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Friction and Wear in Timing Belt Drives

Timing belt tooth goes into contact with a drive pulley, stretched to the maximum, because of the previous tension. When the contact begins the peak of the belt tooth makes the contact with the outer surface of the pulley teeth. The process of the teeth entering into the contact zone is accompanied with the relative sliding of their side surfaces and appropriate friction force. The normal force value is changing with the parabolic function, which also leads to the changes of the friction force. The biggest value of the normal force and of the friction force is at the tooth root. Hollow between teeth and the tip of the pulley teeth are also in contact. Occasionally, the face surface of the belt and the flange are also in contact. The friction occurs in those tribomechanical systems, also. Values of these friction forces are lower compared with the friction force, which occurs at the teeth root.

Keywords: *Timing belt drive, friction, wear.*

1. INTRODUCTION

Timing belt is a relatively young drive, firstly designed as a drive for a sewing machine by engineer Richard Y. Case in 1946. It was a rubber belt with trapezoidal teeth profile [1,2].

These motions are due to torque, circumferential force, previous tension, radial force, centrifugal force, air, belt deformation due to bending and tension, belt's design, tractive element and the belt pulley, precision of manufacture and assembly, quality of contact surfaces machining, etc. Considering the large number of parameters influencing the transmission of power and motion, kinematic analysis of the coupling and friction is very complex process [3,4,5].

2. KINEMATICS AND FRICTION OF MESHING IN TIMING BELT DRIVES

The timing belt drives with trapezoidal teeth profile of the belts and the belt pulleys are the most frequently used in exploitation. The largest application of these belts is found in automobile industry. Considering that experimental tests were performed on a timing belt drive with trapezoidal teeth profile, the total kinematic analysis is linked to these belts. Leave one clear line before and after a main or secondary heading and after each paragraph [6].

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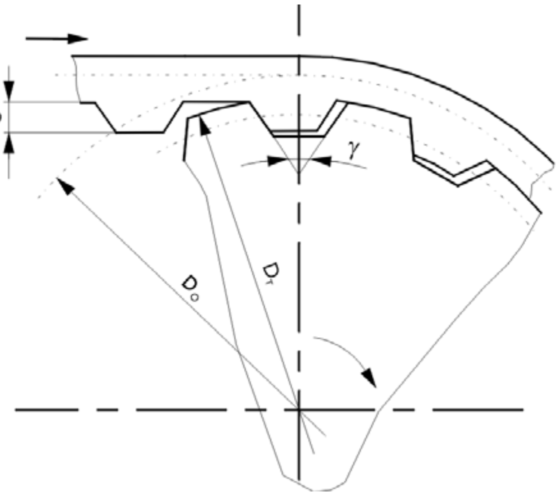

Figure 1. Layout of coupling between the belt and the drive belt pulley

Transfer of power and motion via timing belt is conducted by shape and by friction. During the power transfer, the belt's teeth enter the coupling with the pulley groove and thereat the lateral and radial plays appear (Fig. 1). During the contact between the belt and the belt pulley, there are the belt's motions in tangential, radial and axial direction.

The side surface of the belt's teeth makes contact with the side surface of the belt pulley's teeth, after entering the coupling. Besides, the inner surface of the belt groove and the outer surface of the belt pulley and, from time to time, the front surface of the belt pulley with the flange ring, are in contact. The belt's tooth enters the coupling with the drive belt pulley, maximally strained due to previous tension. During entering the coupling, the belt tooth's apex contacts the side surface of the belt pulley's tooth. In that moment, a line contact occurs. Due to interference, the belt's tooth cuts into the side surface of the belt pulley's tooth. Due to elastic properties of the belt and the large stiffness of the belt pulley, deformation of the belt's tooth occurs (Fig. 2, position 4). Deformation of the belt's tooth grows, while, at the same time, the contact surface between the belt and the belt pulley increases. The contact point between the belt's tooth and the belt pulley' tooth moves from the belt pulley's tooth apex towards its root.

Maximal tooth deformation takes place in position 2 (Fig. 2). The reduction of deformations occurs due to action of internal stresses and turning of the belt and the belt pulley. Full coincidence of the side surfaces of the belt's teeth and the belt pulley's teeth occurs in position 1 (Fig. 2). Now, contact over surface occurs. Relative sliding of their side surfaces, with appearance of the friction force, follows the process of belt's teeth entering the coupling with the belt pulley. The value of normal force varies according to parabolic law, which leads to variation of the friction force. The greatest values of normal force and friction force are at the teeth's roots.

