

## GEOMETRICAL DESIGN OF GEARS USING MOTION ANALYSIS IN CAD SOFTWARE

**Abstract:** The utilization of tools provided by CAD software has become an essential component of any design process in modern mechanical design. These tools provide a simplified design methodology that does not require expert knowledge for the design of complex mechanical parts. Gears, as one of the most used mechanical components, have precisely defined and well-understood several types of tooth geometry. However, different shapes of tooth profiles cannot be easily analyzed and designed without knowledge of mathematics and analytical geometry. With modern design tools, especially CAD software, that knowledge is not necessarily required in the design process. Engineers can simply define the relative motion of one component to produce all necessary parameters that define the shape and geometry of another component.

**Key words:** geometrical design, gear geometry, gear profile, CAD design, SolidWorks, motion analysis.

### 1. INTRODUCTION

Gears are essential mechanical components widely used in countless applications to transmit motion and power between rotating shafts. The design of gears has traditionally relied on involute tooth profiles due to their recognized qualities and simplicity of manufacture. Some of the advantages of the involute profile are:

- The capacity to keep the angular velocity ratio between the mating gears constant during the meshing cycle, which results in smooth and uniform motion transmission,
- Effective power transmission that reduces sliding friction and energy losses during operation due to the involute gears' gradual tooth engagement,
- The ability to accommodate certain misalignments between shafts without fundamentally compromising their functionality,
- Simplified gear design, analysis, and compatibility enabled by becoming the involute tooth profile standard in gear design, with well-established mathematical formulas and guidelines for gear tooth geometry and sizing,
- Standard gear-cutting machines and procedures for manufacturing involute gears, which makes their production reasonably simple and economical.

Although the involute tooth profile offers many benefits, there are disadvantages that should be considered in certain applications. These are a few disadvantages related to the involute tooth profile:

- In the case of gears with a small number of teeth or high-pressure angles, undercutting can occur. The undercut indicates the phenomenon of cutting the gear root deeper than the involute tooth curve,
- Convex-convex contact is more unfavorable than a concave-convex contact that can be achieved with non-involute gears [1],
- Involute gears may produce higher levels of noise and vibration compared to some non-involute profiles.

Researchers are actively exploring methods to avoid the disadvantages of involute gears by changing the tooth profile of the gear. They employ two primary approaches to achieve this. The first approach involves defining the shape of the tooth flanks based on a desired path of contact (the curve that connects the points of contact of the tooth flanks). For example, in [2] design method for the tooth profiles based on the given parabolas as the line of action is applied. The second approach is to define the shape of the flanks of the rack, for example S-shaped, Wildhaber-Novikov gears [3], or worm gear [4]. In this study, the second approach mentioned will be utilized.

The main goal of this paper was to observe how changes in the rack's flank shape influenced the resulting gear tooth profile focusing exclusively on geometric considerations without involving mathematical calculations and equations. To determine the geometry of the gear teeth that will be produced with the utilization of racks with different profiles, motion analysis in the software package SolidWorks was used.

#### 1. 1 Gear tooth profile generation using rack cutter

During the process of manufacturing gear teeth, the gear rack undergoes oscillatory translational motion, while the gear undergoes rotational motion. The formed involute tooth profile represents the envelope of a series of consecutive positions of the cutting edge (the tool's cutting edge) when it moves along with the generating line rolling on the base circle.

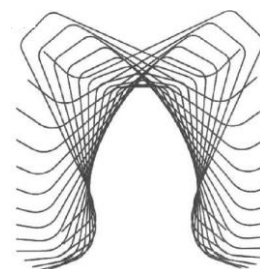


**Figure 1** The method by which the cutter generates the gear tooth profile [5]

## 2. PROBLEM DESCRIPTION - DEFINING THE PROFILE OF THE RACK

In order to confirm that the designed approach in SolidWorks gives reliable results, the initial simulation was conducted using a standard rack. The teeth of a standard rack are trapezoidal. The parameters of the rack were determined based on reference [6], and they are illustrated in Figure 2. The adopted values are:

