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FAILURE ANALYSIS OF THE TIMING BELT DRIVES

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Abstract: *This paper refers to testing of timing belt drives. Timing belt drives are relatively young drives that originate from 1950's. Considering the larger and larger use of timing belts and their limited lifetime, their testing is justified. A large number of factors have influence on timing belt drive's lifetime: wear, amount of transmitted power, operating environment, coaxiality of shafts and belt pulleys, handling before and during assembly and others. Failure most frequently occurs because of damage of belt's and belt pulley's teeth or damage of tractive element due to wear. The paper presents the results of experimental testing of wear and failure of timing belt drives originating from change in their geometrical dimensions. Gained experimental results fully coincide with theoretical assumptions and similar tests around the world.*

Keywords: *wear, failure analysis, timing belt drive, friction*

1. INTRODUCTION

Timing belt drive is relatively new conception of power transfer, accepted in all areas of industry today. They are flat belts with series of equal spatial teeth inside addendum diameter.Timing belt transfers the torque by means of its shape. The teeth, equally spaced at inner side of timing belts, contact the belt pulley's teeth with their hollows between teeth and, thus, by conjugate gear action, achieve the meshing between the belt and the belt pulley and transfer the torque.

Considering their purpose and very important role in transmission of power and motion, it is necessary to adequately know tribological characteristics of timing belt drives.

In spite of advantages in operation, timing belt drives have only recently achieved great application. It was yet after their application as IC engine's camshaft drive, that their purposefulness of application had become obvious. Popularity of timing belts in automotive industry has accelerated their use in other branches of industry [1-5].

2. FAILURE OF TIMING BELT DRIVE

A large number of factors have influence on the working life of the timing belt drives:

- friction and wear in the belt - belt pulley contact,
- the belt's tension,
- coaxiality of the shaft and the belt pulley,
- working environment and
- other.

2.1 Influence of friction and wear

Basic tribomechanical systems in timing belt drive are: belt's tooth - belt pulley's tooth (1), belt's face – flange (2), space between teeth of the belt – apex of the belt pulley's tooth (3) (Figure 1). Analysis of these tribomechanical systems shows that the influence of the friction forces that occur in them may not be neglected and directly influences the power and motion transmission and working life of the drive [3,6].

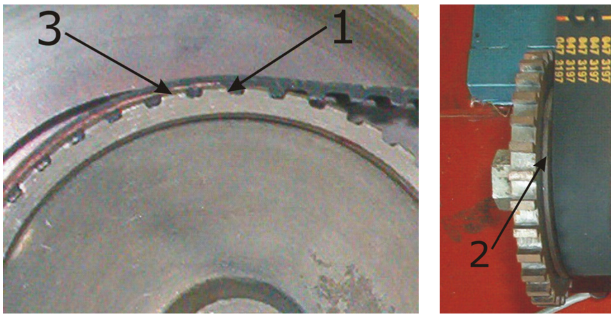

Figure 1. Timing belt drive and basic tribomechanical systems

Values of the friction force are different for all three analyzed tribomechanical systems. Friction force has the largest values at the side surface of the belt's and the belt pulley's teeth. Friction force has somewhat smaller values between belt's face surface and flange, while the lowest values are between the apex of the belt pulley's teeth and the space between belt's teeth. Direction, sense and intensity of these forces are related to kinematics of couplings in timing belt drives.

2.2 Influence of the belt's tension

The belt's tension has an important part in design of the timing belt drive. Proper belt's tension provides normal coupling between the belt and the belt pulley, minimal losses in the drive, smaller wear in bearings and smooth operation of the drive. The belt should be pretensioned according to the producer's recommendations. Checking of the belt's tension is done by tensiometer. Inadequate belt's tension reflects as insufficient or exaggerated belt's tension.