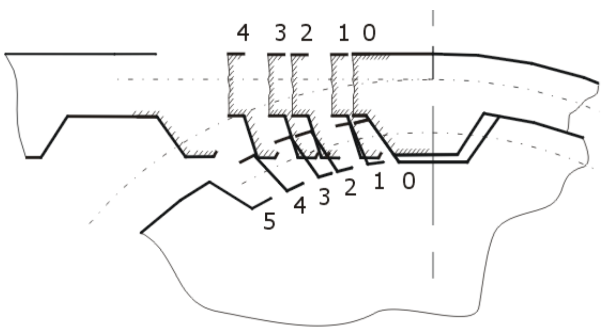

Figure 2. Layout of belt's teeth entering the coupling with the teeth of the drive belt pulley

Due to action of radial force, centrifugal force and air, additional radial motion of the belt occurs. Relative sliding of side surfaces of the belt's teeth and of the belt pulley's teeth occurs during this motion. Motion is followed by the appearance of the slide friction force with values less than values of the friction force that appears during the entering of the belt's teeth into the coupling with the belt pulley.

During the motion of the belt along the envelope angle of the belt pulley, bending and tension of the belt occur. In contrast to flat belts, where bending occurs along even curve, bending of timing belts is occurs along polygonal profile. Bending of the belt leads to internal losses, as well as to fatigue of the belt or the tractive element. Bending and tension of the belt along the envelope angle leads to the belt's deformation. Besides, the load of the belt's tooth decreases as the tooth enters the coupling with the belt pulley, until it comes out of the coupling. The first tooth in the coupling is the most loaded and the greatest deformations occur on it. Considering different teeth loads, uneven deformations of the belt's teeth occur along the envelope angle. Difference of deformations leads to relative motion of the belt in tangential direction. In addition, the belt enters the coupling with the belt pulley maximally strained and leaves it unloaded.

The influence of the axial force reflects in pressuring the belt towards the flange. Praxis has shown that the timing belts have the inclination to run into the flange or to slide off the belt pulley if there is no control. This is noticed especially in wide belts. In the case where the drives operate at high speeds or larger centre distances or if they are considerably pre-tensioned, there are larger pressures of the belts front surfaces on flanges. Friction forces arise in the contact and lead to wear of the belts endings. After several months of operation, only 80% or less of the belt's total width is utilized [7,8].

The basic tribomechanical systems in the timing belt drives are:

- belt's tooth – belt pulley's tooth
- belt's face – flange
- the belt groove – apex of the belt pulley's tooth

3. TESTING OF TIMING BELT DRIVE

Testing of timing belt drive is conducted on a test bench designed on purpose and made at the Laboratory for mechanical constructions an mechanization of the Faculty of mechanical engineering from Kragujevac. Test bench operates on a principle of opened loop power [3,9].

In order to obtain a true picture on tribological characteristics of the timing belt, measurement of roughness parameters and determination of geometrical values are conducted. Measurement of these values is conducted according to previously determined dynamics.

Before the tests began, the state of the contact surfaces and initial values of the belt's geometrical values were established. Further measurements were conducted after a certain operation time and are shown in Table 1.

Table 1. Time intervals of measurement of roughness parameters and belt's geometrical values

Number of measurement	1	2	3	4	5	6	7	8	9	10
Operation time [h]	0	5	10	20	50	100	150	200	250	300

4. MEASUREMENT OF GEOMETRICAL AND ROUGHNESS PARAMETERS

In addition to measurement of geometrical values, measurement of roughness parameters is conducted during testing of the timing belt.

Measurement of geometrical values of timing belts was conducted on eight belt's teeth. Measurement is conducted on optical microscope ZEISS ZKM01-250C. The following values were measured (Figure 3):

- belt's pitch (t),
- belt's width (b),
- groove's thickness $(h_b = h_s - h_t)$ and
- belt's total height (h_s).

