is in steps-precision combination. The more precise model should be the smaller steps should tool carry out, but smaller steps mean longer generation time [8].

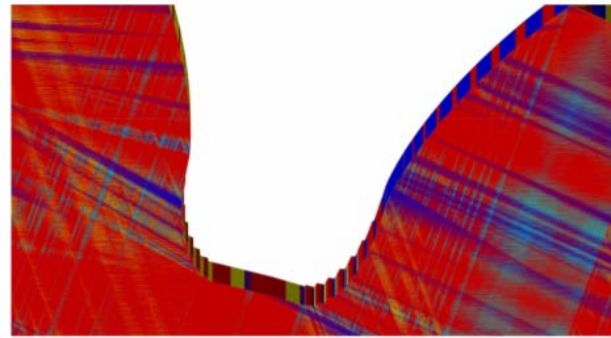


Fig. 2. Tooth gap made by subtraction [8]

Mixed CAD modeling is also a simulation of the same machining process, but instead of solid tool, there is used only a profile of the tool (Figure 3). This profile carries out the same step movement like in subtraction method described above, but the main difference is that this profile only generates points. Generated points make a point cloud, which has to be edited, preferably by algorithm, in a way that excessive points are removed (Figure 4-a). At the final stage, the generated and edited point cloud is used for surface generation (NURBS modeling) (Figure 4-b). By adding volume inside generated surfaces, the CAD model is generated. By obtaining point cloud, the gear generation is much faster and can also be more precise than subtraction of volumes.

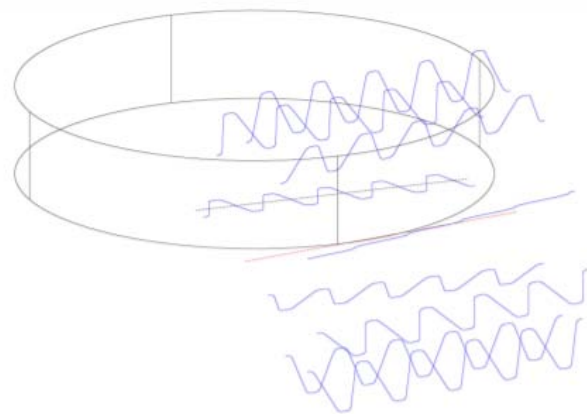


Fig. 3. Principle of mixed CAD modeling method

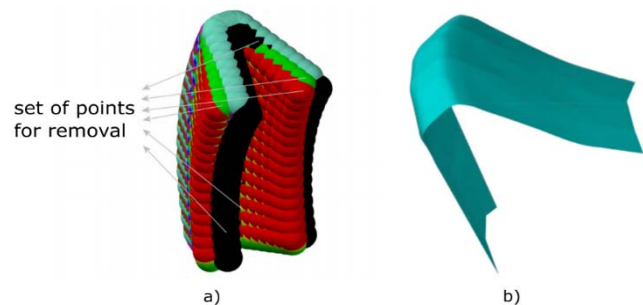


Fig. 4. Tooth generated by a) points, b) surfaces made through points

#### 4. APPLICATION OF PARAMETRIC MODELING OF GEARING

This method is applicable to spur gears, helical gears and also gears with a special tooth shape. The principle of this method is to calculate all of the values of the gear wheel first, and then the involute curve and the transition curve in the CAD program are created using the parametric curve function, or other means of modeling [9]. The gearing is created by removing the profile that forms the tooth gap, but there are methods which generate teeth as a solids. Subsequent copying of this profile around the circumference of the gear wheel at equal intervals results in total gearing.

##### 4.1 Application of parametric modeling in Pro/Engineer environment

Use of this program and suitable parameterization, makes it possible to construct a wide range of gears of acceptable accuracy in a shorter period of time. The Pro/Engineer program, by its nature of work, enables the construction of a general gear model from a time-consuming point of view in a relatively simple way by means of modeling. It is then possible to incorporate individual gear parameters into this model and to interconnect them with mathematical expressions. By modifying the dimensions of the gearing, such as the modulus, the number of teeth, the displacement and the like, it is possible to create any gear wheel, or it is also possible to further modify it.

