

Research of the influence of axial displacement on the wear of hob milling tools

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Abstract: The need to increase productivity and cost-effectiveness of gear cutting of cylindrical gears with oblique teeth creates favorable conditions for the development of research in the field of tribology and the increasing application of tribological knowledge in industrial practice. Improving the gear cutting process by hob milling is important and useful for both gear manufacturers and hob milling tools manufacturers. Increasing productivity and increasing of the quality of serration are the basic directions of improving the process of gear cutting by hob milling. Technological parameters significantly affect the wear of cutters and taking into account the parameters for defining the economy of the process affect the achievement of optimal parameters of the cutting regimes. Based on experimental research, the paper presents an analysis of the influence of axial displacement, as one of the technological parameters, on the wear of hob milling tools in the gear cutting of cylindrical gears with oblique teeth.

1. Introduction

Gear pairs are tribomechanical elements for power transmission in which energy transfer is achieved by engaging the teeth of the drive and driven gear. They are characterized by small size in relation to the transmitted loads, high degree of utilization, durability, the possibility of application for very wide areas of power and transmission relations. The negative effect of these tribomechanical elements are vibrations, noise, gaps in couplings and other places of contact, wear and others [1].

Hob milling is the most widely used in the gear cutting of cylindrical gears with oblique teeth due to the high productivity of the process. Complicated kinematic and geometric connections between the hob milling tool and the workpiece create a number of difficulties and problems that prevent the optimal use of the hob milling tool and the hob milling machine [2,3,4]. One of the problems is the maximum and even use of as many teeth of the hob milling tool as possible in the gear cutting of cylindrical gears with oblique teeth. In this paper, certain attention is paid to the mentioned problems.

2. Methods of hob milling and uniform distribution of wear of cutting elements of tools

During gear cutting, with regard to the direction of auxiliary movement, the following types of machining have been developed:

- axial hob milling

- without additional movement of the hob milling tool in the direction of its own axial axis
- with additional movement of the hob milling tool in the direction of its own axial axis
- diagonal hob milling
- radial hob milling
- tangential milling
- radial-axial diagonal hob milling.

Figure 1[2] shows four possible variants of gear cutting of cylindrical gears with oblique teeth by hob milling.

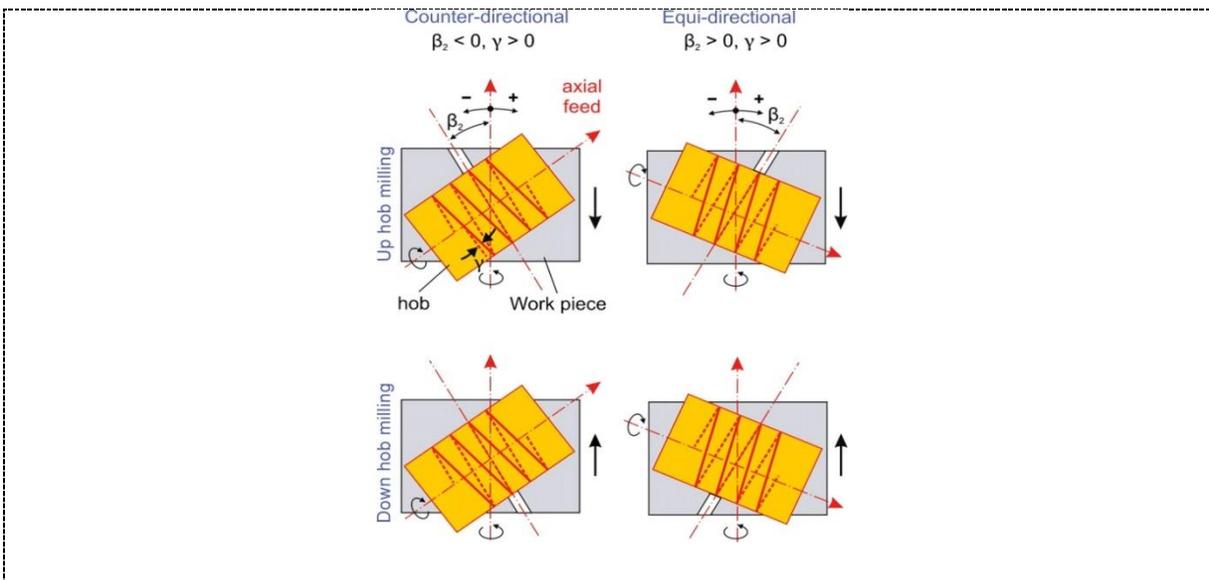


Figure 1. Four possible variants of gear cutting of cylindrical gears with oblique teeth by hob milling

