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# ABOUT A STRATEGY FOR MODIFICATION THE TEETH PROFILE OF CYLINDRICAL GEARS

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**Abstract:** *The paper synthetically presents the proposed strategy for the modification of the teeth profile of cylindrical gears with straight teeth in front and longitudinal plane, taking into consideration the elastic strain under weight of the gears teeth, the execution and connection errors of the transmission gear. Within the proposed strategy, used is an analytical-numerical method based on the finite element analysis.*

***Key words:*** *gears, profile modification, head and foot correction, bulging, finite elements.*

## 1. THEORETICAL CONSIDERATIONS

The activity domains that use transmission gears with modified profile of the teeth of gears are growing large; from aero-nautical industry to automobile industry, from the naval industry to the energetic equipment industry, etc. The modification of the teeth profile of cylindrical gears with straight teeth in front and longitudinal plane appears to be an acute necessity in order to ensure a good functioning, a uniform allocation of the load on the tooth, the noise and vibration reduction, the growth of the charging capacity and the localization of the contact spot.

## 2. STRATEGY CONCERNING THE MODIFICATION OF THE TEETH PROFILE OF CYLINDRICAL GEARS

The research has taken into consideration the profile modification in front plane by correcting the head and/or the foot of the gear's tooth and the profile modification of the gear's tooth in longitudinal plane, by bulging.

### 2.1 Front plane modifications

Shocks appear as a result of the elastic straining of the teeth, even at very precisely executed gears, because when they enter the transmission gear, the teeth flatten and bend under the weight, and so the basic step of the set of teeth of the driving gear becomes smaller and the one of the driven gear becomes larger with respect to the theoretical value. As a result, the tooth top of the driven gear collides against the surface of the foot of the tooth of the driving gear and this produces vibrations and noise and a bad functioning. Beside the elastic straining of the gear's teeth, the execution errors, mainly the step aberrations, determine a bad functioning. "The cure" for these phenomena remains the profile modification by head correction of the gear's tooth.

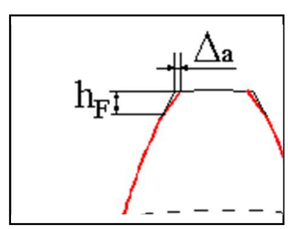


**Fig. 1**. Tooth with modified profile.

The depth of the modification on the tooth top is recommended, as seen above, especially for high precision of the gears, to be determined using the relation (Mera, 2003):

$$\Delta_a = f_{\Sigma_{Pb}} + \delta_e \quad (1)$$

Where:

- $\delta_e$ is the value of the elastic strain of the gear's teeth under the load
- $f_{\Sigma pb}$ is the quadratic mean deviation of the limit deviations of the pinion steps and of the gear and is computed using the formula:

$$f_{\Sigma_{Pb}} = \sqrt{f_{pb1}^2 + f_{pb2}^2} \qquad (2)$$

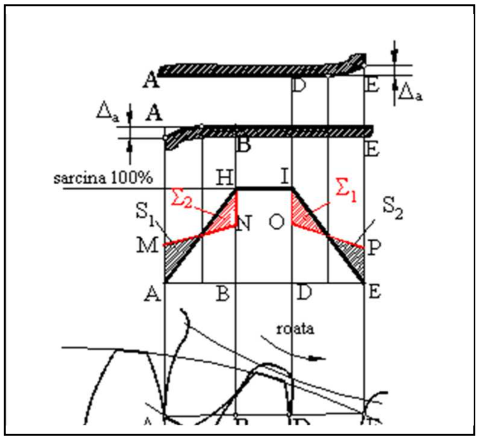


**Fig. 2**. Load distribution on the modified profile gear tooth.

The conclusion is that the value of the profile modification is determined, on one side, by the precision class of the execution of the gear (step and profile precision) and on the other side on the quality of the material used in their manufacturing by elastic straining. When choosing the value of the profile modifying parameters, one recommends a differential approach.

The depth for modifying the profile must be considered so as to eliminate the edge collisions, which appear mainly because of the step errors and elastic straining of the teeth under loading.

One recommends that the value of the depth of the profile modification (fig. 1), $\Delta_a$, be equal with the maximal elastic strain that appears during functioning for very precise gears (IT 3-4 and IT 5-6), determined using the method that will be presented, to whom one should add the quadratic mean deviation of the limit errors of the pinion steps and of the gear due to execution errors; then $\Delta_a$ should be calculated using relation (1).

For the gears in the precision classes IT 7-8, when computing $\Delta_a$ the step errors should be taken into account. The research that has been made, the value of the depth of the modification of the tooth profile has been considered as being dependent on the elastic strain of the transmission gear under loading and on the execution errors of it, mainly through the allowable step errors of the pinion and those of the gear.

