GEAR TEETH BENDING TEST UPON THE GEAR WITH ASYMMETRIC TEETH

Sándor RAVAI NAGY[1] and Mircea LOBONȚIU[1]

ABSTRACT: This paper presents the method and the comparative studies done upon the gear teeth with asymmetric teeth and upon those with symmetric teeth in order to realize a correlation by means of correlative coefficients. Thus, we shall be able to use gears with symmetric teeth by applying specific corrections for sizing these gears with asymmetric teeth, with the recognized relations talked of in the specialized literature. The method and the device used in this study have the advantage of being able to gather data regarding the behaviour of a tooth of the gear teeth bending without the need of entirely executing it.

KEY WORDS: gear teeth bending test, gear with asymmetric teeth, test method, gear test device, compare.

1 INTRODUCTION

Over the last years, researchers have turned the classical gears towards asymmetrical toothed gears, which mean that the gear's teeth will have different profiles from one flank to the other. The tooth is defined by two different involutes, which gears with the equivalent involutes of the conjugated gear teeth.

As a growth solution for the performance of the gear teeth, the asymmetric tooth will lead to promising results and big potential. Through this solution, new gears are found, with different gearing properties, according to the rotation direction, or even unidirectional gears, with auto stop properties for the reverse sense.

The gearing conditions of one of the sides are favourable to the other side as well, and this can be realized for most gears, because generally, in the industrial equipments, gear teeth can rotate only in one direction. In order to reverse the rotation direction, reversing gear teeth are provided.

By testing the asymmetric and the symmetric teeth under the same loading conditions, we can define corrective coefficients of the asymmetric tooth so that the sizing of these years to be possible according to the relations already consecrated in the specialized literature.

Aiming to realize the previously mentioned comparative study, we tried to find answers for the following questions:

-How can we define the tooth fitting section according to the dimensioning equation of the tooth while bending?

-How can we use the existing relation for the (symmetrical) gear tooth dimensioning through bending in the case of asymmetric teeth?

-Which are the methods we can use to get information about the behaviour of an asymmetrical tooth during loading?

-How to manufacture test pieces that will cover the analysed field and will be financially efficient?

By answering these questions, we also define the methodology of research and innovation, as mentioned by (Diciuc & Lobonțiu, 2013).

2 HOW CAN WE DEFINE THE TOOTH FITTING SECTION ACCORDING TO THE DIMENSIONING EQUATION OF THE TOOTH WHILE BENDING?

The calculation of the bending stress of the gear with symmetric teeth is standardized, and makes the object of the following documents: STAS 12268, DIN 3990 and ISO 6336. These standards substantiate the methodology of bending stress calculation taking into consideration the bending stress of a single tooth, which then determines the necessary correction correlated with transverse contact ratio.

The calculation is based on the fact that the gear tooth is under a bending stress that is at maximum levels the moment the contact between the teeth reaches point E when coming out of the gear, or point A when entering the gear. In these two situations, the normal force F_n acts upon the top of the tooth, (Rădulescu, 1986).

1 Universitatea Tehnică din Cluj-Napoca, Centrul Universitar Nord din Baia Mare, Dr. Victor Babeș 62A, 430083 Baia Mare, România.

E-mail: ravai.nagy.sandor@cunbm.utcluj.ro; mircea.lobontiu@cunbm.utcluj.ro

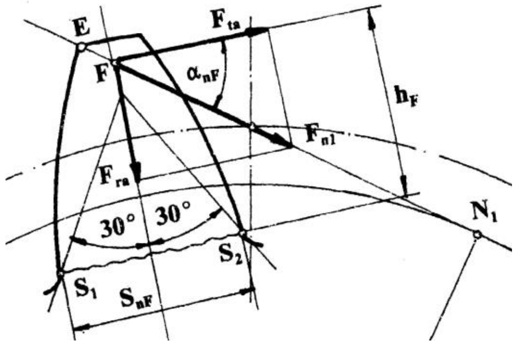

Figure 1. The hypotheses of estimating the resistance of standardized cylindrical gears with symmetric teeth (Rădulescu, 1986)

From the point of view of the stress and values, F_{ta} is neglected in the estimation, the tangential force F_{ta} being the one that will stress the tooth when bending in the area considered for fitting S_1S_2 (Gafițeanu, 1983), (Rădulescu, 1986).