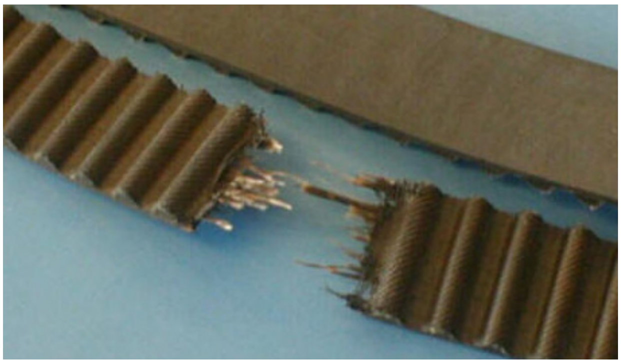

Figure 2. Cracking of the drive element

Exaggerated tension of the belt leads to increase of power losses at idle speed and reduces the efficiency. In addition, if the belt is over-tensioned, drive element's fibres are additionally loaded in view of their strength, which leads to sooner cracking of the drive element (Figure 2). Increase in belt's tension directly influences the kinematics of coupling between the belt and the belt pulley. Hence, cracks appear in the belt's tooth root on the side, which is in contact with the belt pulley's tooth.

The crack in the root of the firstly loaded tooth spreads towards the apex of the tooth and leads to its shearing (cracking) (Figure 3). Besides, the teeth's contact surface decreases, which additionally loads neighbouring teeth on which the cracks in the roots have appeared. Due to over-tension, there is more intensive wear of the belt's surface layer, until the driving element becomes visible.

Over-tension, as well as insufficient tension of the belt, may lead to too early failure of the timing belt drive.

Figure 3. Crack in the belt tooth root

Namely, when the power transmitted by the timing belt is rather large, there may be teeth skipping during operation of the loose belts. Insufficient tension reduces the contact surface between the belt and the belt pulley, which increases the pressure on the teeth surface. Due to large pressure jump, there appear the cutting off of larger number of the belt's teeth and the belt's failure (Figure 4).

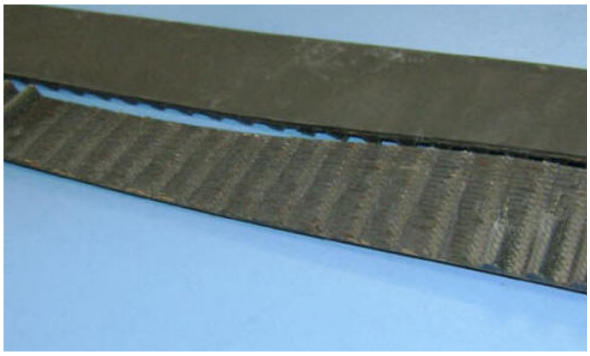

Figure 4. Cutting off of larger number of the belt's teeth

2.3 Coaxiality of the shaft and the belt pulley

Coaxiality of the shaft and the belt pulley has a great influence on the working life of the timing belt drive. If there is no angular coincidence of the axes of the drive's shafts, then the contact surface area between the belt's teeth and the belt pulley's teeth reduces. One side of the tooth is more loaded than the other. This load may lead to appearance of intensive wear of the belt and the belt pulley and to rapid damage or failure of the belt.

Another problem due to lack of coaxiality is related to the belt pulley's design. Namely, if the belt pulleys are manufactured with flanges, then one face of the belt is loaded more. Due to lack of coaxiality, the face surface is firmly leaned against the flange and then there comes the abrupt damage of the face surface of the belt (Figure 5). These damages spread towards the centre of the belt, reduce the contact surface, additionally load the nearby teeth and lead to rapid failure of the belt.

Due to lack of coaxiality of the shafts, there appear the increase of unevenness of drive's operation, increase of noise and vibration and even the falling off of the belt from the belt pulley.

The belt's damage also appears due to the belt pulley, which dimensions deviate from design documentation. If diameters of the belt pulleys or teeth are not manufactured with corresponding tolerances, large damage of the belt appears. These deviations lead to damage of protective surface layer of the belt. Damage appears in all directions, they are not distinctive and they look undefined.

