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WEAR OF TIMING BELT DRIVES

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ABSTRACT

The timing belt drives are synchronous drives that transmit power and motion via side surfaces of belt teeth and, partially, through friction between belt teeth and belt pulley teeth. Failure of the timing belt drives occurs due to wear of its components. Analysis of process of friction, as a main cause of wear, is conducted based on coupling kinematics. During exploitation, changes of the basic geometrical values of the timing belt occur. Changes that appear are direct consequence of friction on the contact surfaces that manifests itself through abrasion and roller wear. Change of some values leads to the reduction of nominal contact surface, which, consequently, leads to larger teeth loads, unevenness of operation, reduction of efficiency, reduction of the carrying capacity and shorter operation time due to failure.

Keywords: timing belt drive, wear, testing, geometrical values.

AIMS AND BACKGROUND

The timing belt drives are relatively new concept of power transmission, which originated in 1950's. (Refs 1 and 2). Transmission of power and motion with the timing belt is done by shape and friction. During the contact between the teeth of the belt and the belt pulley, movement of the belt in tangential, radial and axial direction occurs. These movements arise due to torque, circumferential force, pre-extension, radial force, centrifugal force, air, deformation of the belt due to bending and extension, design of the belt, the driving element and the belt pulley, accuracy of manufacture and assembly, quality of machining of the contact surfaces, etc.[3]

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The side surface of the belt teeth makes contact with the side surface of the belt pulley teeth, after entering the coupling. Besides, the inner surface of the space between the teeth of the belt 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.

Transmission of power by the timing belt has a series of good qualities: small mass, small sliding, inexpensive maintenance, easy replacement, high efficiency, low noise levels, etc. Nevertheless, the main shortcoming of the timing belts is their great sensitivity to irruption of a foreign body and sensitivity to oils, solvents and high temperatures.

Considering the larger and larger use of the timing belt drives and their limited working life, the analysis of friction and wear has become more important since the end of the 1990's. Childs, Dalgarno et al. are engaged in analyses of coupling and tribological processes on contact surfaces[4,5]. Failure of the timing belts occurs due to damage of the belt teeth or the driving element[6]. Apart from abrasion, fatigue wear is the main cause of reduction of the working life of the timing belt drives.

EXPERIMENTAL

Testing of timing belt drive was conducted on a test bench designed and made at the Laboratory for mechanical constructions and mechanisation of the Faculty of mechanical engineering from Kragujevac. Test bench operates on a principle of opened loop power[2,3].

Basic elements of the test bench are:

(1) drive unit (electric motor),
(2) cardanic drive,
(3) measuring (input) shaft,
(4) input shaft rotational speed transducer,
(5) input shaft torque transducer,
(6) tested drive (timing belt drive),
(7) output shaft,
(8) mechanical brake,
(9) tension mechanism and
(10) amplifier bridge.

Figure 1 shows the test bench with basic elements.

In order to obtain a true picture on tribological characteristics of the timing belt, measurement of roughness parameters and determination of geometrical values were conducted (Ref. 1). Measurement of these values was conducted according to previously determined dynamics.