The first step is to define the geometric parameters for the spur gearing. An example is shown in Figure 5.

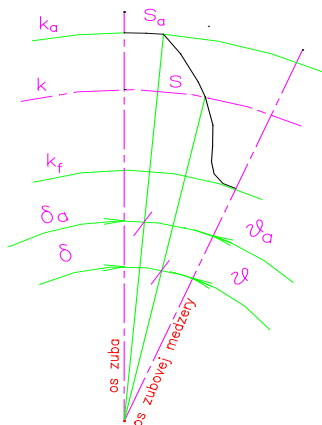


Fig. 5. Example of spur gear dimensions

A parametric description of the respective sketch or model is shown in Figure 6. For corrected gearing, it is advisable to do the parameterization on the model. Variable values, such as the number of teeth  $z$ , the modulus  $m_n$  and the unit height displacement  $x$  should be defined using various elements (date planes - e.g., offset by a value that will show e.g.,  $\pm x$ , or it may be a shape element that does not affect the final investigated values - e.g., for values  $z$ ,  $m_n$  and others).

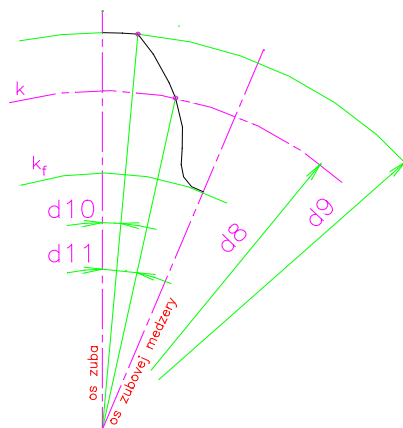


Fig. 6. Example of parametric description of the model

The following change in the designation of individual parameters was used in the parametric description:

- the number of teeth  $z$ , was indicated as  $d0$ ,
- the normalized value of the modulus  $m_n$  was indicated as  $d1$ ,
- the unit height displacement  $x$  was indicated by the symbol  $d2$ ,
- the helical angle  $\beta$  was indicated by the symbol  $d3$ .

Then, all equations for calculating the gear dimensions were parametrically defined. The diameter of the pitch circle determined by equation (1) was parametrically defined by equation (2).

$$d = \frac{z \cdot m_n}{\cos \beta} \quad (1)$$

$$d8 = d0 \cdot d1 / \cos d3 \quad (2)$$

The diameter of the addendum circle determined by equation (3) was parametrically defined by the equation (4).

$$d_a = d + 2 \cdot (1 + x) \cdot m_n \quad (3)$$

$$d9 = d8 + 2 \cdot (1 + d2) \cdot d1 \quad (4)$$

The angular coordinates of the involute point lying on the pitch circle given by equation (5) were parametrically defined by equation (6).

$$\delta = \frac{s}{d} \cdot \frac{180^\circ}{\pi} \quad (5)$$

$$d11 = \frac{(0,5 \cdot \pi + 2 \cdot d2 \cdot \sin 20 / \cos 20) d1 \cdot 180^\circ}{(d8 \cdot \pi \cdot \cos d3)} \quad (6)$$

In this way, all the gear parameters were successively defined.

##### 4.2 Application of Face Gears Modeling

The face gear (Figure 7) is a widely researched new transmission mechanism. This mechanism found its use in special transmission type group e.g., in aviation industry.

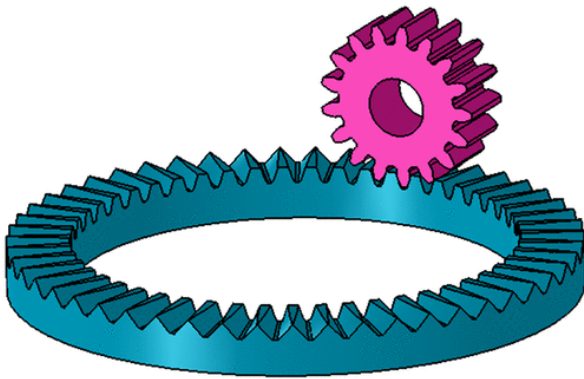


Fig. 7. Model of face gearing

The coordinate system used for the involute tool tooth surface corresponds to the coordinate system in Figure 8, and its cross section is an involute tooth type.