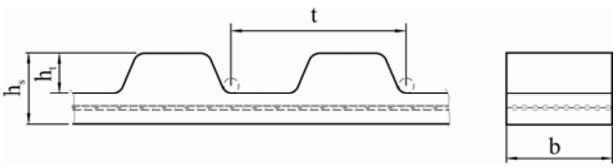

Figure 3. Measured geometrical values of the belt

The following roughness parameters are especially interesting for further analysis:

R_a - mean arithmetic deviation of profile from midline of the profile and

R_{max} - maximal height of roughness along reference length.

Measurement of roughness parameters is performed on three measuring points (Figure 4):

- at the apex of the belt's tooth - 1,
- at the flank of the belt's tooth - 2 and
- at the space between belt's teeth - 3.

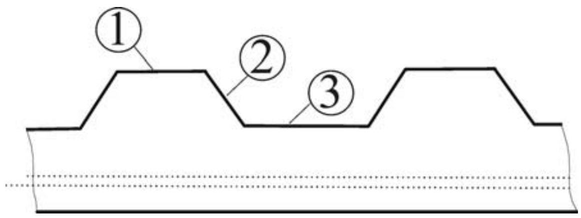

Figure 4. Measuring points on the belt for measurement of roughness parameters

Average values of variation of geometrical values are presented in Figure 5. Measurement of roughness parameters of the belt's tooth was conducted before the device started to operate and during the testing, according to previously determined dynamics. Measurements were conducted on four teeth. Results obtained by measurement are given in Table 2-4 and Figures 6-11.

For better clearness of the graphics, without a change of the analysis essence, the results for two belt's teeth are presented in the following table and diagrams. The results obtained for other two teeth are quite close to given values. This match of the results meets the expected image of tribological processes on contact surfaces of the belt's teeth.

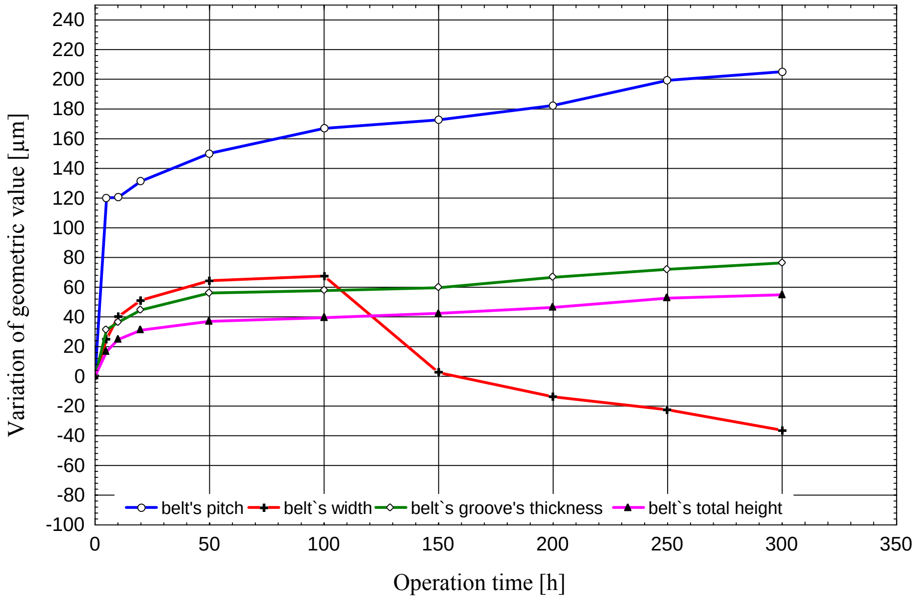

Figure 5. Average values of variations of geometric values

Table 2. Roughness parameters (R_a, R_{max}) at the apex of the belt's tooth

Belt tooth	Roughness parameter	Operation time [h]									
		0	5	10	20	50	100	150	200	250	300
1	R_a $[\mu m]$	4.7	7.9	5.8	8.1	5.3	4.5	4.4	4.2	4.1	3.9
	R_{max} $[\mu m]$	59	72	67	69	53	48	43	40	38	35
2	R_a $[\mu m]$	5.9	5.8	5.9	7.1	6.3	5.2	4.7	4.6	4.3	4.1
	R_{max} $[\mu m]$	53	61	54	74	69	57	53	50	48	40