- Module –  $m_n = 3$  mm;
- Addendum (the distance between the pitch line and the tooth tip) and dedendum (the distance between the pitch line and the tooth root) are identical and equal to the module;
- The root radius is omitted;
- The tooth width and tooth space are equal along the pitch line of the rack, and the value is equal to half of the pitch  $p$  ( $p = m_n \pi$ );
- Pressure angle –  $\alpha_n = 20^\circ$ ;
- The number of gear teeth –  $z = 35$ ,  
The diameter of the raw material from which the gear will be created is  $d = m_n \cdot z = 105$  mm.

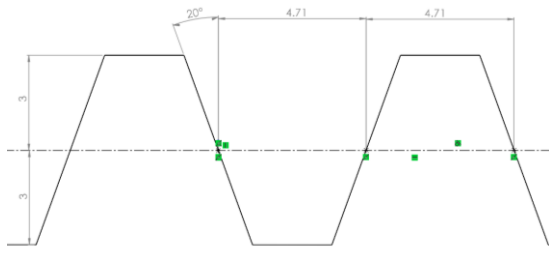


Figure 2 Geometric dimensions of the standard rack profile

The additional profiles of the gear rack utilized in the simulations are as follows:

- Convex Involute (Figure 3),

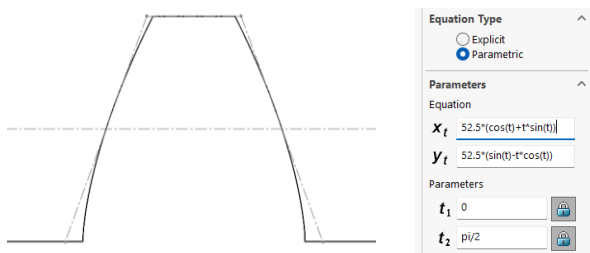


Figure 3 Appearance of the convex involute profile of the rack and parameters of involute

- Concave involute (Figure 4),

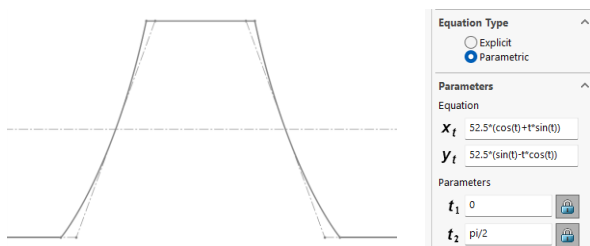


Figure 4 Appearance of the concave involute profile of the rack and parameters of involute

- Rectangular (Figure 5),

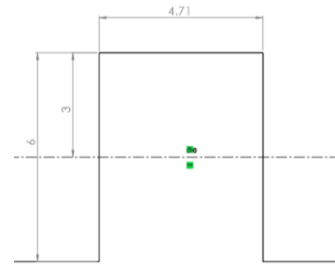


Figure 5 Geometric dimensions of the rectangular rack profile

- Stepped (Figure 6).

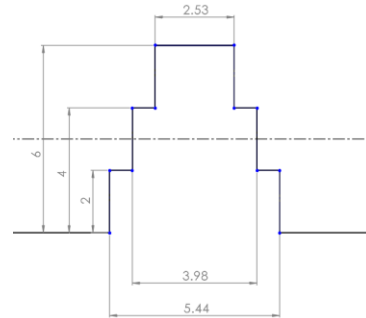


Figure 6 Geometric dimensions of the stepped rack profile

## 3. METHODS USED - MOTION ANALYSIS IN SOLIDWORKS

After defining the geometry of the rack, the next step was to define parameters for motion analysis, which will simulate the process of manufacturing gear teeth.

The rack and the raw material are coupled through the rack and pinion mate, along with other mates that ensure alignment of specific planes and surfaces. The profile shift is zero; that is, the pitch line of the rack tangentially coincides with the pitch circle of the gear.