Axial hob milling without moving the hob milling tool along its own axial axis is historically the first developed method of hob milling of gear teeth. The hob milling tool is short and has no possibility of axial movement in the direction of its own axial axis. The length of the active part of the hob milling tool is identical to the width of the grip between the tool and the workpiece, and therefore each tooth of the hob milling tool plays a certain role in removing excess material from the gullet of a certain form and dimensions. This is also the biggest drawback because not all teeth are uniformly loaded and do not wear uniformly. For hob milling tools that work without axial movement along their axial axis, the wear of maximum loaded tooth of the tool is adopted as a wear criterion. Due to that, short hob milling tools were used are uneconomically. The manufacturers of hob milling tools have switched to the production of hob milling tools of larger lengths, thus enabling the hob milling tools to be moved by the appropriate size in the direction of own axial axis when gear cutting in order to economically use one of the most expensive tool for chipping removal. In that way, the maximum load is shifted to the next teeth that were less loaded and lie in the area of the zone that continues to the previous one. The size of the axial displacement of the hob milling tool determines which tooth will be maximally loaded. Figure 2 [3] shows the theoretical distribution of wear on the teeth of the hob milling tool when gear cutting with a certain axial displacement of the tool along the own axial axis.

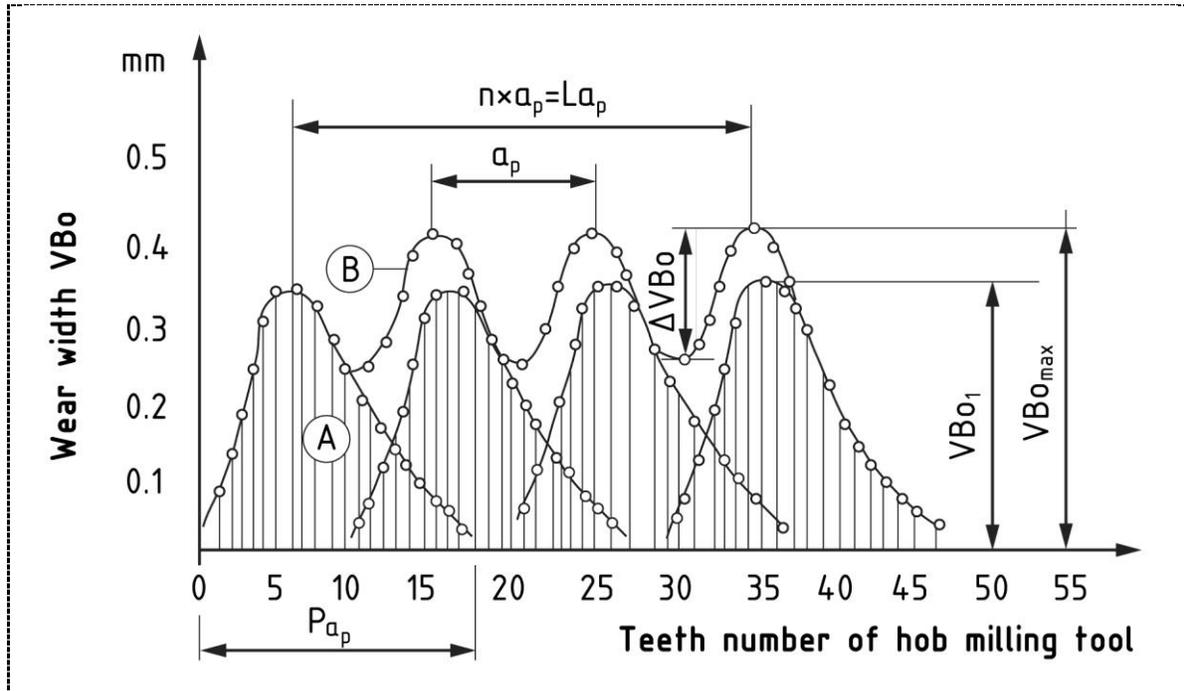


Figure 2. Theoretical distribution of wear on the teeth of hob milling tool during gear cutting with a certain axial displacement along the own axial axis