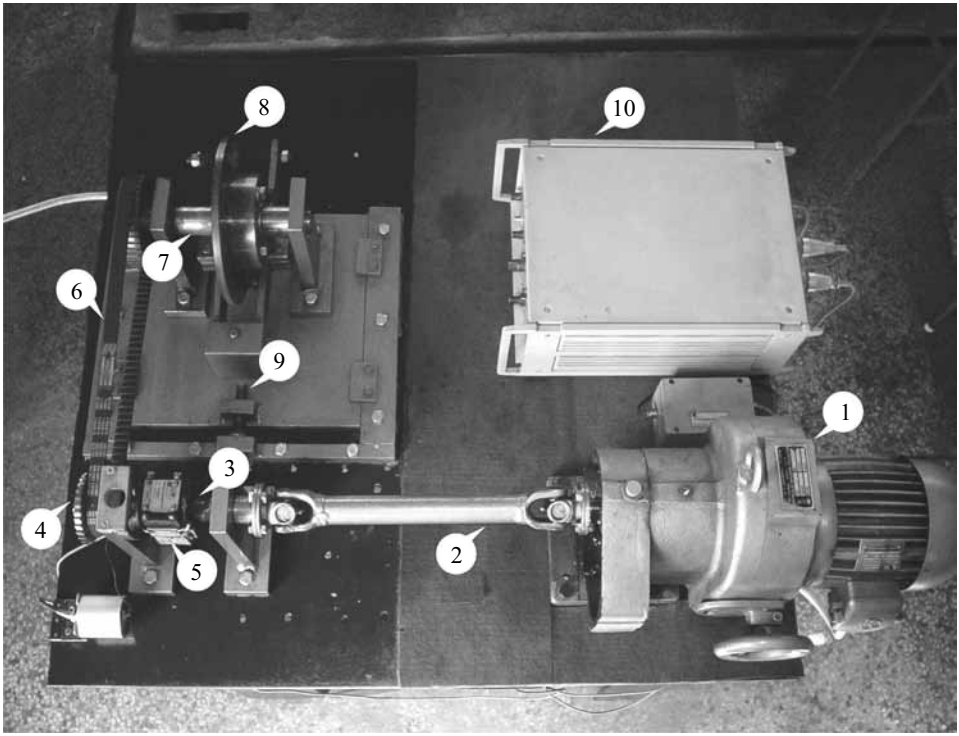

Fig. 1. Test bench for testing of timing belt

Table 1. Time intervals of measurement of roughness parameters and belt 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

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

RESULTS AND DISCUSSION

Measurement of geometrical values of timing belts was conducted on 8 belt teeth. The following values were measured (Fig. 2) (Ref. 7):

- belt pitch (t),
- belt width (b),
- belt groove thickness ($h_b = h_s - h_t$) and
- belt total height h_s.

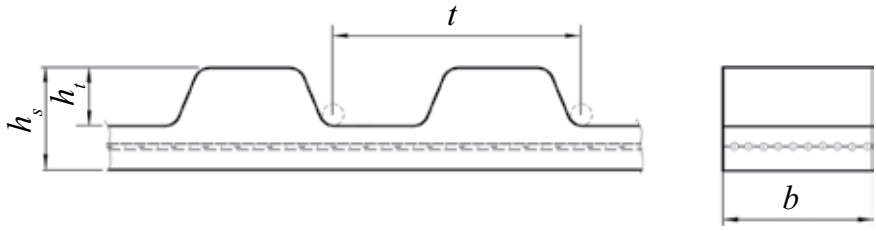

Fig. 2. Measured geometrical values of the belt

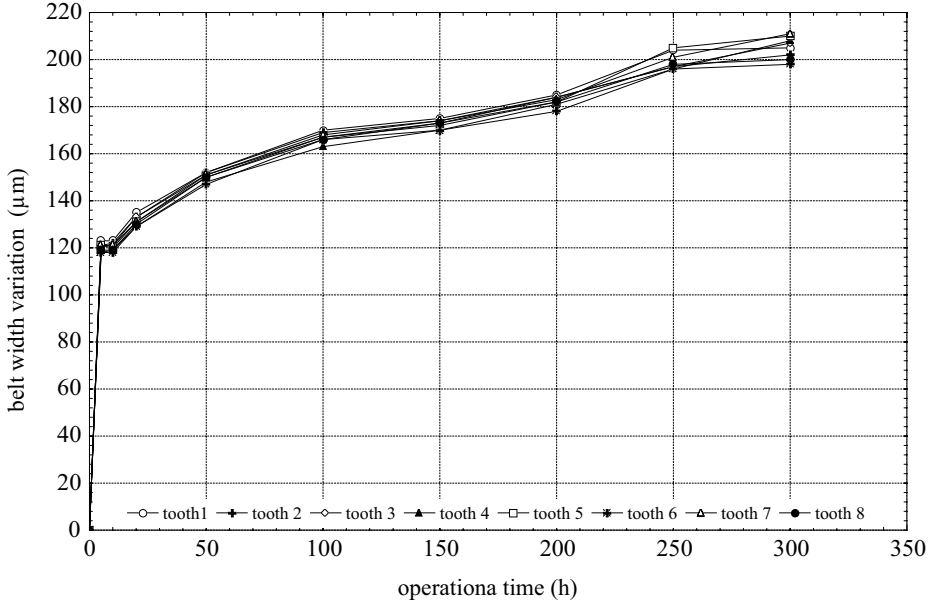

Fig 3. Belt pitch variation during exploitation

The following diagrams show variation of the mentioned values during the testing (Figs 3–6).