The bending stress of the tooth foot is (Rădulescu, 1986), STAS 12268, ISO 6336:

$$\sigma_b = \frac{F_{ta} \cdot h_F}{\frac{S_{nF}^2 \cdot b}{6}} \tag{1}$$

3 HOW CAN WE USE THE EXISTING RELATION FOR THE (SYMMETRICAL) GEAR TOOTH DIMENSIONING THROUGH BENDING IN THE CASE OF ASYMMETRIC TEETH?

In the case of the gears with asymmetric teeth, the (1) formula changes into:

$$\sigma_{b\frac{m_+}{m_-}} = k_\sigma \cdot \frac{F_{ta} \cdot h_F}{\frac{S_{nF}^2 \cdot b}{6}} \tag{2}$$

where k_σ is the correction coefficient of the asymmetric tooth, h_F, S_{nF} are the arm of the bending stress and the fitting section of the symmetric tooth.

The approach of the bending stress estimation of the tooth of the asymmetric teeth gear is made under the same conditions. The fitting section $P_{m+}P_{m-}$ is on the same hypothesis as in the case of symmetric teeth (Figure 2) with F_{m+} as admitted stress point of the tooth with the force F_{ta_m+}.

In this context, from the (1) relation we admit for the symmetric tooth gear, we shall make a correction with the k_σ coefficient, which will take into consideration the new stress conditions and the new area theoretically admitted as a fitting section $P_{m+}P_{m-}$.

This k_σ coefficient depends on:

a)The angle of the modified reference rack;

b)The wheel width;

c)The nature of the material and the heat treatment of the gear with asymmetric teeth.

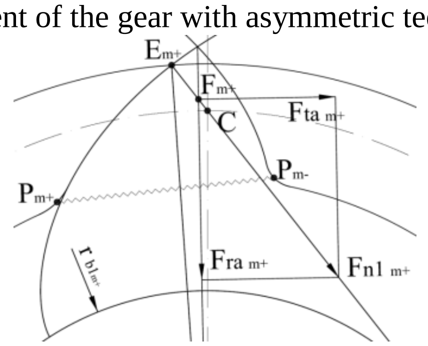

Figure 2. The tooth fitting section

As a consequence, one of the first experimental approaches would be determining the experimental values of the k_σ correction coefficient and, implicitly, determining the fitting section and correlating it with the specialised literature (Rădulescu, 1986), (Gafitanu, 1983).

4 WHICH ARE THE METHODS WE CAN USE TO GET INFORMATION ABOUT THE BEHAVIOUR OF AN ASYMMETRICAL TOOTH DURING LOADING?

Results of studies on the behaviour of the gear tooth are based on:

-Studies made with FEA. In this case, the practically obtained data through tests must be verified and validated.

-Tests performed on gears. Reviewing the dedicated literature, we have found only solutions that use completely machined gears. This means that we should manufacture gears to be able to study the fitting section of the asymmetrical tooth. And for this we would need the manufacturing technology, as well as sufficient financial resources.

As the result of bibliographic study, we identified one suitable device, introduced by (Aaron, 2010) and presented in figure 3.

When testing, a complete gear wheel is used, and the wheel locking is achieved by means of a pad placed under a tooth which has not been tested.

After studying the existent solutions, a new method and a testing device have been created (Ravai Nagy, 2012), by means of which the fitting modalities of the gear with symmetric or asymmetric teeth can be studied, simulating the gearing between a teethed wheel and a rack. (Figure 4).