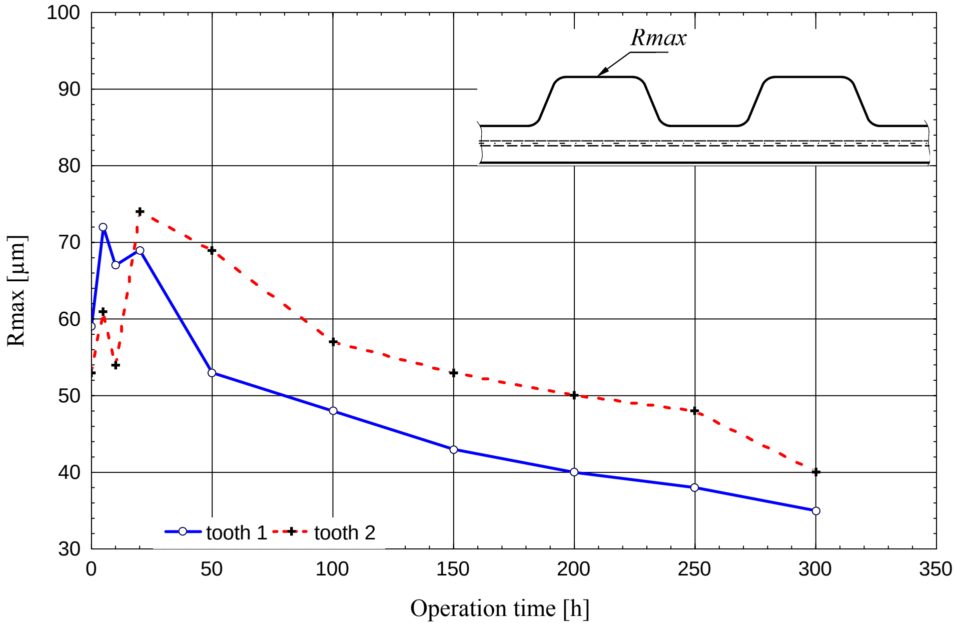

Figure 6. Change R_{max} at the apex of the belt's tooth during operation

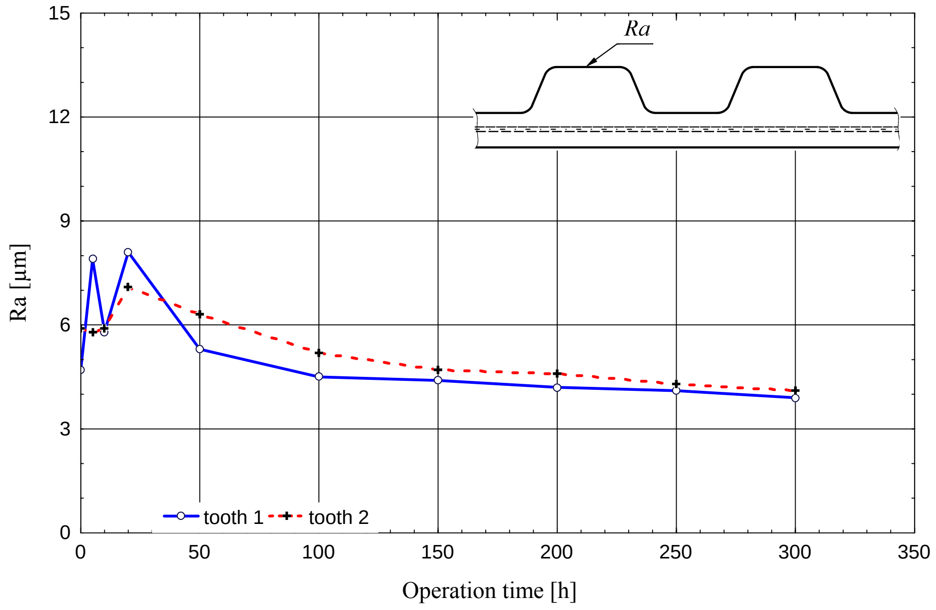

Figure 7. Change R_a at the apex of the belt's tooth during operation

Table 3. Roughness parameters (R_a, R_{max}) at the flank of the belt's tooth

Belt tooth	Roughness parameter	Operation time [h]									
		0	5	10	20	50	100	150	200	250	300
1	R_a $[\mu m]$	9.33	11.2	8.9	8.3	11.57	9.0	9.2	6.4	5.0	4.8
	$R_{\max}$ $[\mu m]$	74.6	69	80	72	86.4	75	64	41	35	32
2	R_a $[\mu m]$	12.42	6.9	11.6	6.6	8.7	10.8	7.9	7.0	4.7	4.4
	$R_{\max}$ $[\mu m]$	105.9	58	93	69	67.4	68	57	41	40	35