In the period of working out, there is a sudden increase of belt pitch. This increase originates from plastic deformation of the belt and from wear of teeth flanks. Roller wear (a special form of elastomeric wear) is specially emphasised there and the consequences are removal of material from belt teeth and increase of pitch. Roller wear appears at the apex and at the side of the belt tooth. Value of the friction force at the side of the tooth is many times higher than value of the friction force at the apex of the belt tooth, which has a consequence in the form of larger roller wear of the side of the belt tooth. In addition to roller wear, abrasive wear appears in the period of working out. Due to resulting plastic deformations, an increase in belt width and reduction in belt height appear.

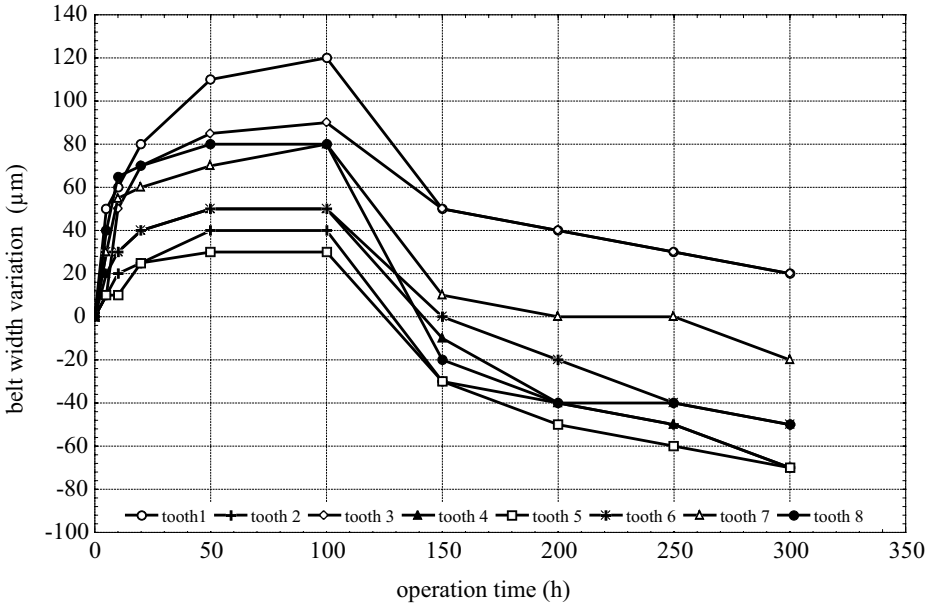

Fig. 4. Belt width variation during exploitation

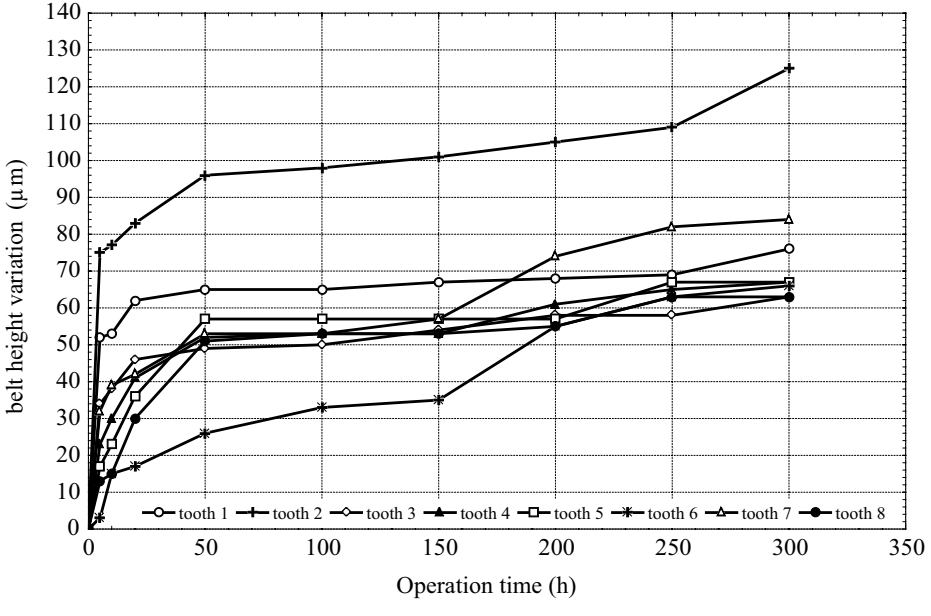

Fig 5. Belt height variation during exploitation

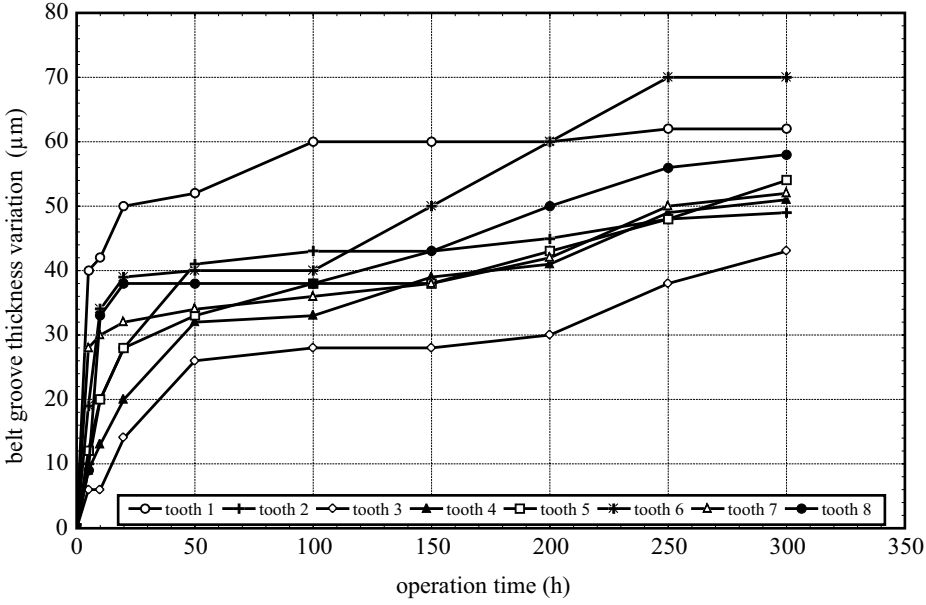

Fig 6. Belt groove thickness variation during exploitation

In the period of normal wear, which appears after 20 h of operation, variation of geometrical values is still strong. After 20 h of operation, the belt pitch is still increasing. Variation of the belt pitch is more pronounced in the period from 20 to 50 h of operation, after which it becomes approximately linear. The results obtained by measurement on all 8 teeth almost do not deviate one from another.