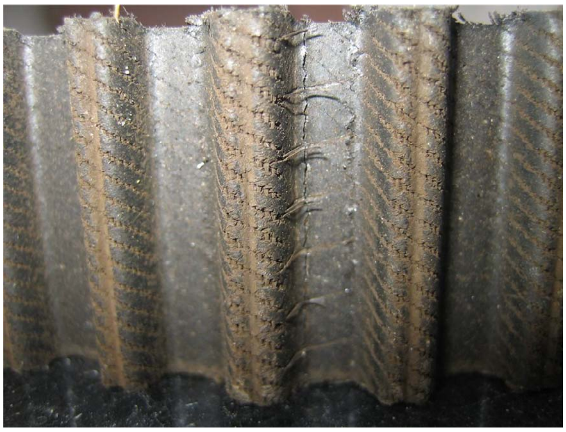

Figure 5. Damage of the face surface of the belt

The increased wear of the belt pulley appears due to over-tension of the belt. Intensive wear of the belt additionally loads the belt pulley's teeth, directly leaving the trace on the belt pulley. Due to extensive wear, the drive element becomes visible and then there is a metal-on-metal contact, which may lead to abrasion and rapid damage of the belt pulley.

2.4 Influence of the environment

The timing belts are especially sensitive to high temperatures, action of chemical compounds and foreign bodies. Materials used for making of the belts are rubber, urethane (polyurethane), neoprene and similar that are more or less not resistant to high temperatures. When rubber belts work at high temperatures for a long period, rubber compounds gradually harden, losing their features. The cracks appear at the back surface of the belt, parallel to space between teeth of the belt. These cracks lead to the cutting off of teeth and to cracking of the drive element.

At urethane and polyurethane belts, the structure, form and shape of teeth change under the effect of temperature and this leads to failure of the belt drive.

Materials of the timing belts are highly sensitive to oils and solvents. There is a large number of chemicals that may come into contact with the belt (antifreeze, fuel, lubricant and similar). Under the action of chemical solvents, the belt reacts similarly as under the action of high temperatures. Rubber compounds harden and the back surface cracks (Figure 6).

Figure 6. Influence of the oil and solvents on belt

The timing belt drives are highly sensitive to the presence of foreign bodies between the belt and the belt pulley. The presence of such bodies leads to heavy damage of the belt, especially the drive element. As soon as the part of the drive element is damaged, the rest is additionally loaded which leads to rapid failure of the belt. Action of the foreign bodies lead to damage of the belt pulley in the form of cuts and scratches, so replacement of the belt pulley is necessary.

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 [7-10]. Test bench operates on a principle of opened loop power.

Basic elements of the test bench are:

1. drive unit (electric motor),
2. cardanic drive,
3. measuring (input) shaft,
4. input shaft's rotational speed transducer,
5. input shaft's torque transducer,
6. tested drive (timing belt drive),
7. output shaft,
8. mechanical brake,

9. tension mechanism and

10. amplifier bridge.

Figure 7 shows the test bench with basic elements.

Mechanical brake provides a given amount of brake torque that is load torque on output shaft of the timing belt drive. Value of the load torque is obtained by readout of a display of digital amplifier bridge which obtains the torque signal from a measuring shaft, through signal preamplifier HBM EV2510A. Rotational speed of input shaft is also read on the amplifier bridge which obtains the signal through inductive sensor and impulse signal receiver of number of revolutions, HBM DV2556. Thus, regime at the input shaft of the driver is defined [10,11].