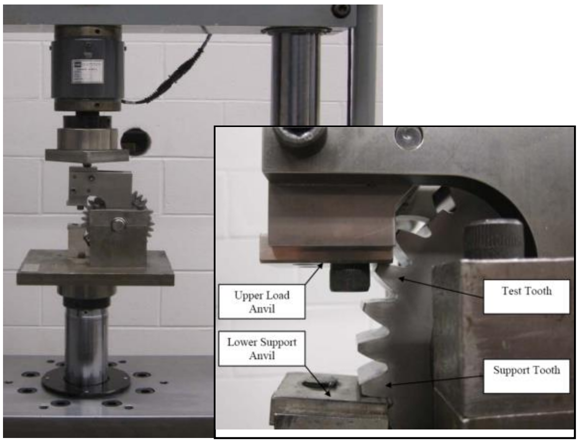

Figure 3. The testing device for gear tooth bending (Aaron, 2010)

The test device for the fitting section of the symmetrical teeth wheel has been created for being used on the universal machines for testing materials, so that it ensures the tooth the necessary fitting force.

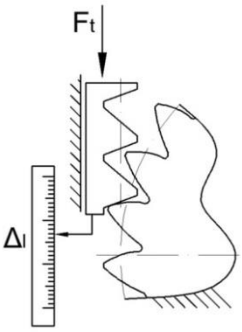

Figure 4. The principle used for testing the gear bending stress

The tooth straining in this case, is done by means of the equipment for measuring the displacement of the material testing machine.

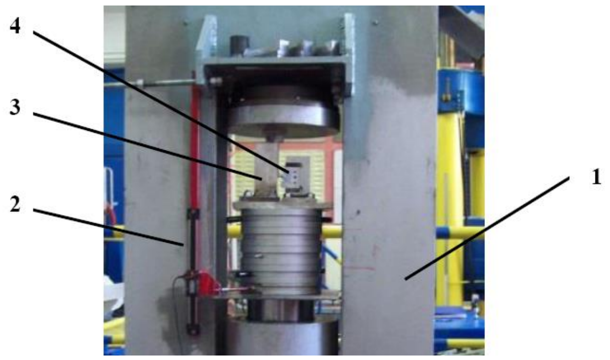

Figure 5. The technological device used for testing the bending stress of an asymmetric toothed gear

Legend:

1. Material testing machine;
2. Digital measuring rods with 0.01mm reading precision;
3. Testing device;
4. Test specimen.

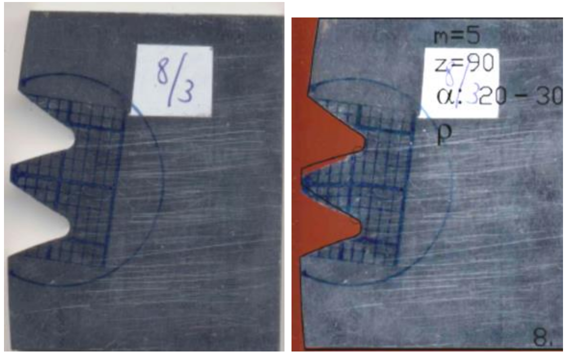

Figure 6. The test specimen before and after testing

5 HOW TO MANUFACTURE TEST PIECES THAT WILL COVER THE ANALYZED FIELD AND WILL BE FINANCIALLY EFFICIENT?

The chosen specimen (see figure 6) easily provides information about the fitting section of the tooth, from the point of view of manufacturing technology being used, and from the point of view of the costs involved. The solution involves using a CNC machine tools in 3 or in 5 axis.

In terms of the specimen processing technology, we used an end mill cutter, on a CNC machine tools with 3 axes.

As controlling technology, we used a 3D control arm CIMCORE Model 5124, by which means we palpated the machined surface, and then we compared the measured points with the 3D model of the piece.

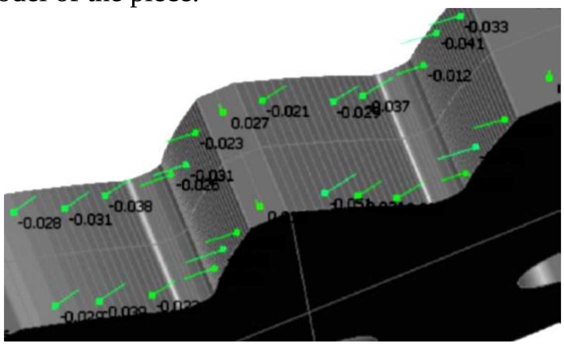

Figure 7. The 3D model and the deviations of the test specimen after the machining

6 TEST MEASUREMENTS OF THE ASYMMETRIC TOOTH ON TWO GEARING DIRECTIONS

As part of the study, a device with special destination has been proposed, designed, realised and tested, in order to create the specific conditions for the gearing of a rack with a toothed gear.