It is known that modern hob milling machines have the possibility of axial displacement both manually and automatically, but there are still two issues of significant impact on the optimal use of the hob milling tool remain unresolved. The first question is after which amount of chip i.e. the width of the machined serration, the axial displacement of the hob milling tool should be done. Another question is how much that axial displacement amount should be. Figure 3[5] shows the basic forms of flank wear zone of the tooth of the hob milling tool.

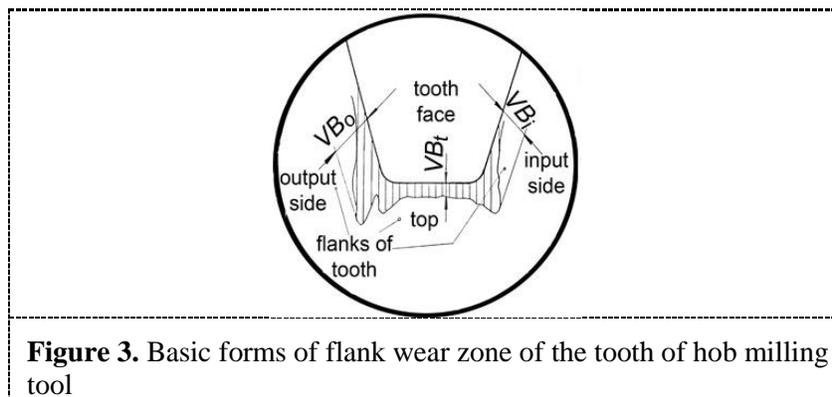


Figure 3. Basic forms of flank wear zone of the tooth of hob milling tool

Based on numerous experimental researches, it has been determined that the parameter VB_o can be adopted with certainty as a criterion for assessing the wear of the teeth of hob milling tool [4]. The wear

curve denoted by A in figure 2[3] refers to the width of the wear zone VB_o on the individual teeth of the hob milling tool when gear cutting without axial displacement of the hob milling tool. After the first axial displacement for length a_p , new wear of the new working area is expected according to the same laws as before the movement. Due to the fact that there is a partial overlap of the working area in the zone marked with P_{ap} , there is a slightly larger width of the wear zone in the area P_{ap} on the individual teeth of the hob milling tool. After n the same axial displacements of the hob milling tool a_p , a greater width of the wear zone occurs, which is shown in figure 2 by curve B. Based on this figure, it can be concluded that by choosing a certain width of the wear zone VB_{o1} before the first movement and a certain size of axial displacement a_p more uniform wear of all cutting teeth in the area $L_{ap} = n \cdot a_p$ can be reached. Figure 4 shows the basic values necessary to define the degree of uniformity of the wear distribution of the tooth of the hob milling tool.

