Acta Mechatronica - International Scientific Journal about Mechatronics
Volume: 9 2024 Issue: 4 Pages: 33-38 ISSN 2453-7306

https://doi.org/doi:10.22306/am.v9i4.128

Received: 05 Nov. 2024
Revised: 28 Nov. 2024
Accepted: 11 Dec. 2024

Possibilities of creating spur gear geometry

Silvia Malakova
Technical University of Kosice, Faculty of Mechanical Engineering, Letna 9, 04200, Kosice, Slovak Republic, EU, silvia.malakova@tuke.sk (corresponding author)
Robert Grega
Technical University of Kosice, Faculty of Mechanical Engineering, Letna 9, 04200, Kosice, Slovak Republic, EU, robert.grega@tuke.sk
Marianna Tomaskova
Technical University of Kosice, Faculty of Mechanical Engineering, Letna 9, 04200, Kosice, Slovak Republic, EU, marianna.tomaskova@tuke.sk
Peter Frankovsky
Technical University of Kosice, Faculty of Mechanical Engineering, Letna 9, 04200, Kosice, Slovak Republic, EU, peter.frankovsky@tuke.sk

Keywords: gearbox, gearing, design, model.

Abstract: The swift advancement of science in computer technology enables the resolution of increasingly intricate engineering challenges through contemporary calculation techniques. Numerical methods employed in mathematics are among these. The finite element method, also known as FEM, is widely recognized as a prevalent numerical technique. The Finite Element Method (FEM) is a versatile technique employed to tackle diverse engineering challenges. These may include problems related to flexibility, strength, heat transfer, and a variety of gear solutions. The Finite Element Method is primarily employed in this domain to address deformation and stress analyses pertaining to the gears under examination. Numerous programs are available for addressing issues through the Finite Element Method. However, a crucial prerequisite for effectively analyzing deformation and stress in gearing is the precise definition of the computer model representing the gear system under investigation. The focus of the article is on discussing the process of designing gear geometry within CAD software systems.

1 Introduction

Complex mechanical systems called gear drives are found in almost every kind of technology, including cars, airplanes, and robots. Gear drive design is a laborious and time-consuming procedure that heavily relies on the designer's intuition and expertise. Many complex issues and a wide range of influencing elements must be taken into account at the early design phase. One of the crucial factors to take into account is the gear transmission chain configuration. The way the gears, shafts, bearings, couplings, clutches, and other components are connected to one another so that the gear transmission system can transfer motion and power is known as the gear transmission chain configuration. It is a crucial choice made early in a gear transmission's design. Any errors in these early design stages can significantly increase the challenges in later design and manufacturing. Decisions made in these stages frequently have a significant impact on the full-life-cycle product properties, including costs, performances, reliabilities, safety, maintenance, and so on. Numerous significant system attributes, including reduction ratios, system level proficiencies, system dynamic features, and even the forces transferred by each component, are impacted by the transmission chain arrangement. In the early stages of a gear drive's design, modeling and configuration assessment are crucial issues. The configuration model can serve as a basis for additional research and assessment [1-3].

Modern calculating techniques may now be used to address even more challenging engineering issues because to the quick advancement of research in the realm of computer technology. Among them are mathematical techniques that use numbers. One of the most used numerical techniques is the finite element method (FEM). Numerous engineering problems, including those involving strength and flexibility, heat transport, and a variety of gear systems, may be resolved using the FEM approach. In this field, deformation and stress jobs in the gears under study are mostly solved using the FEM. Although there are several programs for utilizing FEM to solve issues, the most accurate determination is one of the requirements for successfully solving the deformation and stress analysis of gears using this approach [4-5].

2 The involute tooth shape modelling conditions for spur gear

Developing a computer model of the thing under investigation begins with the creation of geometry. Involute gear geometry may be created using a variety of CAD programs, including AutoCAD, Bentley, Pro/Engineer, I-DEAS, Solid Works, NX, and others.