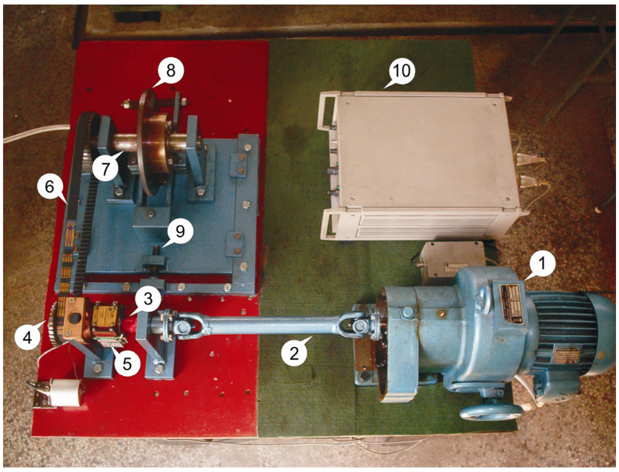

Figure 7. Test bench for testing of timing belt

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.

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

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.

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 8):

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

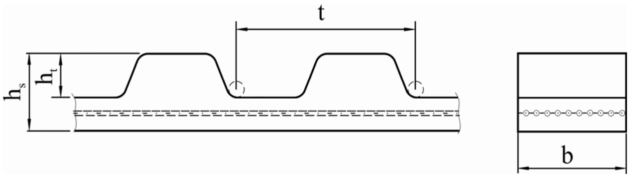

Figure 8. Measured geometrical values of the belt

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 9):

- 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.

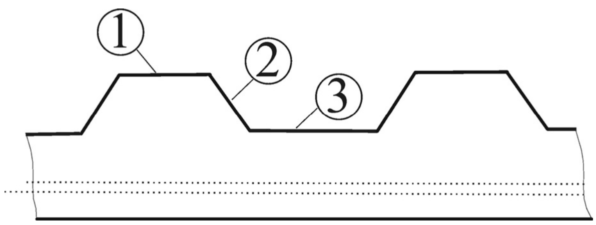

Figure 9. Measuring points on the belt for measurement of roughness parameters

Average values of variation of geometrical values are presented in Figure 10 [9-11].

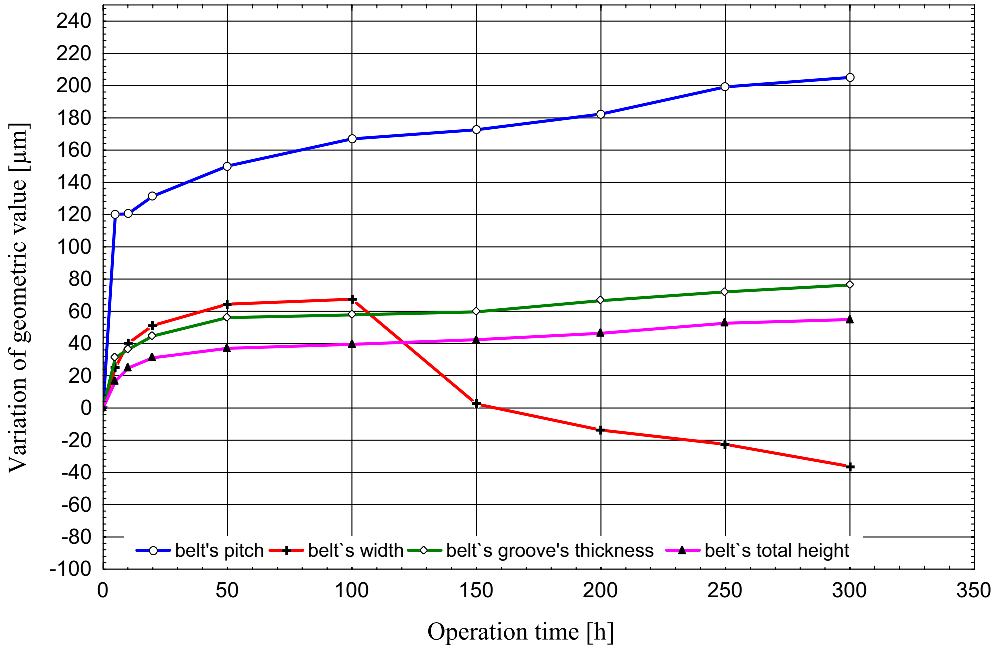

Figure 10. Average values of variations of geometric values

5. ANALYSIS OF THE OBTAINED RESULT

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.