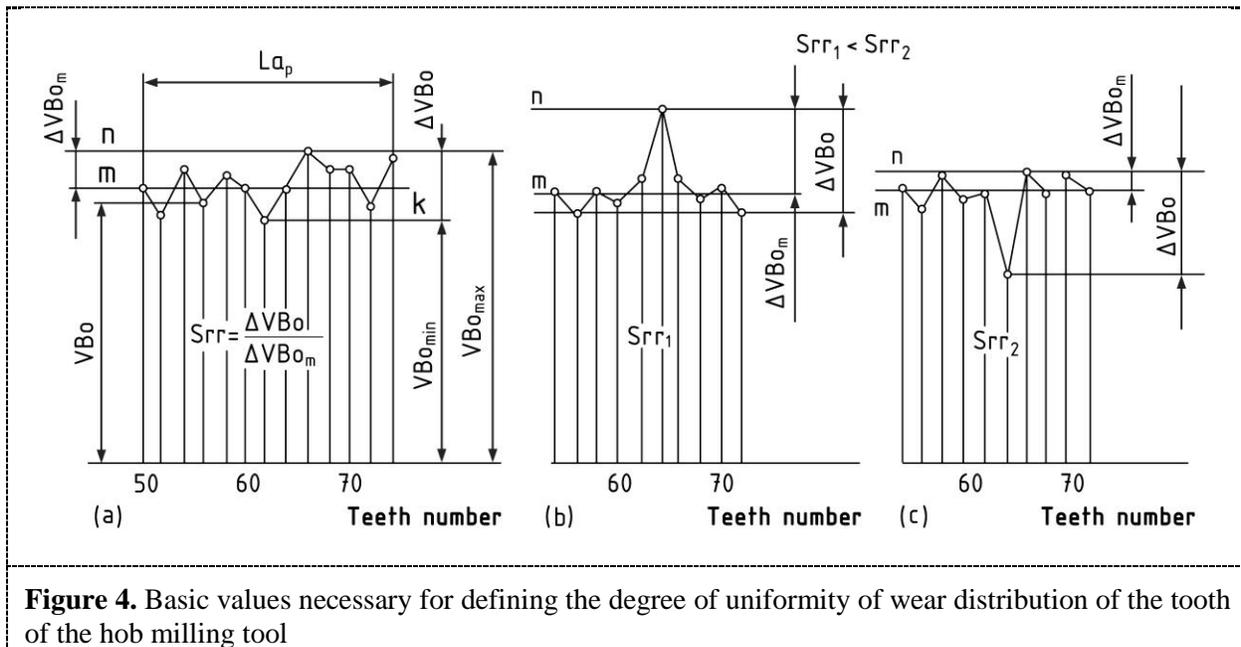


Figure 4. Basic values necessary for defining the degree of uniformity of wear distribution of the tooth of the hob milling tool

Basic values in figure 4 are:

- n - tangent line to the maximum width of the wear zone VB_o
- k - tangent line to the minimum width of wear zone VB_o
- m - midline, parallel to the lines n and k, is the arithmetic mean value of width of the wear zone VB_o at the length L_{a_p}
- ΔVB_{o_m} - mean dispersion of the width of the wear zone VB_o measured from line n to line m

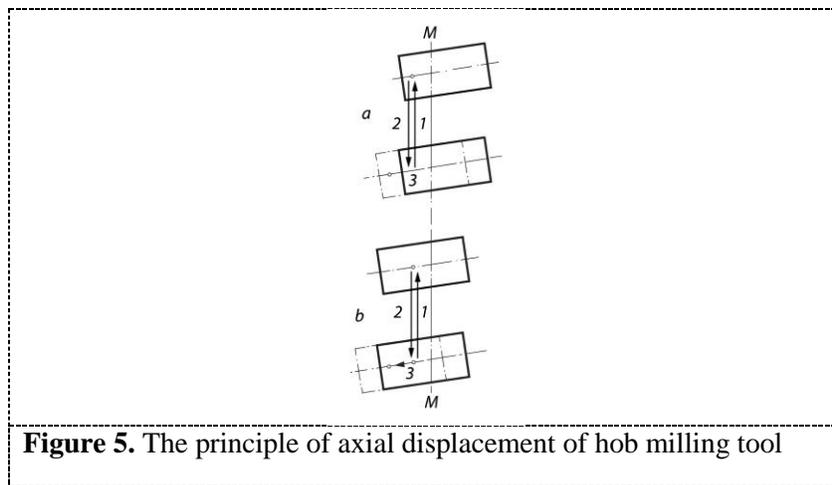
Based on these values, an expression for the degree of uniformity of the teeth wear distribution of the hob milling tool can be written as:

$$S_{rr} = \frac{\Delta VB_o}{\Delta VB_{o_m}} \quad (1)$$

Axial displacement of the hob milling tool along its own axis can be performed in two ways:

- displacement by a certain length after machining one or more serrations
- continuous movement of the hob milling tool, i.e. automatically for a certain length during gear cutting using diagonal hob milling