It should be mentioned that the side of the involute tooth is made up of the involute and dedendum transition curves for modeling spur gears manufactured with a rack tool without protuberance. When the gear wheel is operating, only the involute portion of the tooth flank may function as the active portion. The transition curve's job is to make the transition from the dedendum circle to the involute portion of the gearing smooth and rounded. As a result, the most accurate involute structures, such the transition portion of the involute tooth's side, must be the main emphasis of any geometric model of spur gearing. The straight portion of the rack tool, which runs from the addendum to the dedendum, forms the involute portion of the tooth. The profile normal is known to be a tangent to the base circle, traveling through the instantaneous center of rolling. The line of action always goes through the instantaneous center of rolling because, for the involute profile, it is the same as the profile normal line, which is the common normal of the two contacting sides of the teeth at their locations of contact. The angle of the tool profile is the same as the gearing's production meshing angle. A planar curve that crosses every tangent perpendicular to the circle is called an involute from a geometric perspective. This circle is its evolute, or by the collection of the involute's centers of curvature (geometric points). It is referred to as the foundation circle for gearing [6-10]. The radius of the fundamental circle is the only parameter that clearly determines the involute. The trochoid building technique states that the involute is formed by the trajectory of a point that is securely attached to the forming line and rolls along its evolute, or base circle (Figure 1).

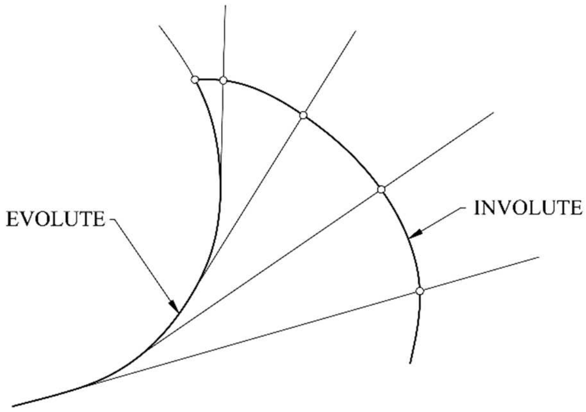

Figure 1 Definition of Involute, Evolute

The dedendum transition refers to the area situated between the involute surface of a gear and the dedendum circle. The purpose of the transition curve is to facilitate a smooth changeover between the gear's involute section and the bottom land. The dedendum transmission curve of a tooth shaped by the rack tool is generated by progressively rolling the rack tool around the gear wheel's pitch circle. The radius of curvature along the transition curve changes at different points [11-15]. Thus, the transition curve is created as an envelope of the rounded positions of the rack tool that moves along the pitch circle of the gear wheel. The tooth shape is formed by connecting the involute section with the transition part. In order to create a complete tooth shape, additional information is necessary, such as the measurements of the addendum and dedendum circles, which will determine the height of the tooth. To design one tooth, it is essential to have the required values of the tooth width at a specific radius (such as the pitch radius) or the corresponding chord length.

In practical applications, corrected spur gears are also utilized. There are two primary types of corrections used in involute gearing. A required correction eliminates the undercut of the gear tooth, while a desirable correction is applied to achieve specific characteristics of the gear profile. When developing a geometric model of a corrected spur gear, it is crucial to begin with the relationships for the fundamental dimensions of these corrected gears.

3 Implementation of combined CAD modelling for spur gears

A technique used for gear production involves simulating either the entire machining process or only specific parts of it. The creation of a CAD model involves the solid modeling of a semi-finished product that will transform into a gear wheel, as well as the tool used in the machining process. These two models need to be positioned correctly. In the subsequent phase of the process, the simulation advances by incorporating specific movement instructions for the tool, and in certain instances, for both the tool and workpiece. The gearing is designed by subtracting the volume of one object from another; specifically, the volume of the tool is removed from the workpiece volume at their intersection points. The drawback of this approach (Figure 2) lies in the pairing of steps and precision. The more accurate the model, the finer the steps it must take, yet smaller steps lead to a longer generation time.

