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**DEFORMATION AND STIFFNESS OF SPUR GEAR TEETH
AND THEIR INFLUENCE ON GEAR NOISE**

Summary. Gear teeth are deformed due to the load. The deformation of gear teeth is causing some negative as well as positive effects. A tooth has a complex shape and due to the complex shape of the teeth, a theoretical determination of the deformation is difficult. The existing experimental techniques are based on static deflection measurements gearing loaded of constant force or seismic measurement deviations at slow rotation. Recently, at ever faster evolving computer technology and the available literature, we can encounter modern numerical methods, such as finite element method (FEM), which can serve as methods for the determination of teeth of gearing. The article is devoted to the problems of gearing stiffness analysis. The problem is solved for spur gears. Deformation analysis solved by FEM is used for calculations of the gearing stiffness. There are many influences that cause vibrations in the gearbox and that have to be taken into account already in the phase of design, manufacture, installation and operation. Detailed analysis of gearboxes manufacturers have shown that improving of the gear accuracy cannot reduce the transmission unit noise to the desired level. Only fundamental changes to the shape of the tooth and changes in production technology can achieve stronger noise reduction of gear mechanism.

Keywords: spur gear, gear noise, teeth deformation, stiffness, FEM

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1. INTRODUCTION

The development of engine plants in past focused on the acquisition of the highest capacity and durability. Engines and machines with gear transmission are very popular and draw sufficient attention. Lowering the weight of the construction machines and engine plants as well as increasing their efficiency and productivity, are all part of the compelling task the construction, technology and research workers must accomplish. These intensity factors have often a significant influence on the increment of vibrations and noise in the monitored engine plants. The society becomes gradually more interested in these noise and vibration emissions produced by the gearing mechanisms. The issue of lowering noise emission in a gearbox is interconnected with the sources of noise, together with measurement and evaluation of vibrodiagnostic performance. Current products constructed with the usage of computer programs for the firmness check of suggested solutions (FEM) together with the rich experience of construction workers, reach optimal parameters from the perspective of rigidity, material utilization and longevity.

2. SOURCES OF NOISE IN THE GEARBOX

The gearbox is an audible enclosed system, from which the noise travels through vibrations of the closet surface or plugged aggregates inclusive of the base construction. One of the essential causes of noise is so-called transmission error. This error is related to kinematic accuracy and durability of the cogging.

The vibrations from the spur gear, transmitted to the case of gearbox, are the most important source of noise. From the physical point of view, the cause of vibrations is the dynamic force which can change its amplitude, direction or origin. The most critical change of amplitude in the evolvent cogging, which main cause is stiffness of teeth and bursts when cogs enter the gear, due to the deformation, deviation of gaps and cog profile from the theoretical ones. Many other effects, i.e. vibrations transmitted into the cogging from the driving or powered aggregate, oscillation of the arbors and bearings, influence the vibrations in cogged wheels in a mesh. All of these elements play a role in the enlargement of amplitude in cogging. The total energy of the radiated noise further increases.

A dominant contribution of noise in a gearbox; however, comes from the creation of vibrations during intervention of the cogged wheels. On Figure 1, a total evaluation of gearbox noise in an automobile, where the contribution of separated noise of the gearbox intervention (defined as N and 3) is at maximum 40 % of the gearbox noise with a contribution of 53% to the total noise, is displayed. The remaining 47% constitute for the background noise (defined as B_{gr}), inside which mainly the noise created by bearing is incorporated [6].

The noise in gear transmissions particularly affects periodic change of stiffness teeth during meshing caused by changing the number of pairs of teeth, which are simultaneously in meshing.

