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The influence of the shape of the body on the deformation and meshing stiffness of the spur gear

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Abstrakt: These days, there is a requirement to increase machine performance metrics while lowering equipment weight. Gear transmissions of large dimensions are characterized by different shapes of gear bodies. The weight of the gear wheel itself and the stiffness, and strength of the gearing are two factors that are taken into consideration when determining whether a certain gear body form is appropriate. The finite element method was used to determine the gear deformation. Based on the deformation, the stiffness of the gearing was determined, depending on which the most suitable-optimal shape of the gear body was judged.

Keywords: spur gear, deformation, shape, design

1. INTRODUCTION

The conceptual design of any component is a phase of the product development process in which engineers and designers create and evaluate multiple design alternatives in order to find the most optimal solutions[1]. The procedures chosen and decisions made at this stage have a strong impact on all subsequent steps of product development, which include various areas such as manufacturing, production, testing, costing and others. It is known that up to 80% of product costs can be determined by the end of the design phase [2]. Therefore, multiple requirements must be considered in the design to avoid the accumulation of additional costs in the later stages of development.

Advances in technology, particularly in computing power, machine learning and related algorithms, have laid the groundwork for the development of intelligent design automation tools. High-performance computing power, available through the cloud, now enables complex optimization and iteration calculations that were previously impossible to perform [3-5]. Designers can thus run advanced simulations to test different product configurations under different conditions in a short time, giving valuable information for well-chosen decisions regarding every aspect of the design. On the other hand, the rapid development of additive manufacturing technologies leads to significant changes in the production and design of components. They enable the production of complex geometries that better meet design requirements, while these could not be produced by traditional production methods [6]. In addition, new materials are being developed that have better properties and are compatible with new production technologies.

Gears are the most widespread type of transmission mechanisms in practice and are used in the most diverse form. Gears are used to transfer rotary motion and mechanical energy from one shaft to another [7, 8]. When two gears engage, i.e. in gearing, the tooth of one wheel fits into the tooth gap of the other wheel. The meshing teeth of the wheels touch each other with their flanks and, by tooth-to-tooth pressure, transmit circumferential force from the drive wheel to the driven wheel [9]. Increasing the performance and improving the loads of gear machines leads to the growth of the technical level of the machines. This is realized many times at the expense of the deterioration of the quality of the environment [10]. One of the factors that worsens the environment is noise, which in gear transmissions is mainly influenced by the periodic change in the stiffness of the teeth during meshing, caused by a change in the number of pairs of teeth that are simultaneously in meshing [11]. In these areas of gears, the authors' attention is mainly focused on the hitherto insufficiently determined stiffness of the teeth of individual types of gears. In recent times, the rapid advancement of computing technology has led to the emergence of sophisticated numerical approaches for tackling the complex issue of gear wheels in the literature. Among these techniques is the finite element method, a numerical approach to mathematics that is frequently used to solve issues with heat transmission, elasticity and strength, flexible body dynamics, and many other engineering challenges [12, 13]. And it is the finite element method that is used as a basis for determining the deformation of the gearing and thus also investigating the stiffness of the gearing depending on the different shapes of the gears.

2. SHAPES OF GEAR BODIES

The shape of the gear body depends on its size, production method and material used. In a system of two gears, the pinion is the smaller wheel and it is often advantageous to make it as part of the shaft by cutting the gearing onto part of the shaft [14]. However, the second wheel of the pair is usually much larger in diameter and therefore usually contains a hub, body and rim. Each of these three parts must be designed to have adequate strength and stiffness and to be designed with resonance and vibration in mind.

Gear wheels of larger dimensions can be produced by welding, forging, casting. There can be different body shapes (Fig. 1).

a)

b)

Fig. 1. Different shapes of the gear wheel body a) forged gear wheel, b) casted gear wheel

It is also possible to produce customized shapes, where in some cases the shape of the gear body can be adapted to meet specific design requirements or meet unique operating conditions. This can include irregular shapes, asymmetrical constructions or features adapted to fit into limited spaces. However, it is important to design such a shape of the body to maintain the stiffness and strength of the teeth of gear wheel.

3. DEFORMATION AND MESHING STIFFNESS OF GEARING

Deformation is defined as the displacement in length that occurs in a solid body due to stress. In the design of machine components, the design must not only be reasonable in considering stress in relation to strength, but also ensure that displacements and deformations are not excessive and are within design limits.

Depending on the application, these deformations can be either very visible or practically imperceptible. Deformation occurs on gear teeth under the condition that they are loaded. This creates negative, but also positive phenomena, and at the same time creates the need for knowledge of the deformation effects of gearing. Due to the shape of the toothing, namely if we take into account the tooth itself, it creates a very complex geometry that is analytically very difficult to describe and calculate in terms of deformations. In the past, works devoted to this issue were based on the basic principles of the theory of elasticity, and thus the deformation of the tooth or gearing was calculated as the deformation of the woven beam.