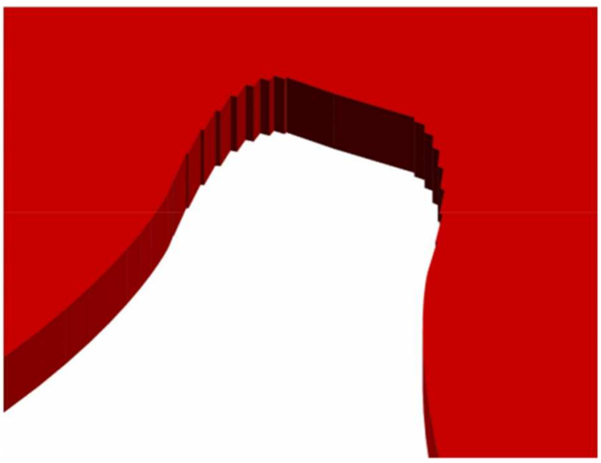

Figure 2 Example of made tooth gap by subtraction

Acta Mechatronica - International Scientific Journal about Mechatronics
Volume: 9 2024 Issue: 4 Pages: 33-38 ISSN 2453-7306

Mixed CAD modeling involves simulating the machining process using a tool profile, rather than a solid tool, as illustrated in Figure 3. This profile performs a similar step movement as described in the subtraction method above, with the key distinction being that it exclusively produces points.

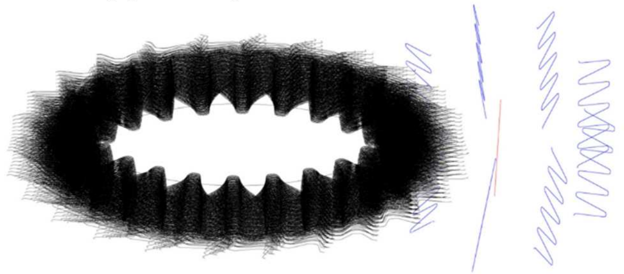

Figure 3 Definition of mixed CAD modelling method

The points produced form a point cloud that needs to be refined, ideally using an algorithm, to eliminate any unnecessary points (see Figure 4-a). In the last phase, the refined point cloud is utilized to generate surfaces through NURBS modeling (refer to Figure 4-b).

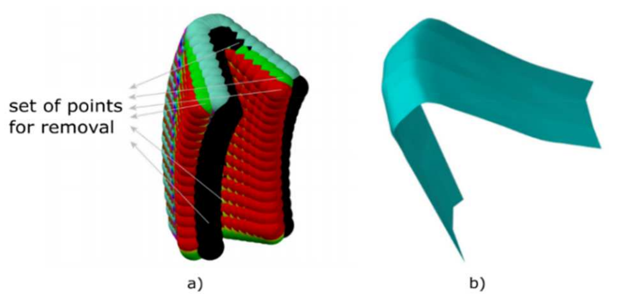

Figure 4 Generation of tooth gearing by a) points, b) surfaces made through points

The CAD model is produced by incorporating volume within the surfaces generated. Obtaining a point cloud enables quicker and m
compared to subtracting vo
in the fact that this method

4 Implementation

This technique can be u
and gears featuring a uniqu
this approach involves initi
the gear wheel and subsec
curve and transition curv
through the application of
alternative modeling techn
by eliminating the profile
the teeth, although there ar
as solid formations. The p
around the gear wheel's p
leads to complete gearing.

By utilizing the ProE
appropriate parameter settings, a diverse selection of gears can be efficiently manufactured with satisfactory precision within a reduced time frame. The Pro/Engineer program allows for the creation of a comprehensive gear model in a straightforward manner, simplifying a traditionally time-consuming process. Afterwards, it becomes feasible to integrate specific gear characteristics into this model and link them through mathematical formulas. It's feasible to craft any gear wheel by adjusting various aspects like the dimensions of the gearing, such as the modulus, number of teeth, displacement, and more. Additionally, further modifications can also be made if necessary. The initial action involves establishing the geometric specifications for the spur gearing. An illustration can be found in Figu