At the same time, a study approach method has been substantiated so that the tests to be made upon segments of toothed wheels. Within this concept, the technological tooth processing conditions are facilitated by the processing upon machines with numeric command.

With the help of the proposed device and method, the k_σ correction coefficient can be experimentally determined for a given situation. Also, by means of this device, we can determine for real, and not only hypothetically, the crack area for gearing a rack with a toothed wheel, the gearing conditions being the same with those of two toothed wheels.

The device (Fig. 8) is made up of the basic board 1, on which the stand of the 5-testing specimen and the 2-rack stand (or die), are mounted.

The 4-testing specimen is introduced in the stand for the testing specimen and fixed with the help of a device called 6-fixing yoke, functioning as a vice-type device. The 3 one-toothed rack glides in the 2-rack stand.

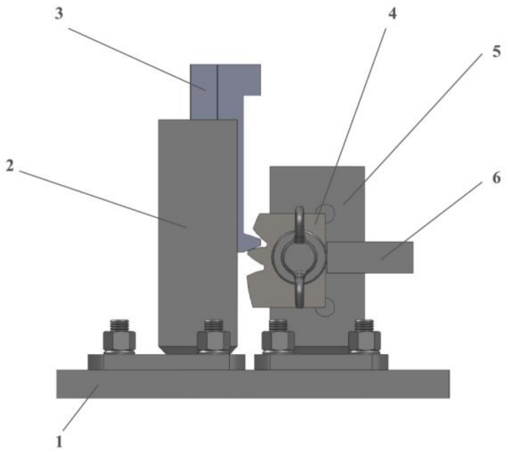

Figure 8. The device used for testing the bending stress of the gear

One can also use the several toothed rack, but in that case, a proper testing specimen must be designed. The pile driver of the material testing device will push upon the superior end of the rack. Through the monitoring system of the testing device, the tooth behaviour can be followed according to the time variation of the tangential component of the gearing force. With the help of the data given by the testing machine, the variation diagram of the tangential force – the tooth distortion rises.

The form of the testing specimen used for applying the proposed testing method is established taking into consideration the fact that the wheel tooth is strained at the maximum bending when the contact point between the teeth reaches point E. At the moment, the normal force F_n acts upon the top of the tooth. (Fig. 4, Fig. 9 and Fig. 10).

The specimen materialises a complete tooth, respectively one side of the previous tooth and one side of the following tooth.

In the point E, the tangent to the basic circle (point T_1) of the involute of the tooth side, is perpendicular on the rack side and passes through point C, which is the pitch point between the rack and the tooth.

Figures 9 and 10, shows the testing scheme of two test pieces that comes from the same asymmetrical toothed gear. Figure 9 presents the testing of the asymmetric teeth when stressing the m- modified flank, and figure 10 shows the stressing of the m_+ modified flank.

One can notice that, depending on the side tested, the rack changes accordingly with the pressure angle $\alpha_{p\,m-}$, respectively $\alpha_{p\,m+}$, the angle of the generating rack.

In the contact point E, between the tested tooth and the rack, the normal force F_n is applied, which acts upon the tooth top and along the pitch line.

The gauge dimensions of the A_E, B_E specimen are established according to the dimensions of the testing device. These can be modified according to the test characteristics and to the testing device capacity.