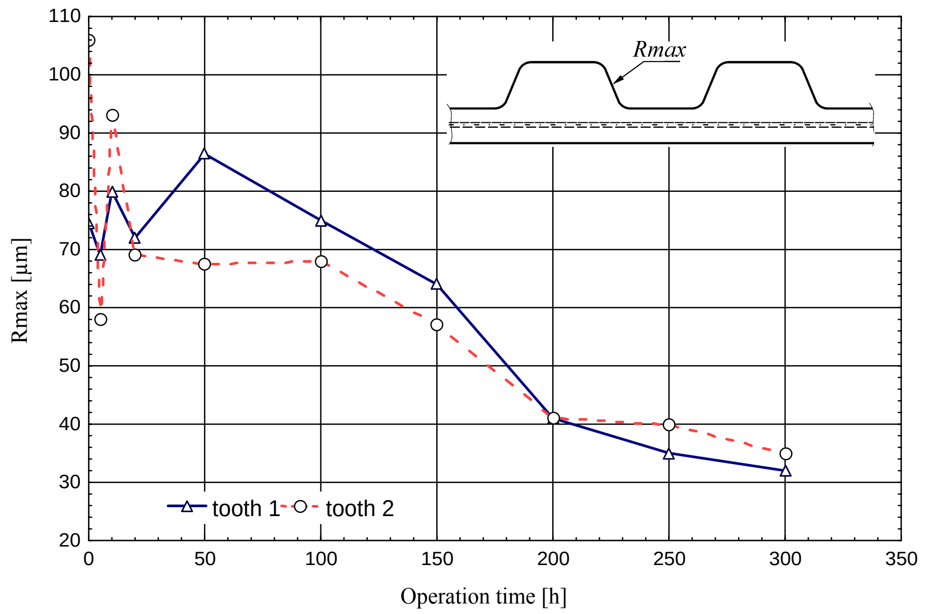

Figure 8. Change of R_{max} at the flank of the belt's tooth during operation

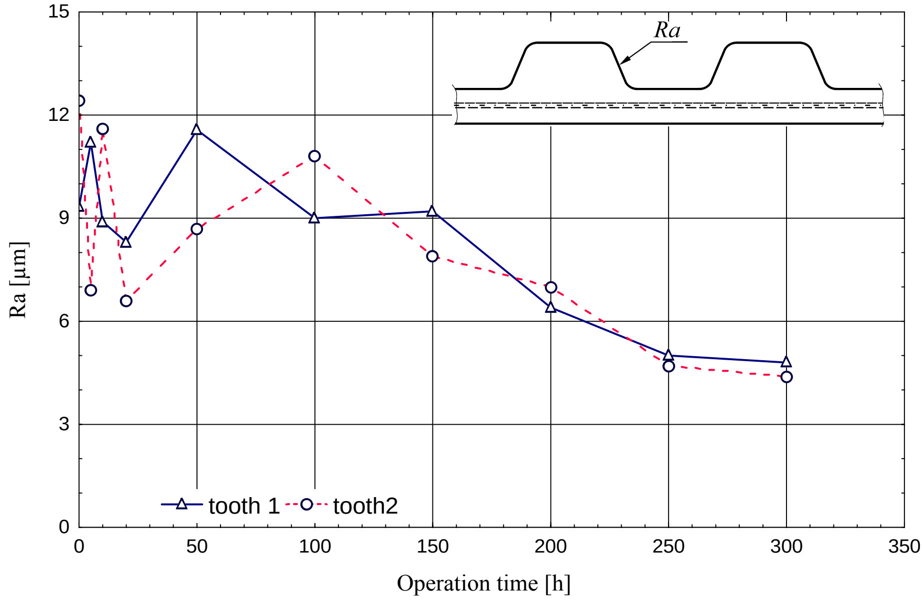

Figure 9. Change of R_a at the flank of the belt's tooth during operation

Table 4. Roughness parameters (R_a, R_{max}) at the space between belt's teeth

Belt tooth	Roughness parameter	Operation time [h]									
		0	5	10	20	50	100	150	200	250	300
1	R_a $[\mu m]$	4.56	3.4	3.0	4.7	4.5	4.3	4.1	3.9	3.7	3.5
	R_{max} $[\mu m]$	46.2	43	35	55	54	45	43	43	40	38
2	R_a $[\mu m]$	4.63	3.7	3.9	4.8	4.5	4.4	4.4	4.2	4.0	3.8
	R_{max} $[\mu m]$	47.5	44	46	58	50	48	42	39	37	35