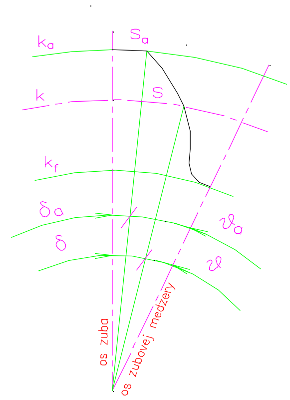

Figure 5 Influence of wheel web on the tooth stiffness

Figure 6 illustrates a detailed portrayal of the sketch or model. It is recommended to perform parameterization on the model for the corrected gearing. Variable values such as the number of teeth z, the modulus mn, and the unit height displacement x need to be specified using different elements. These elements could be defined by specific features, like offsetting by a value to display as ±x, or by

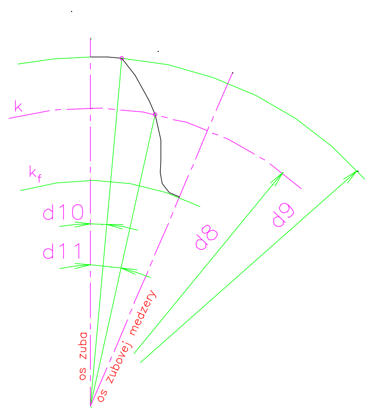

Figure 6 An illustration showcasing the parametric description of the model

Acta Mechatronica - International Scientific Journal about Mechatronics
Volume: 9 2024 Issue: 4 Pages: 33-38 ISSN 2453-7306

The parametric description incorporated a modification in the designation of individual parameters:

- the quantity of teeth, denoted as d0, was referred to as z,
- the normalized value assigned to the modulus m_n was denoted as d1,
- the symbol used to represent the unit height displacement x is denoted as d2,
- the symbol d3 denotes the helical angle β.

Subsequently, the equations necessary for determining the gear dimensions were defined parametrically. Equation (1) parametrically defined the diameter of the pitch circle as determined by equation (2).

$$d8 = d0 \cdot d1 / \cos d3 \tag{2}$$

$$d = \frac{z \cdot m_n}{\cos \beta} \tag{1}$$

Equation (3) parametrically defined the angular coordinates of the involute point on the pitch circle described by equation (4).

$$d11 = \frac{(0{,}5 \cdot \pi + 2 \cdot d2 \cdot \sin 20 / \cos 20) d1 \cdot 180°}{(d8 \cdot \pi \cdot \cos d3)} \tag{3}$$

$$\delta = \frac{s}{d} \cdot \frac{180°}{\pi} \tag{4}$$

In this manner, all the gear parameters were sequentially determined.

5 Implementation of Face gears modelling

The face gear depicted in Figure 7 is a novel transmission mechanism that has been extensively studied. This mechanism has been implemented in a specialized transmission group, especially within the aviation sector.

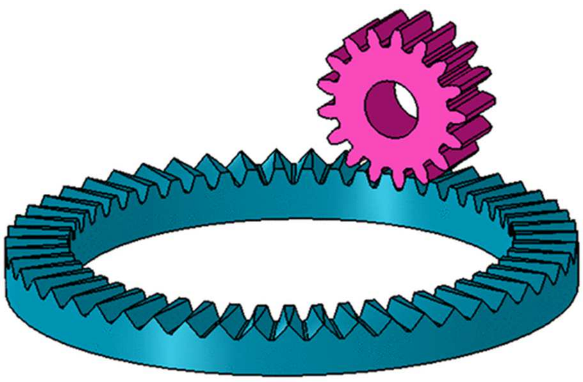

Figure 7 Face gearing model

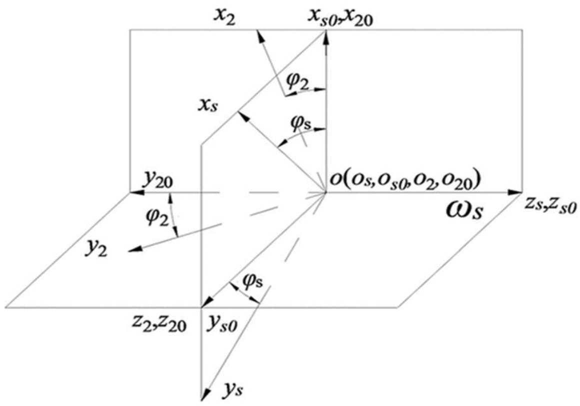

Figure 8 Face gear generation coordinate system

The coordinate system employed for the involute tool tooth surface aligns with the one shown in Figure 8, featuring a cross-section that embodies an involute tooth design.