The rack was set to undergo translational motion, while the raw material from which the gear will be created was set to rotate. In SolidWorks software, a body cannot intersect itself. To avoid this limitation, the raw material needs to move additionally along the axis of rotation.

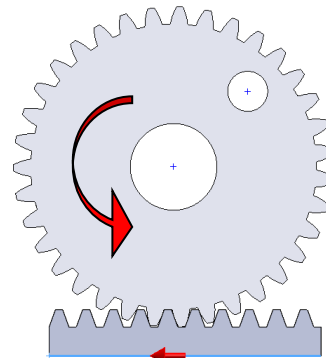


Figure 7 Motion analysis: Gear Rotation and Rack Translational Motion

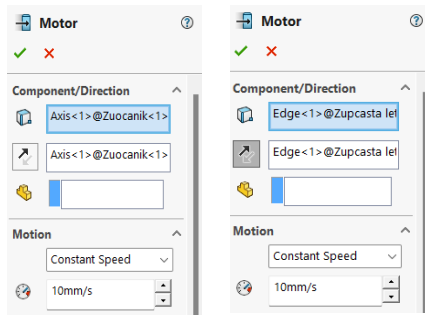


Figure 8 Prescribed Speeds for Gear and Rack

During motion analysis, the trajectories of points along the cutting edge of the gear rack are tracked. Using these trajectories, bodies are formed. One such body, in the case of involute tooth generation, is depicted in Figure 9.



Figure 9 Body for Generating Involute Gear

The silhouette of such a body is projected onto the surface of the raw material, and a cutting operation is performed (Figure 10). This procedure is iterated along the entire circumference of the raw material, resulting in the creation of a gear.

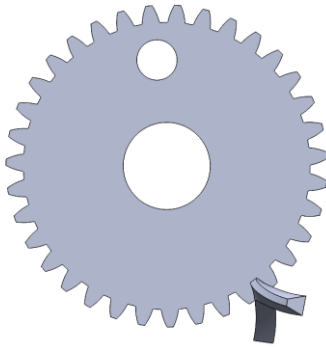


Figure 10 Silhouette projection for gear generation

## 4. RESULTS

### 4.1 Gear teeth formed by the trapezoidal shape of the cutting edge of the rack

As it is commonly known, the rack with the trapezoidal shape of the cutting-edge forms gears with an involute tooth profile. The involute is the curve described by each point on the tangent of the base circle as it rolls on the base circle.

The shape of the gear teeth produced by the simulation is shown in Figure 7. Through comparison with the involute, it is shown that the resultant profile corresponds

to an involute shape. This suggests that using the same procedure with racks of different shapes will produce reliable outcomes.

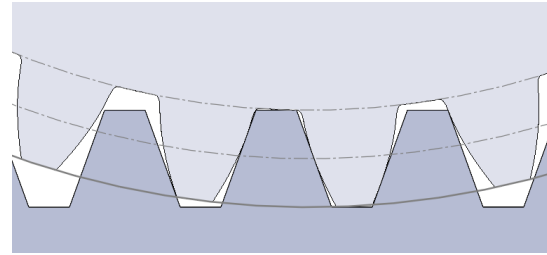


Figure 11 Illustration of a trapezoidal rack tooth profile and a generated gear tooth profile

### 4.2 Gear teeth formed by the convex involute shape of the cutting edge of the rack

The question arises: if a trapezoidal profile of the gear rack produces an involute gear profile, would an involute profile of the gear rack yield a trapezoidal gear profile? The simulation provided a positive confirmation.

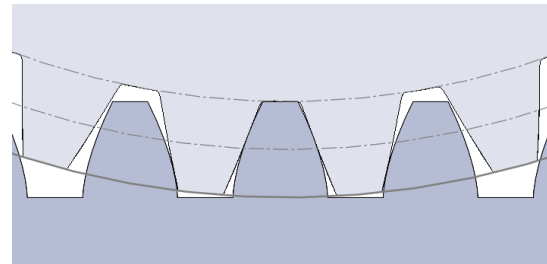


Figure 12 Illustration of a convex involute rack tooth profile and a generated gear tooth profile

### 4.3 Gear teeth formed by concave involute shape of the cutting edge of the rack

The next case considered involves a gear rack with teeth in the shape of a concave involute. If the teeth of the rack were to have a convex involute shape, then the gear would have teeth shaped as depicted in Figure 11.