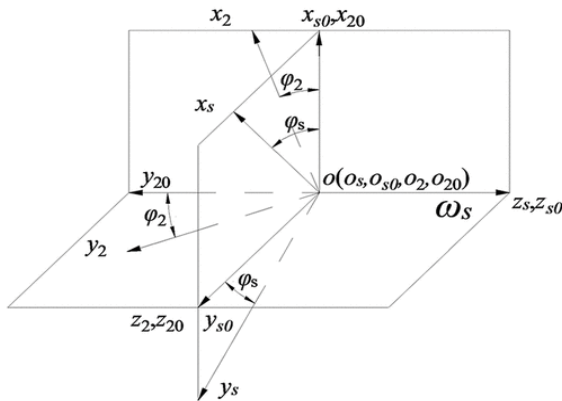


Fig. 8. Coordinate system for face gear generation [10]

The specific shape and parameters are shown in Figure 9.

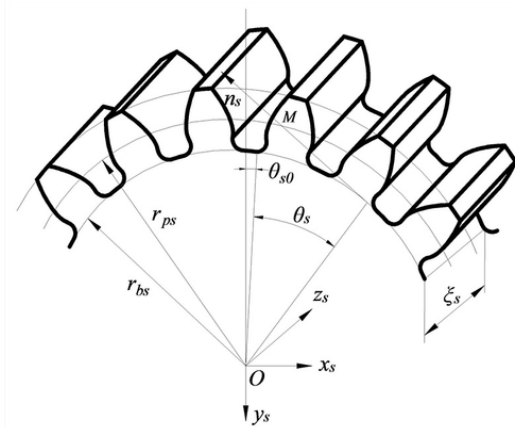


Fig. 9 Parametric model of the involute tool

An example of the parametric definition of the tool involute tooth surface vector equation  $r_s$  is given by equation (7):

$$r_s(\xi_s, \theta_s) = \begin{bmatrix} x_s \\ y_s \\ z_s \end{bmatrix} = \begin{bmatrix} \pm r_{bs} [\sin(\theta_s + \theta_{s0}) - \theta_s \cdot \cos(\theta_s + \theta_{s0})] \\ -r_{bs} [\cos(\theta_s + \theta_{s0}) + \theta_s \cdot \sin(\theta_s + \theta_{s0})] \\ \xi_s \end{bmatrix} \quad (7)$$

where  $\xi_s$  is the axial parameter of a point on the tooth surface of the tool and determines the tooth width of the tooth surface of the tool;  $\theta_s$  is the angle parameter of the point on the involute curve of the tool and determines the height of the tooth surface of the tool;  $r_{bs}$  is the base circle radius of the tool involute; and  $\theta_{s0}$  is the angle parameter of the tool slot symmetry line to the starting point of the involute.

The calculated point coordinates are edited to generate point cloud in CAD software accepted files. The surface of the tooth is generated in a CAD program. Whole gear wheel is created by array of individual teeth and discs.

## 5. CONCLUSIONS

The quality of gears is largely decided by their geometric design. If the geometric design is incorrect, the reliability of the transmission will not be ensured even by the use of the highest quality materials. Conversely, sometimes excellent geometric gear design can save expensive material costs. Therefore, creating an accurate geometric model of the gear plays a crucial role.

CAD programs have become an integral tool for designers. Thanks to their advantages, they have been very rapidly expanded and developed by developers to such degree that they are now applicable in every aspect of engineering practice. One of these aspects is the design and creation of gear models. When designing gears, it is necessary to be able to create a 3D model, for better visualization and later for control, by the finite element method or others, as quickly and accurately as possible. An unwritten rule is that the more accurate the model, the longer it takes to create or generate it. However, with the continuing development of CAD programs and increasingly powerful computing technology, this difference is disappearing.

Using a CAD application, we can create a geometric model of gearing with sufficient accuracy. The computer-modeled bodies can then serve as drawing documentation or for further use, for example in solving problems of elasticity and strength, such as solving static deformation and stress analysis of gears using the finite element method.

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