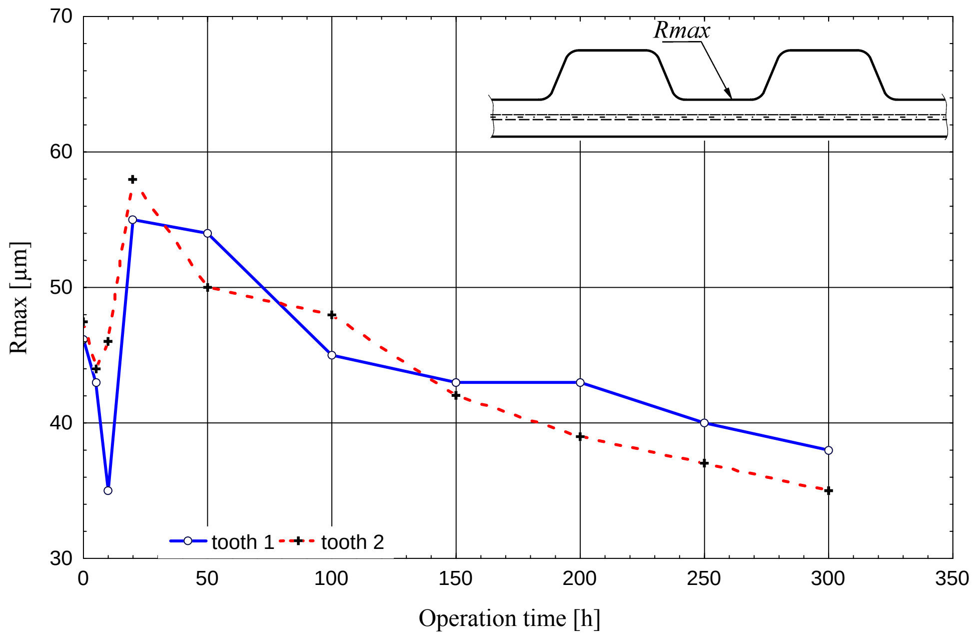

Figure 10. Change of R_{max} at the space between belt's teeth during operation

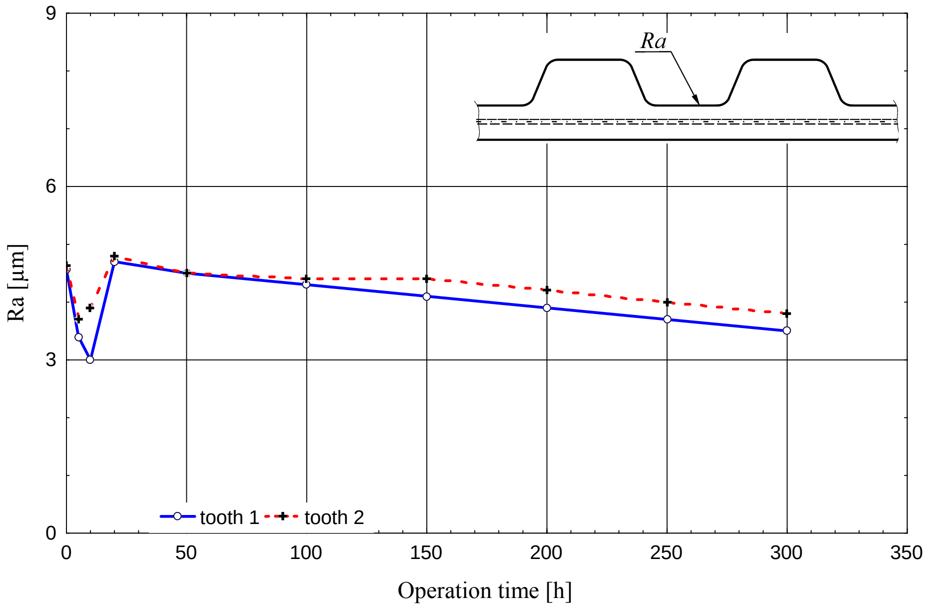

Figure 11. Change of R_a at the space between belt's teeth during operation

5. ANALYSIS OF OBTAINED RESULTS

By monitoring the roughness parameters in the period of working out, their decrease after 5 hours of operation may be noticed. Then topography is changed due to transition from technological to exploitation topography. Already in the next phase of the period of working out (5 to 10 hours of operation), monitored roughness parameters increase. In the first 5 hours of operation, the highest roughness peaks are being flattened, so the profile gets more even. However, in the next 5 hours, roller wear already occurs, that is rollers at the belt's tooth are generated. Part of material leaves the belt and then topology of the contact surface is changed, that is roughness parameters grow. Due to this specific form of wear that is characteristic for non-metals, roughness parameters have stochastic variation all the time.

In the period of normal wear which appears after 20 hours of operation, variation of geometrical values is still strong. After 20 hours of operation, the belt's pitch is still increasing. Variation of the belt's pitch is more pronounced in the period from 20 to 50 hours of operation, after which it becomes approximately linear. The results obtained by measurement on all eight teeth almost do not deviate one from another. Absolute average values of variation of geometrical values are presented in figure 12.