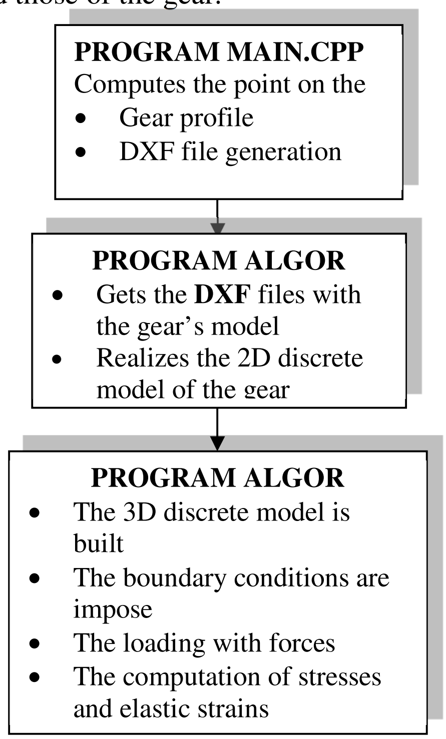


**Fig. 3** Block diagram of the FEM analysis algorithm

The elastic strain that appear under load is determined using finite element analysis, for each type of gear. The execution errors, especially those concerning the limit errors of the pinion and of the gear, are those from the Standards. The finite element analysis algorithm (Fig. 3) starts from the profile of the tooth of the gear, that will be subjected to a profile modification, the correction of the tooth's head, more precisely.

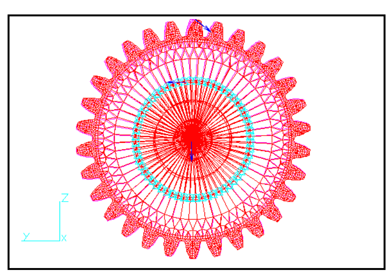

**Fig. 4** Front view of the 3D discrete model

The profile of the tooth of the gear is obtained using MAIN.CPP (Mera, 2002). The gear's model is than exported using DXF files, in order to be used by the ALGOR finite element analysis software.

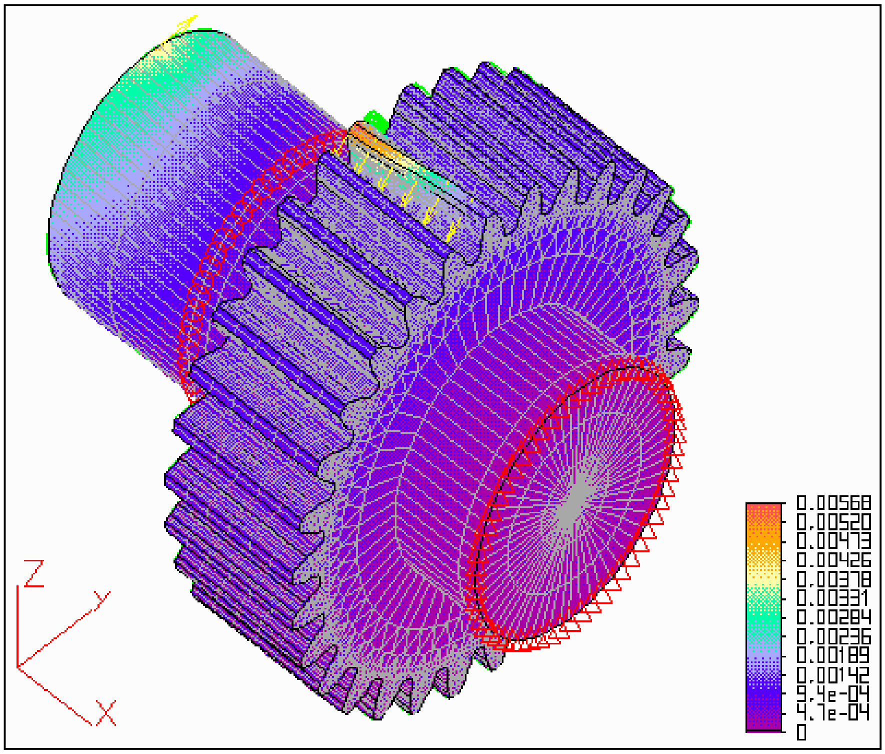


**Fig. 5** Elastically deformed gear

Using this program, one realizes the 3D discrete model of the gear (Fig. 4), imposes the boundary conditions, applies the forces and so determines the corresponding stresses and elastic strains.

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### 2.2 Longitudinal plane modification

The modification of the set of teeth by bulging enlarges the carrying capacity of the transmission gear because it diminishes the concentration of the specific efforts that appear on the side of the tooth, due to its finite length and especially to the dipping during the functioning of the gears because of the shaft straining, and to the execution errors. This type of modification is recommended to gears strongly stressed. One should pay attention to the bending and twisting stress to which the gears of the cylindrical transmission gear are subjected.