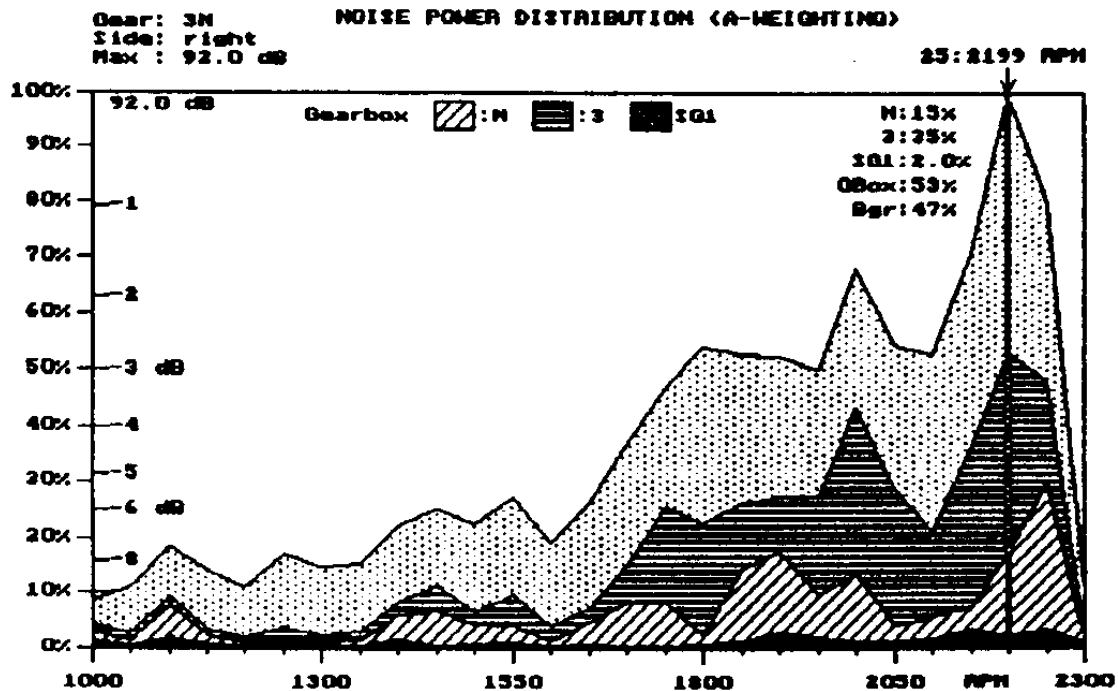


Fig. 1. Example of evaluation of noise gearbox of car [6]

3. THE TEETH STIFFNESS AND THEIR IMPACT FOR GEARBOX NOISE

Periodic changes in the stiffness tooth mesh, caused by changes in the number of pairs of teeth, which are also mesh in a significant noise impact on teeth. Stiffness of gearing is defining as a proportion load across the width of the teeth and the resulting deformation [1]. Since the involute tooth of spur gear has a complex shape, the theoretical determination of the deformation the tooth is a difficult. The existing experimental techniques are based on static deflection measurements gearing loaded of constant force or seismic measurement deviations at slow rotation. Recently we can meet with modern numerical methods, such as finite element method (FEM), which can serve as one of the methods for the determination of deformation gearing [4]. As the basis for calculating the stiffness of gearing results serve deformation analysis examined gearing solved by FEM.

Create a geometric model of the gear is considered the first step to deal with tooth deformation FEM. Universal user to create geometry computer model does not exist. In this case, the geometric model has been created a combined method. The final shape of 2D was by created in program AutoCAD. 3D model of examined the spur gear with straight teeth was by created in program COSMOS/M as editing from the 2D model. To determine the computer model for studying deformation of the teeth using FEM was necessary to determine the material constants, define the type of finite element, and selecting appropriate boundary conditions (geometry and power).

We will focus on the value of the total deformation in the direction of action forces. To determine the deformation of gearing under load is necessary to know the apportionment of the load on each gearing pairs with two pairs meshing. At the beginning was considered with the simplest, ideal load apportionment. The load for the two pairs meshing is divided by half for each couple of teeth in the meshing.

To determine the resulting deformation of the teeth is necessary to determine the deformation of individual pairs. In Figure 2 shows the progress of the overall deformation of teeth solved by FEM for the spur gears with number of teeth $z_{1,2}=24$, the module of teeth

$m=3,75[mm]$, the force $F_N=1000[N]$ and width of gearing $b_{1,2}=10[mm]$, which in the meshing reaching gear ratio 1 and for the ideal division of load. Deformation of pairs of teeth over the meshing along the length of meshing line is changes. Maximum value of deformation shall in this case the endpoints lonely meshing (if we consider the image-pair) and the minimum value shall also meshing in two pairs of endpoints lonely meshing. The points B and D, it is the solitary meshing points leads to a step change deformation teeth and it will input the next couple teeth to meshing.