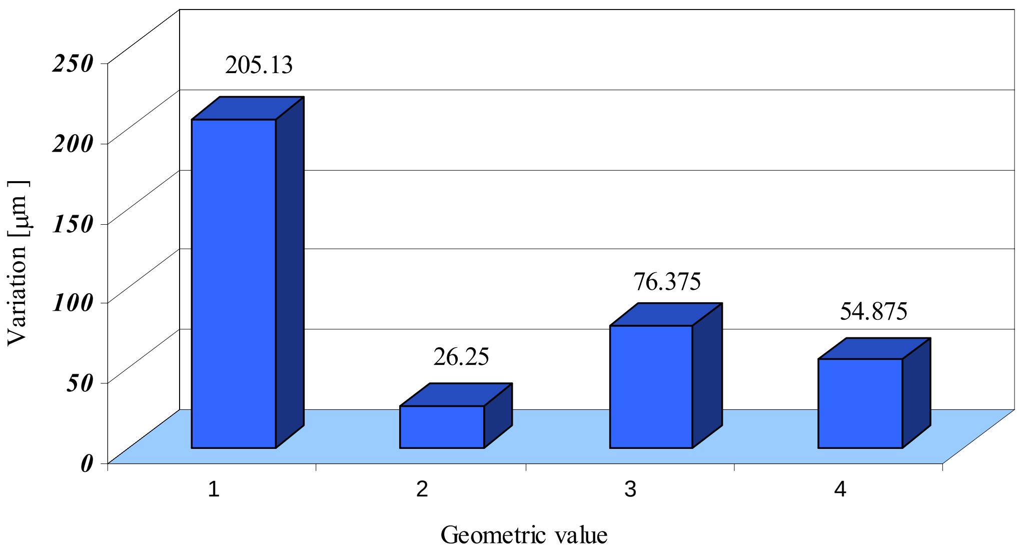

Figure 12. Average values of variations of geometric values
1 - Belt' pitch; 2 - Belt's width; 3 - Belt's total height; 4 - Belt groove's thickness

6. CONCLUSION

Initial contact between the belt and the belt pulley in the period of the beginning of the coupling, starts with the contact of the side surfaces, but also with special kind of belt's tooth interference which cuts into the side surface of the belt pulley's teeth. Due to the belt's elasticity and the large stiffness of the belt pulley, the initial contact is followed by the belt's teeth deformation. Turning of the belt pulley moves the contact surface from the tooth's tip towards its root, whereat the period of entering into the coupling is followed by relative sliding between the side surfaces of the belt's teeth and the belt pulley's teeth, that is by occurrence of the slide friction.

By analysis of wear curves obtained by measurement of geometrical quantities, certain dependence may be noticed. Namely, pitch, height and thickness of the belt's groove change according the similar laws. In the starting period or the period of working out, the changes of considered quantities are the greatest. Continual growth of their changes, but in smaller amounts, appears in the period of normal wear. Only the change of the belt's width has different change, conditioned by design of the belt and by appearance of wear on face surface of the belt.

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