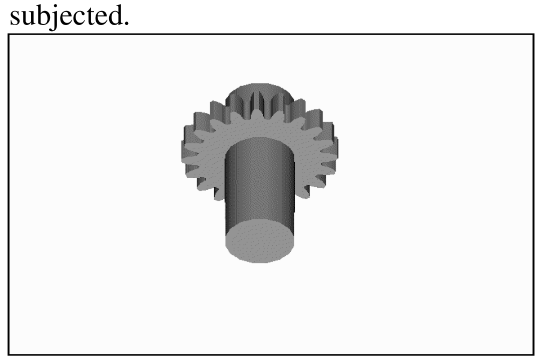

**Fig. 6** Shaft-pinion solid model

Figure 6 presents the shaft-pinion under study, in order to determine the values of the parameters for modifying the teeth in the longitudinal plane.

Under the action of the normal force $F_n$ (linearly distributed in fig. 7), the shaft on which the gear or the shaft-pinion is fixed, is becoming deformed at the bending, in the gear plane.

The gear fixed on the shaft also becomes deformed, having different deformations $f_{ix}$ on its width, and so errors of the tooth's direction appear. The size of these deviations is

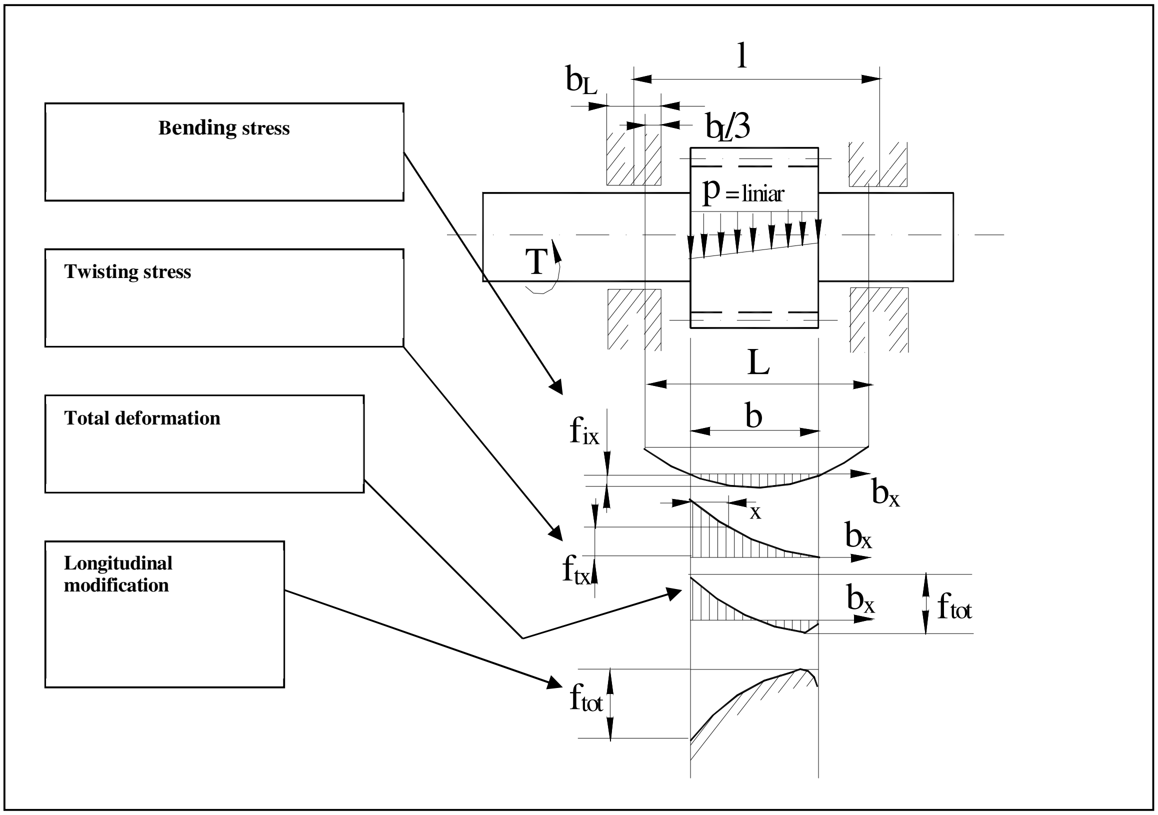


**Fig. 7** The elastic strain of the shaft-pinion

influenced by the width of the gear, its position with respect to the bearings, the shaft's stiffness, the strains and bearing clearance. That's why one recommends, for each gear, the realization of the 3D model or the solid model that will be than subjected to the finite element analysis.