The belt tooth height continues to reduce in the period of normal wear. In the period between 20 to 50 h, this change is apparent. After 50 h of work until 200 h, there is no major change in height of most of the teeth. The largest plastic deformations occur in the period of working out. Considering that these deformations are small in the period of normal wear and that roller wear of teeth apices is not so distinguished, the teeth height slightly changes. After 200 h of work, variation of height appears again on all teeth.

Change of teeth groove has similar dependence as the previous two values. The largest change appears in the period between 20 to 50 h and it remains slight until the end.

The belt width changes most significantly during exploitation. The belt width increases even after the period of working out, which is approximately 20 h until 100 h of drive operation. The increase of the belt width in this period occurs due to plastic deformation of the belt. Measurement of geometrical values after 150 h of work shows rapid change of the belt width, while the other values have constant change. Results of measurements show that the belt width reduces. The abrupt reduction of the belt width (between 100 and 150 h of work) has appeared due to

contact between the belt and the flange. During this contact, abrasive wear of face surfaces of the belt appear. The drive belt pulley of the tested timing belt drive was manufactured with the flange.

The axial motion of the belt may have occurred due to inadequate assembly, poor straining, large deviations of speed, decrease of braking torque or its sudden increase. Between 150 and 300 h of work, the belt width continues to decrease, but this decrease is continual and applies to all teeth.

Absolute average values of variation of geometrical values are presented in Fig. 7.