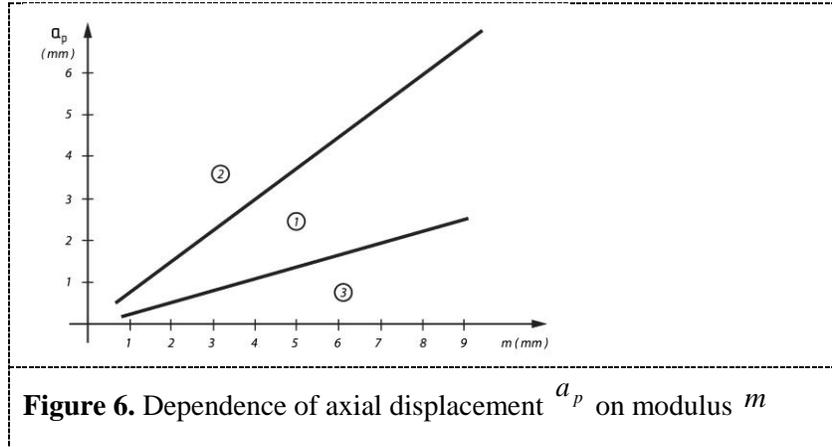
The principle of axial displacement of the hob milling tool is shown in figure 5 [6].



One of the basic problems in the application of axial displacement of hob milling tools in the gear cutting is the determination of the optimal size of axial displacement a_p , which depends on a large number of parameters. The influence of the module on the size of the axial displacement can be represented by the expression:

$$a_{p\ opt} = (0.25 \div 0.75)m \quad (2)$$

where m is the module. Based on the above expression, a diagram is shown in figure 6 [3].



It can be noticed in the figure that the area of optimal axial displacements also increases with the increase of the modulus. In figure 6, 1 indicates the area of optimal axial displacements, and 2 indicates the area of insufficient utilization of the hob milling tool, and 3 indicates the area of deterioration of the hob milling tools.

The number of axial displacements can be calculated based on the following expression:

$$n_{a_p} = \frac{L_1 - (l_{no} + l_s)}{a_p} = \frac{L_{a_p}}{a_p} \quad (3)$$

- n_{a_p} number of axial displacements
- L_1 length of the working part of the hob milling tool
- l_{no} required length for gear cutting of one serration
- $l_s = 0.4 \cdot t_n$ safety length of the hob milling tool
- L_{a_p} length of the hob milling tool for axial displacement
- a_p axial displacement
- t_n normal pitch

Based on the above, it is possible to define the basic rules regarding the application of axial displacement of hob milling tools in the gear cutting of cylindrical gears with straight and oblique teeth:

- large length of axial displacement will give an ununiform distribution of wear of the tooth of the hob milling tool
- the small length of the axial displacement will result in a large wear of the teeth of the hob milling tools
- when the gears have small serration widths, a small number of teeth and a small module, it is necessary to machine more serrations between two axial displacements
- when the gears are of greater width, a larger number of teeth and a larger module, it is usually done with one workpiece, i.e. one serration between two axial displacements is machined. In extremcases, diagonal hob milling must be applied.

Gear cutting of cylindrical gears with straight and oblique teeth can be performed by the down hob milling and up hob milling.

3. Experimental research and results analysis

Experimental investigations of the influence of axial displacement on the wear of hob milling tools during gear cutting of cylindrical gears with oblique teeth were performed in production conditions. On the original form for monitoring the distribution of wear of the teeth of hob milling tools and the development of tribological processes, data on the workpiece, data on the hob milling tool, data on the hob milling machine, process data, workpiece sketch, sketch of wear of the hob milling tool teeth, data on axial displacement of the hob milling tool, etc. are entered.

Workpiece data are: workpiece outside diameter $d_k = 125.5\text{mm}$, number of gear teeth $z_2 = 40$, standard module $m_n = 2.75$, contact angle $\alpha = 20^\circ$, angle of inclination $\beta = 23.33^\circ$, right direction R , gear width $b_2 = 18\text{mm}$, serration width $b = 36\text{mm}$, material HS-6-5-2-5, coolant REZANOL HP40, hob milling machine MODULE 5WZ-250x5A.

Data on the hob milling tool: integral uncoated hob milling tool number 58, diameter of the hob milling tool $d_y = 110\text{mm}$, length of the hob milling tool $L_y = 150\text{mm}$, module $m = 2,75\text{mm}$, basic profile II, normal pitch $t_n = 8.639\text{mm}$, direction of thread right R , number of treads $t_1 = 1$, number of grooves $i = 14$, material of the hob milling tool HS-6-5-2-5, hardness $HRC = 65$, accuracy class A, hole diameter $d = 40\text{mm}$.