The shaft is stressed at twisting too, and so it becomes deformed on the length of its axis, or the length where the twisting torque acts. This deformation is transmitted to the gear, thus to the tooth.

The deviation on the direction of the tooth $f_{tx}$ is different on the width of the gear, varying with the stressed length. Altogether these position of the gear on the shaft, so with its deviations determine the $f_{tot}$ error of the tooth's direction due to the bending and twisting of the pinion and its shaft. This analysis has taken into account the
execution errors, which contain deviations of the tooth direction, parallelism and coplanar deviations of the shaft axis.

Figure 8 presents the shape the body and the tooth of the pinion has under loading. Without a longitudinal modification of the sides of the gear's tooth, the configuration of the bearing that sustains gears has a displacement towards the end, where the twisting effort applies.

The total of the shaft-pinion tooth is determined by the superposition of the bending and of the twisting strain of the pinion in the contact plane.

The notations in figure 8 signify:

- $f_{ix}$ – the gear's tooth bending deformation, at the distance x from the front surface of the tooth;

- $f_{tx}$ - the gear's tooth twisting deformation, at the distance x from the front surface of the tooth;
- $f_{tx}$ - the gear's tooth twisting deformation, at the distance x from the front surface of the tooth;
- $f_{tot}$ - the tooth's cumulated deformation, due to it's bending and twisting;
- T – the twisting torque;
- $b_L$ – width of the bearing;
- b – the width of the set of teeth of the gear;
- p – Specific applied force [N/mm].

In conclusion, for modifying the tooth in longitudinal plane by building the elastic deformed shape of the gear's tooth under the bending-twisting stress. The strategy supposes: building a 3D discrete model of the gear fixed on the arbor with respect to the real position in the transmission gear, the consideration of the bearings that sustain the shaft, by imposing the limit conditions, the appliance of the loads that appear in the gear, including the torque of the transmission twist. One determines the elastic deformations of the gear's tooth, in longitudinal plane. Using the values of these elastic strains, which are a result of the superposition of the bending and twisting stress, one can build the deformed shape of the tooth. The mirrored image of this one represents the initial shape the gear's tooth must have in order to work accordingly under the action of the stress in the transmission gear. The shape of the tooth will then be approximated by technological curves, so that the tooth can be executed.

## 3. PERSPECTIVE

The research allows, beside of the determining of the values of the parameters used in the modification of the profile of the teeth of the cylindrical gears with straight teeth, some studies that help in establishing:

- The influence the load allocated on the width of the tooth has on the modification of the parameters value for the gear's teeth profile;

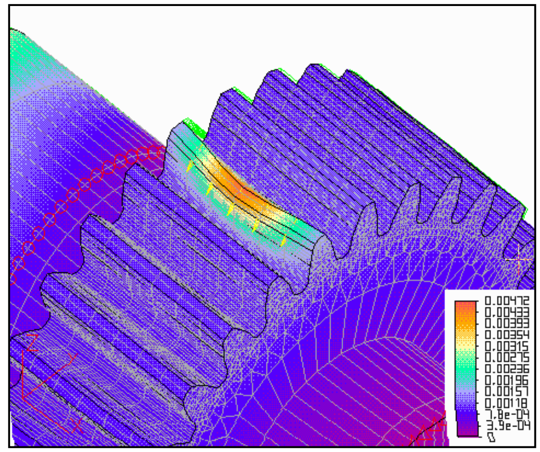

**Fig. 8** Longitudinal elastically deformed tooth

- The influence the position of the gear with respect to the bearings has on the modification of the parameters value for the gear's teeth profile;
- The influence the execution and assembly errors have on the modification of the parameters value for the gear's teeth profile.

## 4. CONCLUSIONS

The strategy presented in the paper allows to determine the value of the modification parameters of the cylindrical toothed gear teeth profile both in the frontal plan (head correction) and in the longitudinal plane (bombardment). The Strategy takes into account execution errors (step errors), elastic deformations occurring during operation, deformations determined by finite element analysis, and mounting errors taken into account by load distribution mode on the width tooth and applied force type.

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## ASUPRA UNEI STRATEGII PRIVIND MODIFICAREA PROFILULUI DINŢILOR ROŢILOR DINŢATE CILINDRICE CU DINŢI DREPŢI

***Rezumat***: *Lucrarea prezintă sintetic strategia propusa legata de modificara profilului dinţilor roţilor dinţate cilindrice cu dinţi drepţi atât în plan frontal cât şi în plan longitudinal, luând în considerare deformaţiile elastice sub sarcină ale dinţilor roţilor dinţate, erorile de execuţie şi montaj ale angrenajului. In cadrul strategiei propuse se aplica o metodă analitico-numerică, care are la bază analiza cu elemente finite.*

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