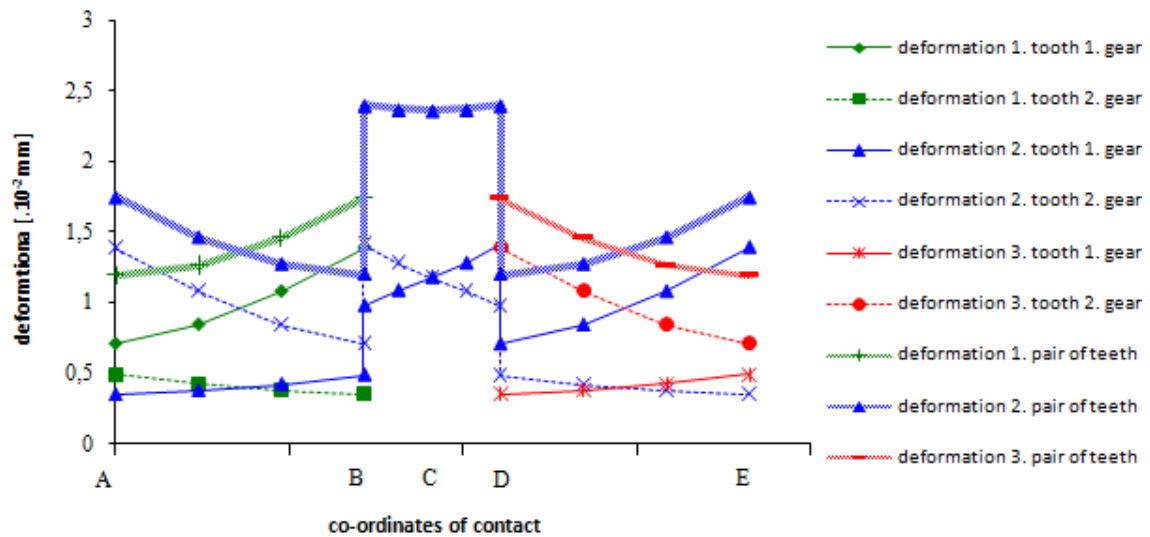


Fig. 2. Course of tooth deformation

One of the ways to specify the tooth stiffness is calculated using the total deformation gearing determined by finite element method (FEM). In general the resulting stiffness c defined by equation (1):

$$c = \frac{w}{\delta} = \sum_p c_p, \quad p = I, II \quad [N/mm.\mu m] \quad (1)$$

where:

w – load across the width of the teeth, equation (2) [N/mm] ;

δ – the resulting deformation [μm].

$$w = w_I + w_{II} \quad (2)$$

where:

w_I – load across the width of the first pair of teeth [N/mm] ;

w_{II} – load across the width of the second pair of teeth [N/mm].

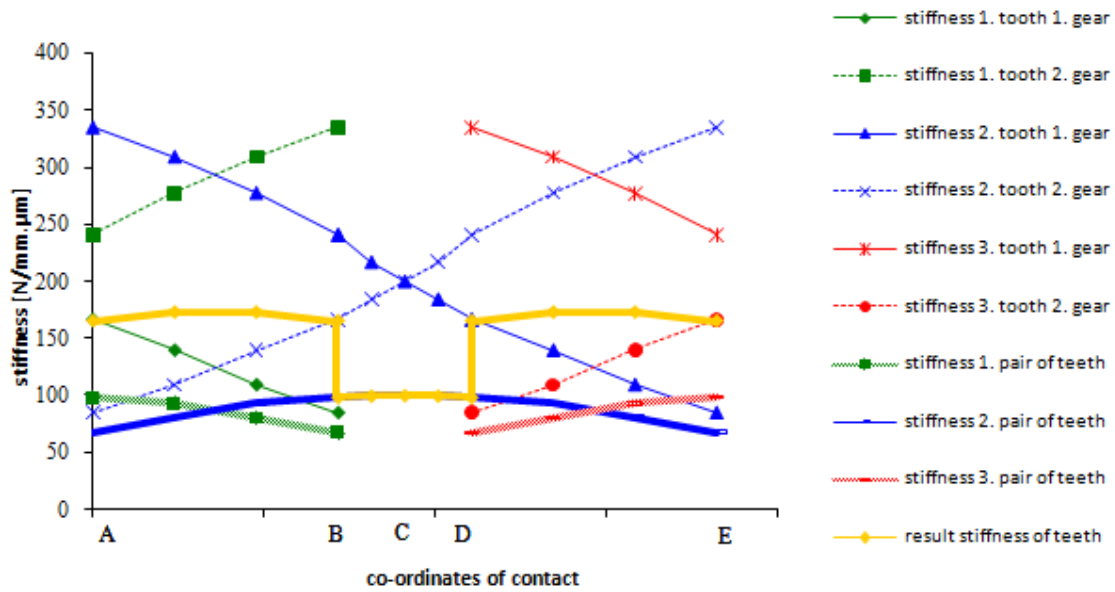


Fig. 3. Course of tooth stiffness

In Figure 3 shows the course of total stiffness of the teeth, tooth pair stiffness and total stiffness of gear teeth for the spur gears, in the teeth, which in the meshing reaching gear ratio 1. The stiffness is individual pairs of teeth in the mesh by changing the length of the engaging line. The minimum value shall end in the engaging points and lines shall at maximum point lone mesh, the so-called pitch point C. The resulting stiffness teeth after track mesh changes periodically with a period equal to the basic pitch frontal. The endpoints solitary mesh leads to sudden changes in stiffness resulting teeth. This is due to a step change in deformation resulting from the entry into another pair of teeth in the mesh his cause's vibrations that cause noise gearbox.