Process data: equ-directional milling, $n = 180\text{ r/min}$, $v = 64\text{ m/min}$, axial feed $s_a = 3\text{mm}$, axial displacements $a_{p_1} = 1.1\text{mm}$ $a_{p_2} = 4.8\text{mm}$ $a_{p_3} = 9.6\text{mm}$, displacement after machining of two teeth in a package, etc. Wear criterion: $VB_o = 0.35\text{mm}$.

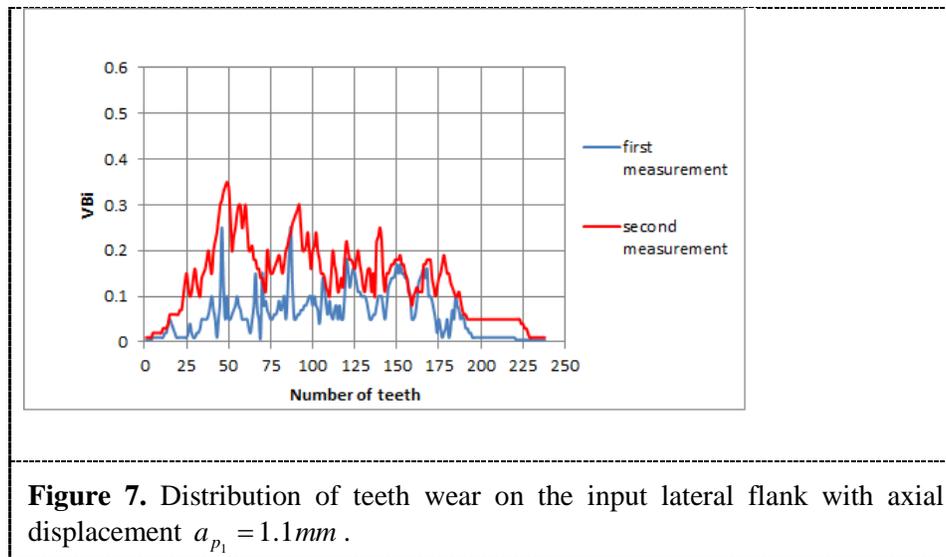


Figure 7. Distribution of teeth wear on the input lateral flank with axial displacement $a_{p_1} = 1.1\text{mm}$.

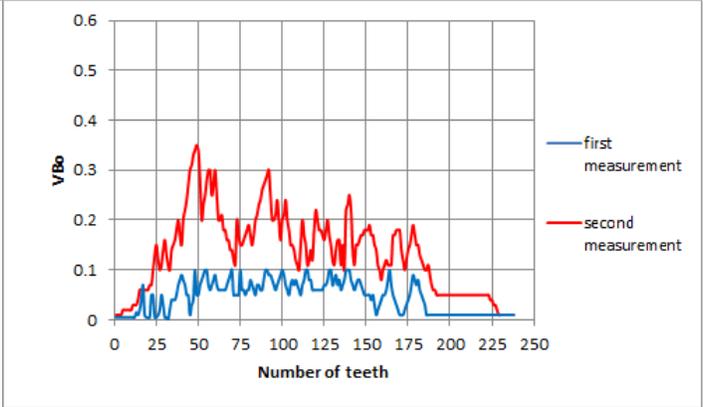


Figure 8. Distribution of teeth wear on the output lateral flank with axial displacement $a_{p_1} = 1.1mm$

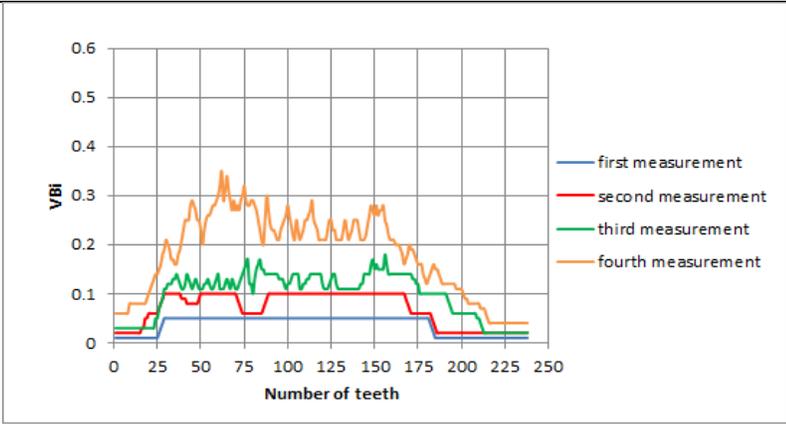


Figure 9. Distribution of teeth wear on the input lateral flank with axial displacement $a_{p_2} = 4.8mm$.