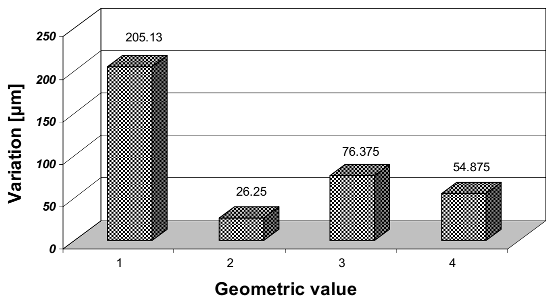

Figure 11. Average values of variations of geometric values

1 - belt' pitch
2 - belt's width
3 - belt's total height
4 - belt groove's thickness

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 11.

6. CONCLUSION

Worn-out belt pulley's teeth induce rearrangement of loads where teeth entering and exiting the coupling have maximal loads. Due to wear of the belt pulley's teeth, nominal contact surface between the belt's teeth and the belt pulley's teeth is reduced. The contact pressure increases, which is the greatest in the belt teeth's groove, according to load distribution along the side surface of the belt's tooth. It all together leads to appearance of the crack in the belts tooth root, which results in separation and cutting off of the teeth. In that case, it is necessary to replace both the belt and the damaged belt pulley.

Reliable and long working life of timing belt drives is possible only under certain conditions:

- belt drive should be isolated from dirt and chemical solvents,
- belt pulleys and belt tensioners should be manufactured and assembled according to technical documentation,

- every lack of coaxiality and existing bending of the axles and belt pulleys should be avoided by control and checking
- belt tensioning should be done according to producer's recommendations and with corresponding devices (tensiometers).

REFERENCES

[1] B. Stojanović, N. Miloradović: Development of timing belt drives, Mobility and Vehicle Mechanics, Vol. 35, No. 2, pp. 29-34, 2009.

[2] Y. R. Case: Timing belt drive, McGraw Hill Book Company, INC, New York, 1954.

[3] B. Stojanović: Characteristics of tribological processes in timing belts (in Serbian), Master's thesis, Faculty of mechanical engineering from Kragujevac, 2007.

[4] T. Johannesson, M. Distner: Dynamic loading of synchronous belts, ASME, J. Mech. Design Vol. 124, pp.79-85, 2002.

[5] T. H. C. Childs, K. W. Dalgarno, M. H. Hojjati, M. J. Tutt, A. J. Day: The meshing of timing belt teeth in pulley grooves. Proc. Instn Mech. Engrs, Part D: J. Automobile Engineering, Vol. 211, pp. 205-218, 1997.

[6] B.Stojanovic, S. Tanasijevic, N. Miloradovic: Tribomechanical systems in timing belt drives, Journal of the Balkan Tribological Association, Vol.15, No.4, pp. 465-473, 2009.

[7] S. Tanasijević: Characteristics of Existence and Development of Machine Element Tribology, Tribology in industry, Vol. 20, No 4, pp. 142-148, 1998.

[8] S.Tanasijević: Tribology in design, Tribology in industry, No. 1, pp. 12-19, 1990.

[9] B. Stojanović, N. Miloradović, M. Blagojević: Analysis of Tribological Processes at Timing Belt's Tooth Flank, Tribology in Industry, Vol.31, No. 3-4, pp. 53-58, 2009.

[10] B. Stojanović, L. Ivanović, M. Blagojević: Friction and Wear in Timing Belt Drive, Tribology in Industry, Vol.32, No. 3, pp. 33-40, 2010.

[11] B. Stojanović, L. Ivanović, N. Miloradović: Testing in Timing Belt Drive, IMK-14, Vol.37, No. 4, pp. 77-80, 2010.