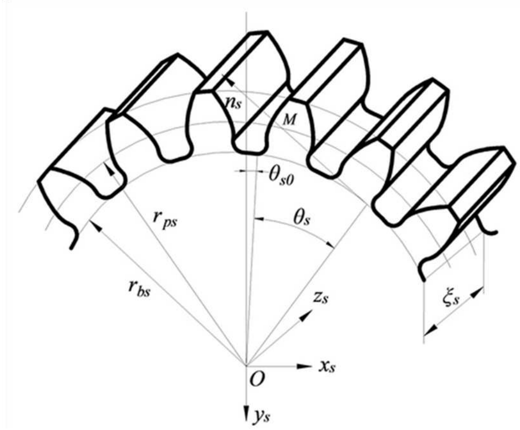

Figure 9 The involute tool's parametric model

The distinctive shape and measurements can be found in Figure 9.

An instance illustrating the parametric definition of the tool's involute tooth surface vector equation rs is expressed in equation (5):

$$\vec{r}_s(\xi_s, \theta_s) = \begin{bmatrix} x_s \\ y_s \\ z_s \end{bmatrix} = \begin{bmatrix} \pm r_{bs}\left[\sin(\theta_s + \theta_{s0}) - \theta_s \cdot \cos(\theta_s + \theta_{s0})\right] \\ -r_{bs}\left[\cos(\theta_s + \theta_{s0}) + \theta_s \cdot \sin(\theta_s + \theta_{s0})\right] \\ \xi_s \end{bmatrix} \tag{5}$$

In the smooth tone of writing, we consider ξ_s as the axial parameter that specifies the tooth width on the tooth surface of the tool, while θ_s indicates the angle parameter along the involute curve, determining the height of the tooth surface. The r_{bs} stands for the base circle radius of the tool involute, and θ_{s0} represents the angle parameter of the tool slot symmetry line from the starting point of the involute.

The calculated point coordinates have been adjusted to create a point cloud in files compatible with CAD software. The tooth's surface is created using a CAD program. The entire gear wheel is crafted through an intricate arrangement of individual teeth and discs.

6 Conclusions

The geometric design plays a significant role in determining the quality of gears. Should the geometric design be flawed, the transmission's reliability cannot be guaranteed, even if top-quality materials are used. On the flip side, skillful geometric gear design has the potential to reduce costly material expenses. Hence, it is essential to craft a precise geometric model of the gear.

CAD programs have become an essential instrument for designers. Because of their benefits, developers have swiftly expanded and advanced them to a point where they are now applicable in all areas of engineering practice. One aspect includes crafting and designing gear models. In the process of creating gears, having the ability to efficiently generate a 3D model is essential. This visual representation aids in better visualization and eventual control using methods like the finite element method, ensuring swift and precise execution. It is commonly understood that the more precise a model is, the more time it requires to be developed or produced. With the ongoing advancements in CAD programs and the ever-increasing computing power, the distinction is becoming less significant.

By utilizing a CAD application, we are able to generate a precise geometric model of gearing. The computer-generated body models can be utilized for drawing documentation or for various purposes, like addressing issues related to elasticity and strength. This includes tackling challenges like static deformation and stress analysis of gears through the finite element method.

Acknowledgement

The work has been supported by the KEGA 037TUKE-4/2024 - Creation of interactive tool for increasing of students' skills and competences in teaching of study subjects relating to elaboration of drawing documentation and VEGA 1/0152/24 - Development of non-destructive mechanics methodologies for the evaluation of mechanical properties of additively manufactured elements.

References

[1] BRIANZA, G. GONZÁLEZ, G.R.: Parametric Geometric Modeling of a Spur Gear Using SolidWorks, *Gear Solution*, vol. 2017, pp. 31-36, 2017.