The histogram shows that the belt pitch changes most significantly (Refs 8 and 9). The belt pitch increases for approximately 0.2 mm, which leads to the increase of the belt length. Total elongation of the belt is approximately 23 mm. Large portion of this elongation is due to plastic deformation of the belt, which is the elongation of tractive element. However, wear of side surfaces of teeth provokes 30% of variation of belt pitch. Elongation of pitch is the greatest in the period of working out and amounts to approximately 60% of total elongation. During this period, mostly plastic deformations occur. At the end of the period of working out and during period of normal wear, the belt pitch changes mostly due to roller wear of teeth side surfaces.

Acquired mean values of changes of geometrical values do not deviate much from individual values of every tooth for pitch, total belt height and groove thickness. Nevertheless, mean value of the belt width deviates from individual values. This deviation is a consequence of the belt design. Namely, the belt having certain width is obtained by cutting from a reel of corresponding length. It has been no-

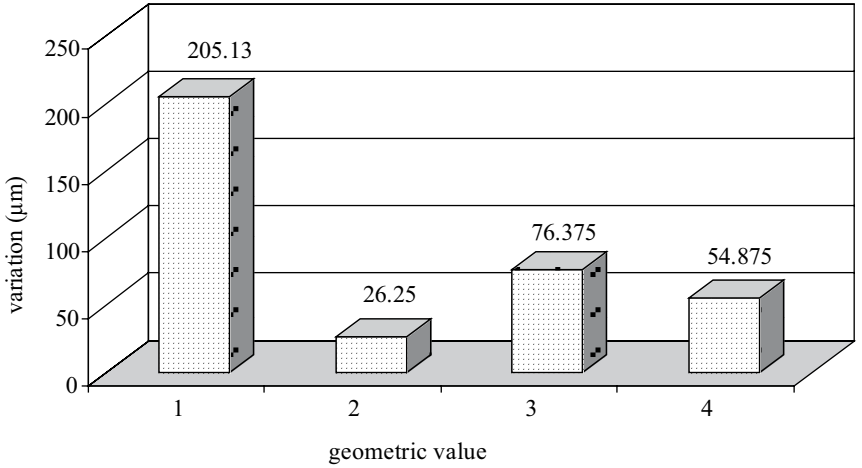

Fig. 7. Average values of variations of geometric values
1 – belt pitch; 2 – belt width; 3 – belt total height; 4 – belt groove thickness

ticed that the variations of initial width are in corresponding tolerances, but the belt does not have equal width everywhere. The driving element is noticeable on some face surfaces. Appearance of the drive element changes the nature of the tribomechanical system the belt face – flange, because two metal surfaces are then in contact. The belt width changes depending on whether there is metal–metal or metal–nonmetal contact. Besides, the low of change of the belt width deviates from other changes. The belt width considerably changes if absolute values of deformations are summed. Namely, the belt firstly expands and then, after 100 h of operation, the width reduces. Due to this phenomenon, mean value of the belt width change has relatively small value. It is obvious that the belt width reduces in the period between 100 to 300 h of operation, due to abrasive wear of face surfaces of the belt, which confirms the analysis of tribomechanical system the belt face – flange. Mean value of the belt width change after 100 h of work is 110 μm and it has the greatest value, beside the change of the belt pitch.

Figure 8 shows relative changes of measured geometrical values expressed in percents. These values are gained by dividing the mean values of changes with the mean values of measured quantities.

By further analysis of these values, it may be concluded that not all quantities change according to the same law. Nevertheless, if further observed, it may be noticed that the total belt height changes considerably more than the belt groove thickness. This leads to reduction of active height of belt tooth that is in contact with the belt pulley tooth. If we take into consideration that, after 150 h of work, the belt width also decreases, we come to conclusion that the nominal side surface of the belt tooth decreases, too. Considering that timing belt drives transmit the