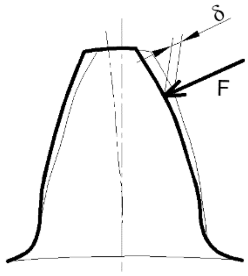


Fig. 2. Deformation at the point of force

The effect of force on one tooth resulted in a total deformation, which is also shown in Figure 2, where the thin line shows the original profile of the tooth and the thick line shows the profile of the tooth after deformation shifted by the given deformation. The total deformation consists of deformation from bending, shearing, deformation at the place of weaving and contact deformation. However, for the accuracy of the resulting deformation value, it is necessary to determine the deformation of the meshing teeth, which means the deformation of a pair of teeth. The amount of deformation varies on the tooth depending on how the meshing tooth rolls along the tooth. Which in practice means that each tooth has the greatest deformation if it is subjected to a load on the tooth head (Fig.3).

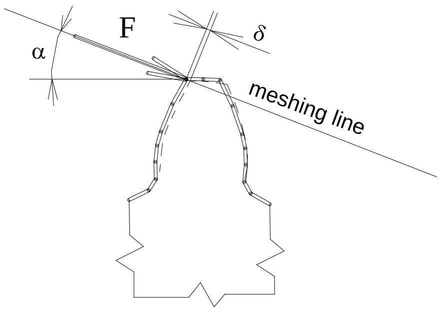


Fig. 3. Maximum deformation

On the basis of the teeth deformation, the stiffness of the teeth is calculated. In general the teeth stiffness c is defined by equation (1):

$$c = \frac{w}{\delta} \qquad (1)$$

where c – teeth stiffness [N/mm.μm],
w – load across the width of the teeth [N/mm],
δ – teeth deformation [μm].

The teeth stiffness values are the basis for assessing the suitability of design of the wheels in this paper.

4. DETERMINATION OF GEOMETRIC AND CALCULATION MODEL FOR INVESTIGATION OF TEETH DEFORMATION USING FEM

The condition for successful handling of this problem is the creation of a geometric and computational model of the examined gears, which are the basis for solving tasks of static deformation analysis by the finite element method using the program Cosmos/M.

The first step for successfully handling the issue of solving the deformation analysis of spur gears with straight teeth using the finite element method is to model the shape of the object under investigation as accurately as possible, in our case the shape of the spur gear. The Solid Works program was used to construct the involute spur gear. I note that there is no universal guide for creating the geometry of a computational model. Deciding how the geometric model will be created is a matter of the experience of the computer engineer as well as access to the necessary computer software.

When solving the requirements for the accuracy of the calculation of technical problems using the finite element method, the basic problem of solving the deformation analysis of spur gears with straight teeth lies in the choice of the solved area of the gear wheel. It is not expedient to calculate the gears as a whole using the finite element method, but only as a part of the gear wheel in the form of a plate of the appropriate thickness.

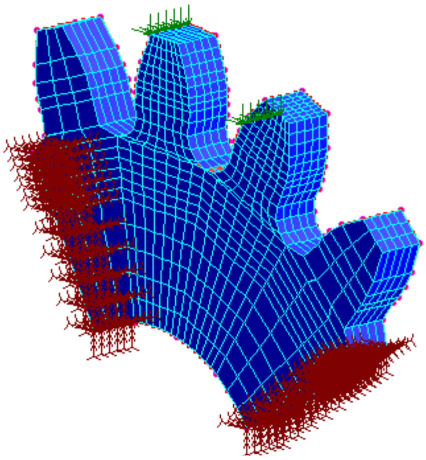


Fig. 4. Three-dimensional computational model of a part of a spur gear with straight teeth for the investigation of tooth deformation using FEM

Another of the conditions for a successful solution to the deformation analysis of the tooth of the spur gear using FEM is the correct definition of the properties of the material of the investigated gear, here the selection of the material was made on the basis of the database offered by the program used. In order to create a calculation model (Fig. 4), it was further necessary to define the force conditions and the selection of a suitable type of finite element, which depended on whether the task was solved as a planar or as a spatial one.

5. THE EFFECT OF WHEEL RIM AND WEB THICKNESS ON THE STIFFNESS OF THE GEAR TEETH

As to [15], which deals with the calculation of spur and bevel gear strength, the wheel rim value needs to exceed the multiple of 3.5 times m_n, where mn represents the standard gearing module ($s_R \geq 3.5$mn).

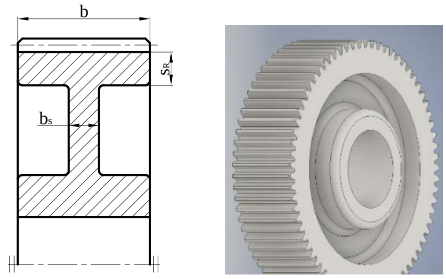
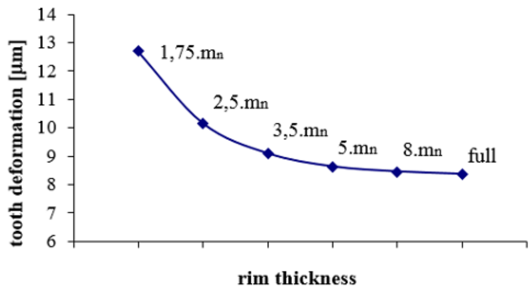
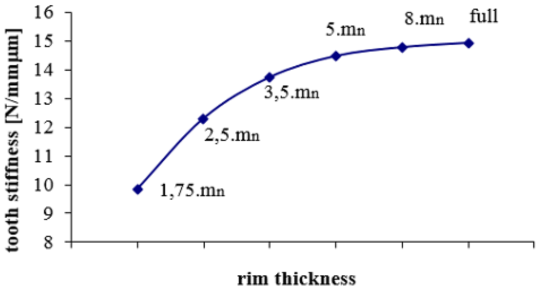