[2] MO, S., GONG, J., JIN, G., ZHU, S., ZHANG, T., FENG, Z., CAO, X.: Precise modeling of complex tooth surface microtopography and multi-degree-of-freedom nonlinear friction dynamics for high-performance face gear, *Science Progress*, Vol. 103, No. 1, pp. 103-113, 2020. https://doi.org/10.1177/0036850419881078

[3] CZECH, P.: Diagnosis of Industrial Gearboxes Condition By Vibration and Time-Frequency, Scale-Frequency, Frequency-Frequency Analysis, *Metalurgija*, Vol. 51, No. 4, pp. 521-524, 2012.

[4] MOHAMMED, O.D., RANTATALO, M.: Gear fault models and dynamics-based modelling for gear fault detection–A review, *Engineering Failure Analysis*, Vol. 117, No. November, 104798, 2020. https://doi.org/10.1016/j.engfailanal.2020.104798

[5] SAPIETOVA, A., DEKYS, V., BUDINSKY, M.: Utilizing of sensitivity analysis in preparation of optimizing procedure, *Scientific Journal of Silesian University of Technology, SeriesTransport*, Vol. 76, pp. 32-38, 2012.

[6] MADEJ, H., CZECH, P.: Discrete Wavelet Transform and Probabilistic Neural Network in IC Engine Fault Diagnosis, *Eksploatacja i niezawodnosc- maintenance and reliability*, Vol. 48, No. 4, pp. 47-54, 2010.

[7] REDDY, E.J., RANGADU, V.P.: Development of knowledge based parametric CAD modeling system for spur gear: An approach, *Alexandria Engineering Journal*, Vol. 57, No. 4, pp. 3139-3149, 2018. https://doi.org/10.1016/j.aej.2018.07.010

[8] SAPIETA, M., DEKÝŠ, V., ŠTALMACH, O., SAPIETOVÁ, A., SVOBODA, M.: Detection of Elastic Deformation in Metal Materials in Infrared Spectral Range, *Materials*, Vol. 14, No. 18, 5359, pp. 1-9, 2021. https://doi.org/10.3390/ma14185359

[9] KELEMEN, M., KELEMENOVÁ, T., JEZNÝ, J.: Four legged robot with feedback control of legs motion, *Bulletin of Applied Mechanics*, Vol. 4, No. 16, pp. 115-118, 2008.

[10] NOGA, S., MARKOWSKI, T., BOGACZ, R.: Method of determining thenormal modes of toothed gears with complex geometry, *Scientific Journal of Silesian University of Technology, SeriesTransport*, Vol. 89, pp. 119-127, 2015. https://doi.org/10.20858/sjsutst.2015.89.13

[11] KELEMEN, M., VIRGALA, I., FRANKOVSKÝ, P., KELEMENOVÁ, T., MIKOVÁ, Ľ.: Amplifying system for actuator displacement, *International Journal of Applied Engineering Research*, Vol. 11, No. 15, pp. 8402-8407, 2016.

[12] SAPIETA, M., DEKÝŠ, V., PASTOREK, P.: Using of activ thermography and lock-in method with ultrasound exication for detection of material defect, *Scientific Journal of Silesian University of Technology, SeriesTransport*, Vol. 84, pp. 119-124, 2014.

[13] CZECH, P., WOJNAR, G., WARCZEK, J.: Diagnozowanie uszkodzeń wtryskiwaczy w silnikach spalinowych pojazdów przy użyciu analizy bispektrum i radialnych sieci neuronowych, *Logistyka*, Vol. 2013, No. 3, pp. 1181-1187, 2013. (Original in Polish)

[14] TOLVALY-ROŞCA, F., FORGÓ, Z.: Mixed CAD Method to Develop Gear Surfaces Using the Relative

Cutting Movements and NURBS Surfaces, *Procedia Technology*, Vol. 19, pp. 20-27, 2015.

[15] ALAM, J., PANDA, S., DASH, P.: A comprehensive review on design and analysisof spur gears, *International Journal on Interactive Design and Manufacturing*, Vol. 17, No. 3, pp. 993-1019, 2023.

Review process

Single-blind peer review process.