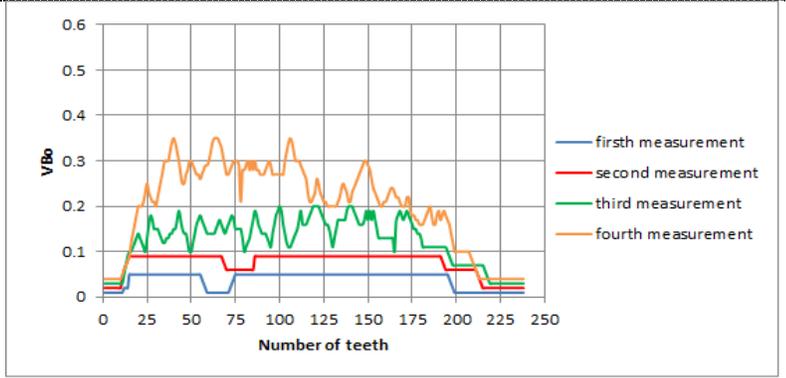


Figure 10. Distribution of teeth wear on the output lateral flank with axial displacement $a_{p_2} = 4.8mm$.

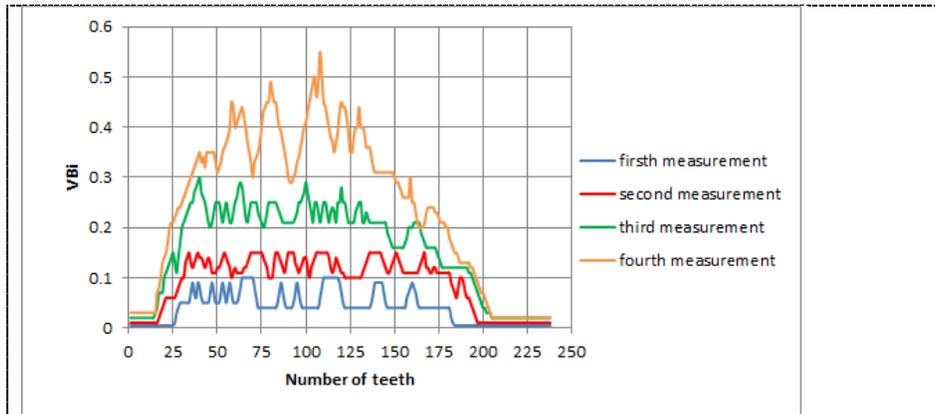


Figure 11. Distribution of teeth wear on the input lateral flank with axial displacement $a_{p_3} = 9.6mm$

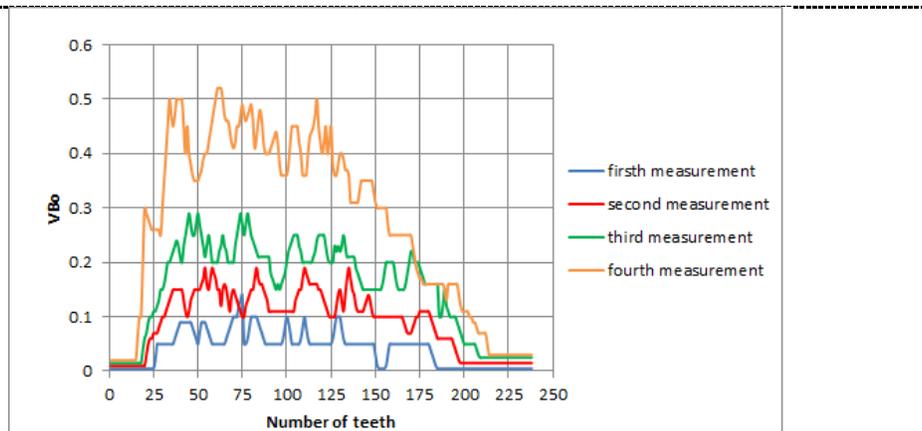


Figure 12. Distribution of teeth wear on the output lateral flank with axial displacement $a_{p_3} = 9.6mm$