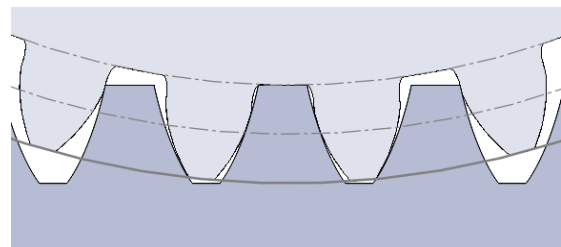


Figure 12 Illustration of a concave involute rack tooth profile and a generated gear tooth profile

### 4.4 Gear teeth formed by the rectangular shape of the cutting edge of the rack

In many research papers, researchers investigate the influence of the pressure angle on the appearance and characteristics of gear teeth. In [7], various tooth profiles are depicted based on pressure angles ranging from 20 to 35 degrees. This study demonstrates how the tooth profile would appear if the pressure angle were 90

degrees, i.e., if the teeth of the gear rack had a rectangular shape. From Figure 12, it can be noted that in this case, undercutting occurs. Based on this and various variations of this case, the conclusion is drawn that undercutting will occur in cases where the profile of the rack above the pitch line is steeper than the standard gear rack profile.

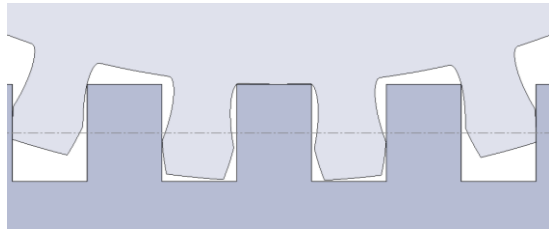


**Figure 13** Illustration of a rectangular rack tooth profile and a generated gear tooth profile

#### 4.5 Gear teeth formed by the stepped shape of the cutting edge of the rack

The final example is an attempt to avoid undercutting by narrowing the profile and creating a 'step' where undercutting is expected.

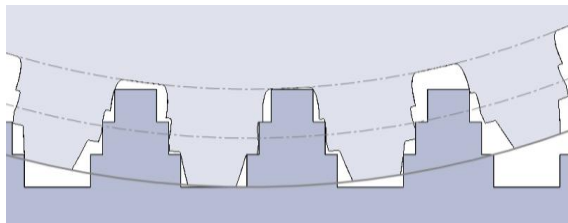


**Figure 14** Illustration of the stepped rack tooth profile and the generated gear tooth profile

### 5. CONCLUSION

In this study, we analyzed the interaction between rack and gear geometry. We explored the effects of different rack shapes, from rectangular profiles to more complicated geometric forms, on the generation of gear tooth profiles through simulation using SolidWorks.

Five different profiles of gear racks were defined, including trapezoidal, convex involute, concave involute, rectangular, and stepped profiles. Based on these defined racks, five distinct gear tooth profiles were obtained using simulation in SolidWorks, and their representations are provided in this paper.

The primary focus of the study was to analyze how variations in the flank shape of the rack impact the resulting gear tooth profile, emphasizing purely geometric factors without resorting to mathematical calculations or equations.

The direction of further research could refer to the kinematic properties, tooth contact analysis, mathematical formulations, and dynamic behaviors of gears generated from different rack profiles. Additionally, the plan is that further investigations will involve experimental validations, prototyping, and

testing to validate the theoretical findings presented in this study.

### ACKNOWLEDGEMENT

The results presented in this paper are the result of research supported by the Ministry of Science, Technological Development, and Innovation of the Republic of Serbia under the Financing Agreement for scientific research conducted by teaching staff at accredited higher education institutions in 2024, ref. No. 451-03-65/2024-03/200105 dated 5th February 2024.

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