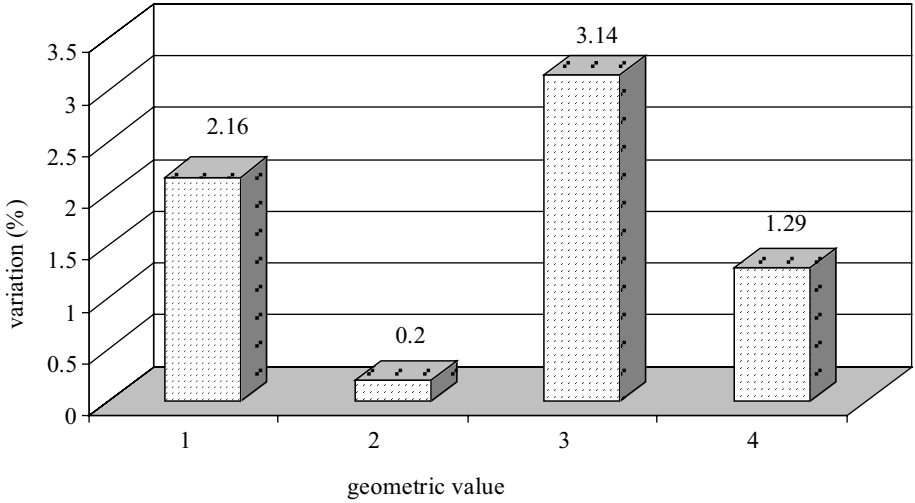

Fig. 8. Relative changes of measured geometrical values
1 – belt pitch; *2* – belt width; *3* – total belt height; *4* – belt groove thickness

power by shape and friction, the increase of the belt pitch and reduction of nominal tooth surface may lead to disturbance in drive operation.

CONCLUSIONS

The analysis of the obtained results shows that phenomenon of roller wear of the tooth apex and side is especially distinguished in timing belts. Roller wear of the tooth side is larger than roller wear of the tooth apex, due to specific features of tribomechanical system the belt tooth – the belt pulleys tooth. Namely, the coupling between the belt tooth and the belt pulley tooth begins with an impact of the belt tooth onto the belt pulley tooth. After that, there comes the sliding of the belt tooth along the side surface of the belt pulley tooth, while there appears sliding friction with rolling. Value of this friction force is the largest compared to friction forces in other tribomechanical systems. In addition to roller wear, abrasive wear appears in timing belt face surface. These two types of wear are dominant.

By analysis of wear curves obtained by measurement of geometrical quantities, certain dependence may be noticed. Namely, pitch, height and thickness of the belt 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 width has different change, conditioned by design of the belt and by appearance of wear on face surface of the belt.

REFERENCES

1. B. STOJANOVIC, S. TANASIJEVIC, N. MILORADOVIC: Tribomechanical Systems in Timing Belt Drives. J. of the Balkan Tribological Association, **15** (4), 465 (2009).
2. B. STOJANOVIC, N. MILORADOVIC, M. BLAGOJEVIC: Analysis of Tribological Processes at Timing Belt Tooth Flank. Tribology in Industry, **31** (3&4), 53 (2009).
3. B. STOJANOVIC, L. IVANOVIC, M. BLAGOJEVIC: Friction and Wear in Timing Belt Drives. Tribology in Industry, **32** (4), 33(2010).
4. T. H. C. CHILDS, M. H. HOJJATI, M. KOHNO, T. NAKAMURA: Land Friction Effects in the Meshing of Timing Belts. In: Proc. Instn Mech. Engrs, Part J. J. of Engineering Tribology, **212**, 87 (1998).
5. K. W. DALGARNO, A. J. DAY, T. H. C. CHILDS, R. B. MOORE: Stiffness Loss of Synchronous Belts. Composites, Part B, Engng J., **29B**, 217 (1998).
6. H. IIZUKA, K. WATANABE, S. MASHIMO: Observation of Fatigue Failure in Synchronous Belts. Fatigue Fracture Engng Mater. Structs., **17,** 783(1994).
7. ISO 5296-1 (1989) Synchronous Belt Drives – Belts. PART 1: Pitch codes MXL, XL, L, H, XH and XXH – Metric and inch dimensions. International Organization for Standardization, Geneva.
8. B. STOJANOVIC, S. TANASIJEVIC, N. MARJANOVIC, L. IVANOVIC, M. BLAGOJEVIC: Wear as the Criterion of Mechanical Transmitters Working Life. J. of the Balkan Tribological Association, **17**, (2011) (in press).
9. B. STOJANOVIC, N. MILORADOVIC, N. MARJANOVIC, M. BLAGOJEVIC, L. IVANOVIC: Length Variation of Toothed Belt During Exploitation. J. of Mechanical Engineering, (2011) (in press).

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