Fig. 5. The gear wheel design for examines the impact of the rim thickness

This study aims to investigate the effects of rim thickness (s_R in Fig. 5) on tooth deformation and stiffness. Specifically, the spur gear with z=61 teeth, m_n=4mm module, b=80mm tooth width, and force F = 5000 N will be studied. The wheel rim's thickness is adjusted to the wheel's entire body from the values s_R=1.75m_n, 2.5m_n, 3.5m_n, 5m_n, and 8mn. The wheels' other geometric measurements remain unchanged.



a)



b)

Fig. 6. Impact of the wheel rim on a) the deformation and b) stiffness of teeth.

These results are determined by the finite element method and are processed in the graph in Fig.6. The findings indicate that when the rim wheel's thickness is reduced, teeth undergo more deformation and less stiffness. According to standard, a wheel rim's minimum allowable thickness is s_R = 3.5mn, where mn is a gear wheel module. Less than 3.5 m_n of wheel rim thickness has a greater impact on tooth deformation and stiffness. The effects of wheel rim thickness more than 3.5 m_n on tooth deformation and stiffness are less pronounced.

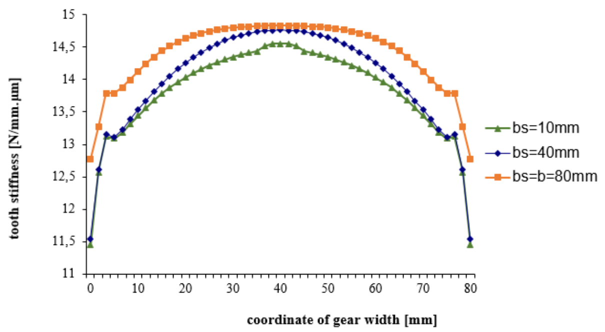
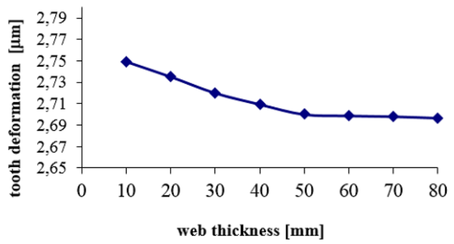
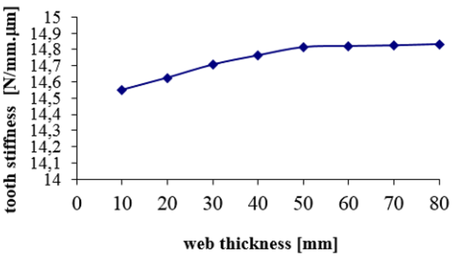


Fig. 7. The distribution of tooth stiffness along the gear wheel width

With a spur gear with z=61 teeth, a module m_n=4mm, and a tooth width of b=80mm, the effect of the rub thickness (value b_S - Fig.5) on the teeth stiffness will be ascertained. The wheel rim value is s_R=22mm.When a gear wheel is fully assembled without a web, the web's thickness changes from 10 mm to 80 mm in the centre of the wheel's breadth. According to Fig. 3, the force is delivered to the tooth's head, or its biggest bend, and the load over the tooth's width is w=40N/mm. Figure 7 displays the findings of the tooth stiffness distribution along the gear wheel width and the finite element technique solution. The local impact of tooth stiffness and its distribution on gear width are shown in this figure.



a)



b)

Fig. 8. Impact of the wheel web on a) the deformation and b) stiffness of teeth.

As illustrated in Fig. 8, the increased thickness of the wheel web at the gearing width's centre results in less tooth deformation and more tooth stiffness. This change in tooth deformation and tooth stiffness is more pronounced to the first half of gearing width.

6. CONCLUSIONS

The evolution of contemporary technology and production methods is characterised by ever rising performance factors in reducing the device's weight. It is a design element that allows the user to select the larger gear's body shape. The teeth's deformation and rigidity are impacted by body wheel gear lightening. As the thickness of the wheel rim lowers, teeth become less rigid. The rigidity of teeth varies even with tooth breadth. In this particular location, there is reduced tooth stiffness if the ends of the mesh line up with the tooth edge. Because of the increased thickness of the wheel web at the centre of the gearing width, the teeth's deformation is decreased and their stiffness is increased. The stiffness of the teeth affects where the wheel web is located. Evaluating the huge cast spur gear wheel's appropriateness for tooth stiffness and deformation is one aspect of determining its proper shape.

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