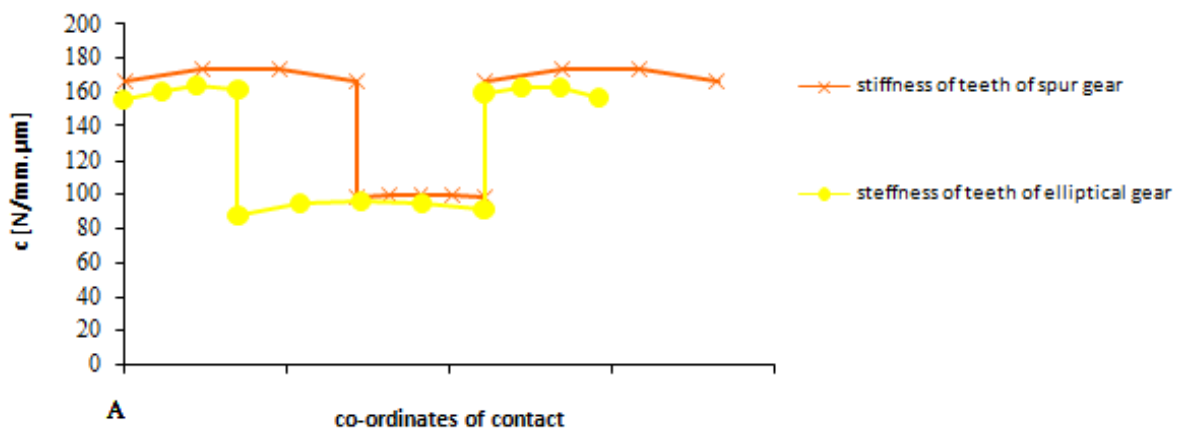


Fig. 4. Comparison of stiffness

In figure 4 shows the comparison of stiffness of spur gear and elliptical gear. The elliptical gear is gear with variable transmission in the range $u = 0,5$ to $2,0$, with the number of teeth $z1 = z2 = 24$ and gearing module $mn = 3,75$ [mm] the distance $a = 90$ [mm] and for a one direction of rotation. They are elliptical gears with axes of rotation of gears placed eccentrically (Figure 5). The centers of rotation are also focus points of the ellipse. Curved active surface of tooth forms is involuta. Torque transmission ensures shape bonded between meshing gears. The

gearing consists of two identical gears. In Figure 4 shows the progress of the overall stiffness of teeth, which in the meshing reaching gear ratio 1. Applies to, that if is the curve of the stiffness smooth, the noise in gearing is lower. Then the noise in elliptical gear is higher than the noise in the spur gear during meshing.

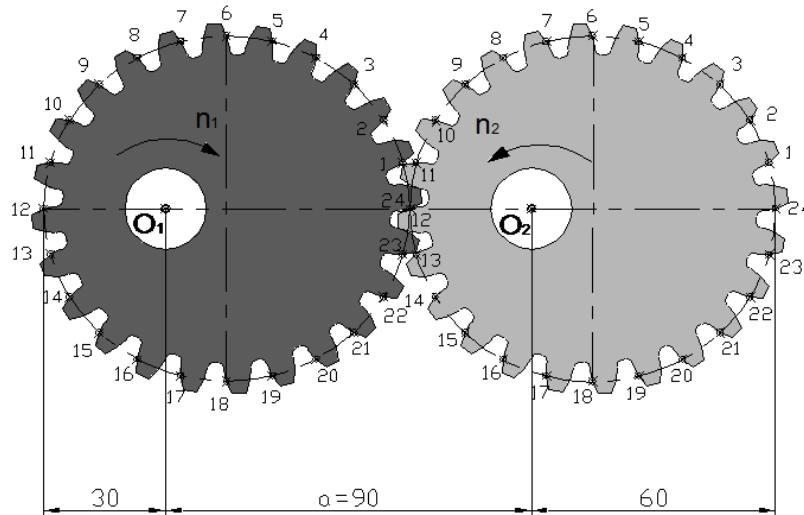


Fig. 5. Designed elliptical gear

4. CONCLUSION

There are many influences that cause vibrations in the gearbox to be taken into account already in the design, manufacture, installation and operation. Detailed analysis of gearboxes manufacturers have shown that improving the accuracy of gears cannot reduce noise transmission unit to the desired level. Only fundamental changes to the shape of the tooth and changes in production technology can achieve stronger noise reduction gear mechanism.

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