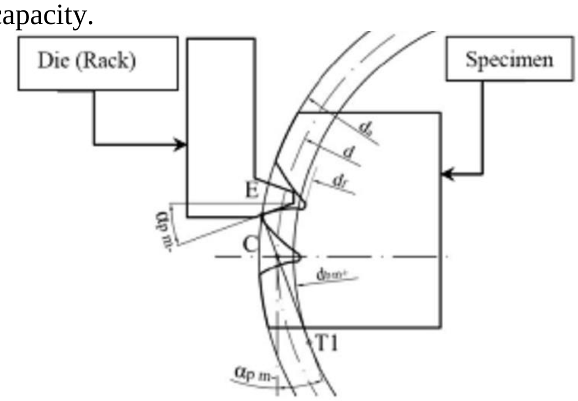

Figure 9. The specimen for the tested side with a smaller pressure angle

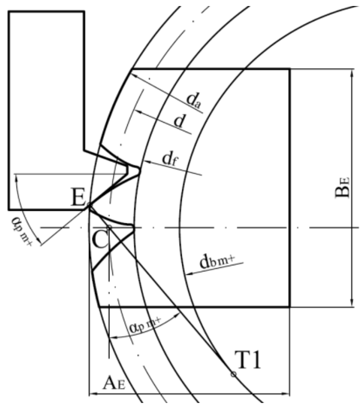

Figure 10. The specimen for the tested side with a larger pressure angle

After the charges (on Tecnotest F050-TC material testing machine) realised with tangential forces that are variable in time, and specimens that materialise symmetric and asymmetric teeth of some wheels, we have obtained the results presented graphically as Ft tangential force – Δl displacement (Figure 11).

In the graphics presented in Fig. 11 and underlined in figure 12, we have highlighted three areas: tooth elastic strain (area A), tooth plastic strain (area B), and finally tooth cutting by the rack action (area C).

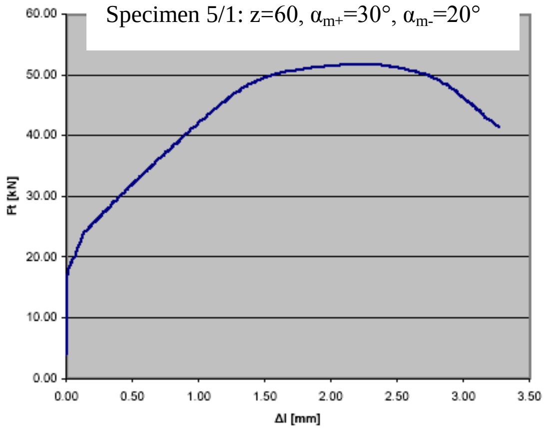

Figure 11. Testing report given by the testing device through the data collection and processing system on the PC

In the strain interval (A), the tested tooth is elastically distorted. With the force increased, the tooth suffers from plastic strain, distortion which is manifested both locally in the contact area with the rack side, and in its totality.

In figure 13 present the numeric values of the tangential force which can be applied on a tooth, with a fillet radius of ρ_f =1,5mm, the width b=8mm, the module m=5mm, material C45V (230-260HB).

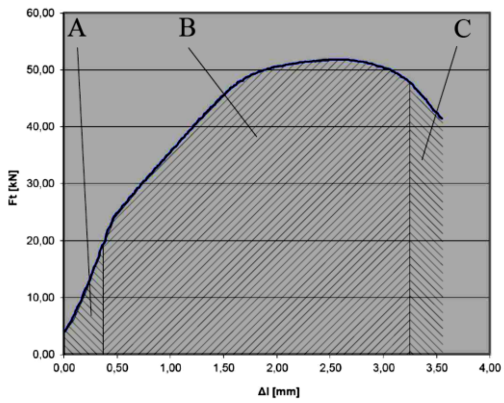

Figure 12. The identified areas on the force-deformation graph of a tooth belonging to a symmetric, respectively an asymmetric gear

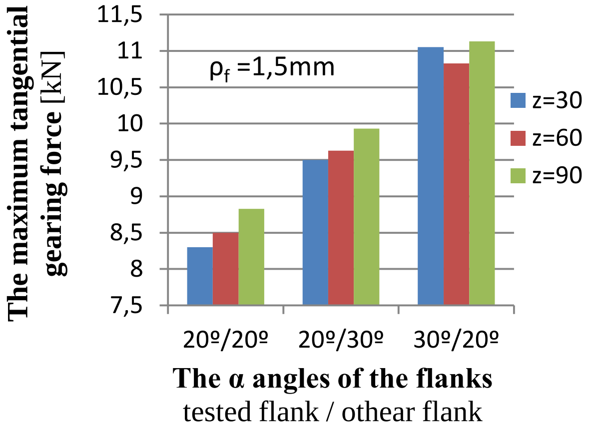

Figure 13. The maximum tangential gearing force and the tooth displacement when fillet radius is 1,5 mm