Figure 7 and figure 8 show the distribution of teeth wear of uncoated hob milling tool number 58 made of HS 6-5-2-5 material when gear cutting the teeth of a cylindrical gear with oblique teeth on the input and output lateral flank with axial displacement $a_{p_1} = 1.1mm$. Figure 9 and figure 10 show the distribution of wear on the flanks of the same tool but now sharpened for the first time when working with axial displacement $a_{p_2} = 4.8mm$. Figure 11 and figure 12 show wear distribution of the input lateral flank VB_0 and the output lateral flank VB_i when applying axial displacement $a_{p_3} = 9.6mm$ in the process of gear cutting of cylindrical gears with oblique teeth with uncoated cutter number 58 made of material HS-6-5-2-5 which was sharpened for the second time.

When gear cutting of cylindrical gears with oblique teeth with axial displacement $a_{p_1} = 1.1\text{mm}$ by hob milling tool there are 140 gear teeth and it was worn-out $VB_0 = 0.3\text{mm}$. Applying axial displacement $a_{p_2} = 4.8\text{mm}$, the hob milling tool machined 112 gear teeth, and it was worn-out $VB_0 = 0.35\text{mm}$. Using the third axial displacement $a_{p_3} = 9.6\text{mm}$ the hob milling tool machined 80 gear teeth and was worn-out $VB_0 = 0.5\text{mm}$. Based on the above, it can be concluded that better results were achieved with a smaller axial displacement $a_{p_1} = 1.1\text{mm}$ compared to larger axial displacements $a_{p_2} = 4.8\text{mm}$ and $a_{p_3} = 9.6\text{mm}$. The experiment was performed with the same tool, i.e. uncoated hob milling tool made of material HS-6-5-2-5. All technological parameters were constant except of different axial displacement. The hob milling tool number 58 was new when working with $a_{p_1} = 1.1\text{mm}$, and it was sharpened for the other two experiments. The axial displacement of the hob milling tool $a_{p_1} = 1.1\text{mm}$ depending on the axial division ε is $a_{p_1} = 1,78 \cdot \varepsilon$, and depending on the module m is $a_{p_1} = 0,44 \cdot m$. The axial displacement of the hob milling tool $a_{p_2} = 4.8\text{mm}$ depending on the axial division ε is $a_{p_2} = 7,79 \cdot \varepsilon$, and depending on the module m is $a_{p_2} = 1,42 \cdot m$. The axial displacement of the hob milling tool when gear cutting of cylindrical gear with oblique teeth $a_{p_3} = 9.6\text{mm}$ depending on the axial division ε is $a_{p_3} = 15,58 \cdot \varepsilon$, and depending on the module is $a_{p_3} = 3,49 \cdot m$.

Considering what is stated in the theoretical part that refers to the magnitude of the axial displacement, it can be concluded that the first axial displacement $a_{p_1} = 1.1\text{mm}$ is in the range of optimal magnitudes of axial displacements depending on the module m . The axial displacements $a_{p_2} = 4.8\text{mm}$ and $a_{p_3} = 9.6\text{mm}$ are in the area of insufficient utilization of the hob milling tool when gear cutting of cylindrical gears with oblique teeth.

4. Conclusion

The process of gear cutting of cylindrical gears with oblique teeth is influenced by a very large number of controlled and uncontrolled factors that make this type of machining extremely complex. This paper presents a part of the research of an interesting area of gear cutting of cylindrical gears with oblique teeth by relative rolling, which refers to the analysis of the influence of axial displacement of hob milling tool along its own axial axis after machining a certain number of serration of cylindrical gear with oblique teeth.

The analysis of the obtained research results showed that in this particular case, less axial displacement $a_{p_1} = 1.1\text{mm}$ provides less wear and more uniform distribution of wear on all teeth of the hob milling tool when gear cutting of cylindrical gears with oblique teeth.

5. References

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