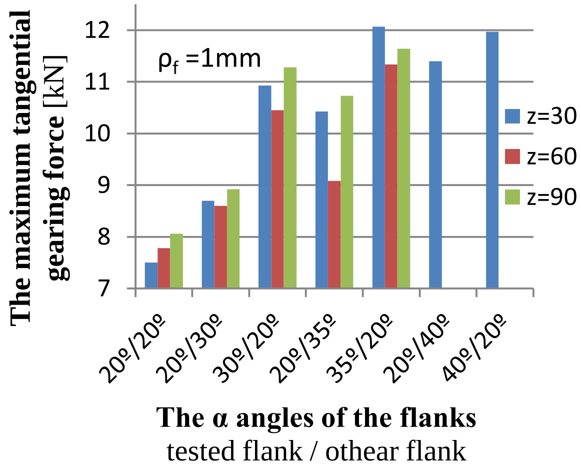

Figure 14. The maximum tangential gearing force and the tooth displacement when fillet radius is 1 mm

To widen the study, we repeated the tests on specimens manufactured with tooth fillet radius ρ_f =1mm. The graph from figure 14 introduces the test results.

Table 1. The maximum tangential gearing forces

α angles of the flanks	z=30	z=60	z=90
	ρ_f=1,5	ρ_f=1,5	ρ_f=1,5
20°/20°	8,3	8,5	8,83
20°/30°	9,5	9,63	9,93
30°/20°	11,05	10,83	11,13
	ρ_f=1	ρ_f=1	ρ_f=1
20°/20°	7,5	7,78	8,06
20°/30°	8,7	8,6	8,92
30°/20°	10,93	10,45	11,28
20°/35°	10,43	9,08	10,73
35°/20°	12,07	11,34	11,64
20°/40°	11,4		
40°/20°	11,97		

7 CONCLUDING REMARKS

For a given charge, the asymmetric teeth are more resistant at bending than the normal symmetric ones (with the angle of the standard reference rack being of 20º). The teeth with symmetric tooth resist at tangential bending forces between 7,50÷8,83 kN, compared to 8,60÷12,07 kN in the case of the teeth with asymmetric flanks.

The asymmetric tooth tested against bending on the modified side + has a higher resistance than in the case of bending on the modified side -;

The tooth split is not in conformity with the principles of the specialised literature (fig. 15).

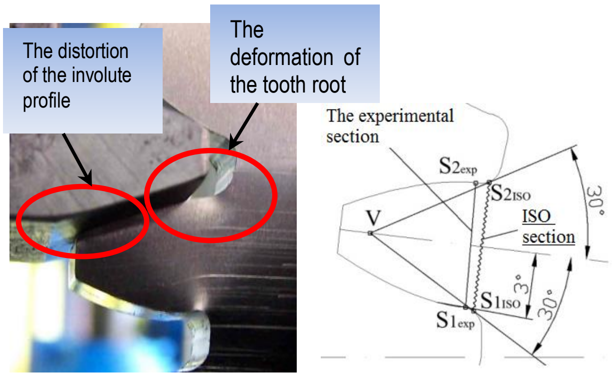

Figure 15. The tooth after the static bending stress test

In the case of the asymmetric tooth defined by the involute sides with 30º/20º, the maximum tangential force F_t is up to 22÷27 % bigger than the one corresponding to the symmetric tooth with the sides 20º/20º;

The maximum tangential force that can be applied on an asymmetric tooth defined by 20º/30º involute flanks is 10÷12% bigger than the one corresponding to a symmetric tooth with 20º/20º flanks.

In the case of asymmetric gears, with z=60 and z=90 teeth having 20º /40º pressure angle the root profile cannot be generated for the ρ_f =1mm fillet radius.

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9 NOTATION

The following symbols are used in this paper:

h_F = the arm of the bending force;

k_σ = correction coefficient of the asymmetric tooth;

$P_{m+}P_{m-}$ = the fitting section of the asymmetric tooth;

S_{nF}= the fitting section of the symmetric tooth;

ρ_f = tooth fillet radius.