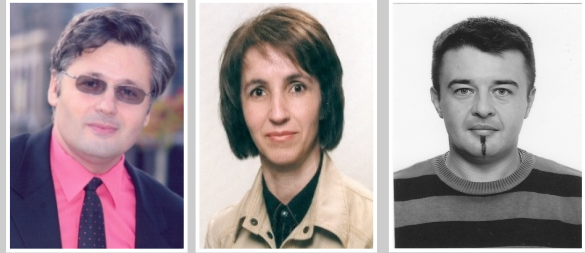


## EXPERIMENTAL DETERMINATION OF TIMING BELT HEIGHT AT INTER-TEETH

### EKSPERIMENTALNO ODREĐIVANJE DEBLJINE MEĐUZUBLJA ZUPČASTOG KAIŠA



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## ABSTRACT

*Experimental determination of timing belt height at inter-teeth is presented in this paper. Firstly, the kinematic analyse of meshing at timing belt power transmitter is done. On the basis of the results, obtained by kinematic analyse, identification and analysis of tribomechanical systems at timing belt-pulley of the power transmitter are done. Special focus is put on tribomechanical system that consist of inter-teeth space-head of pulley teeth. Experimental testing was done by special, custom design and made, testing device that operate as open power loop. Variations of timing belt pitch, width and height of timing belt, so as variation of timing belt height at inter-teeth are registered during experimental testing. The registration and analysis of changings of timing belt height at inter-teeth are done with simulation of real exploitative conditions.*

**Key words:** timing belt, experimental testing, tribomechanical system, friction, timing belt height at inter-teeth

## 1. INTRUDITION

Timing belt drives present relatively new concept in transmission of power and motion. The basic function of timing belt power transmitters is to transmit power and torque from driving to driven shaft. Transmission of power from driving to driven pulley is done by direct contact of timing belt teeth

with teeth of the pulley. The first design of timing belt was developed by Richard Case in 1946.

Reliability and working life and of timing belt transmitters are highly influenced of invariability of timing belt geometrical dimensions. Primarily, this is related to timing belt pitch and its width, height of timing belt at inter-teeth and total height of timing belt. Variation of only one of those values cause unbalanced operation, vibrations, noise and failures of timing belt transmitter and whole machine system. It is obvious that shape and design of timing belt cannot by significantly optimized, so analysis of its geometrical properties must be done during exploitation [1-3].

## 2. KINEMATIC OF MESHING AT TIMING BELTS

Timing belts and pulleys with trapezoid shape of teeth are commonly used for regular industrial applications. The widest area of applications of timing belts is automotive industry. Kinematic analysis of timing belt, presented in this paper, is done at timing belt power transmitter with trapezoidal profile, as it is experimentally tested one. Transmission of power and torque by timing belt is done by friction and contact of profiles. During transmission of power, teeth of timing belt come in mesh with inter-teeth of pulley with side and radial gaps (Fig. 1).

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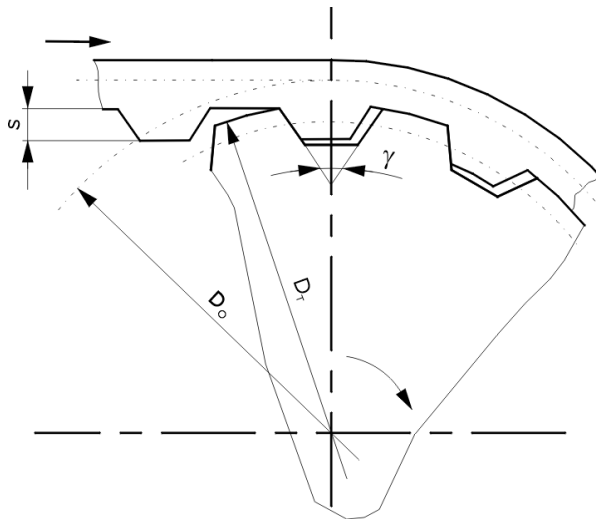


Figure 1. Scheme of timing belt meshing with driving pulley

The motions of timing belt in tangential, radial and axial direction are caused during contact of timing belt and pulley. Those motions are caused by torque, leading forces, tension forces, radial and centrifugal forces, air resistance, deformations of timing belt due to flexion and elongation, design solution, driving element and pulley properties, precision of production and installation properties, so as quality of surface finish. As there are large number of parameters influent to transmission of power and motion, kinematic analysis of meshing is very complex procedure.

Side surface of timing belt teeth, after come in mesh, have direct contact with side surface of pulley. After that, contact is at internal surface of inter-teeth space of the belt and external surface of the pulley teeth with simultaneous contact at side surface of the belt with pulley rim.

The teeth of timing belt are maximally deformed when came in mesh with driving pulley due to pre-tensioning. When come in mesh, the heads of belt teeth make contact with side surfaces of pulley teeth. The contact is at line for the moment. Due to interference, teeth of the timing belt interfere with surface of pulley teeth. Due to elastic properties of timing belt and high rigidity of pulley, deformation of belt teeth is done (Fig. 2, position 4). By increase of teeth deformation, enlargement of contact surface between belt and pulley is caused. Contact point of belt teeth and pulley teeth move from the head to its base.

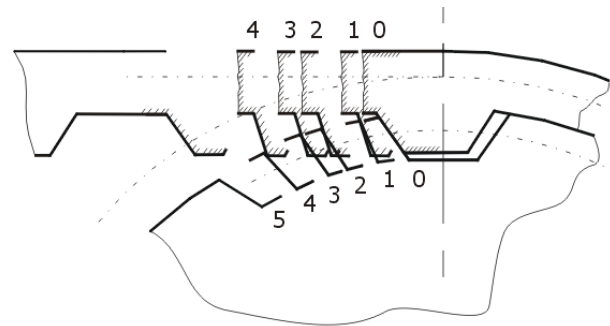


Figure 2. Schematic presentation of process when timing belt teeth come in mesh with driving pulley teeth

Maximal deformations of teeth are at position 2 (Fig. 2). Due to effects of stresses and rotation of belt and pulley, deformations are reduced. The full superposition of side surfaces of belt teeth and pulley are done at position 0 (Fig. 2). For now, contact is at surface. Process of timing belt teeth come in mesh with pulley is followed by relative sliding of its side surfaces, when friction is caused. Value of normal force have parabolic dependence and this caused change of friction force. The highest value of normal and friction force are at the bases of teeth.

### 3. FRICTION AT TIMIG BELTS

The largest amount of power and motion is transmitted by shape contact, while much smaller amount of power is transmitted by friction. But, effects of friction cannot be neglected in general case. Friction and its effects at timing belt power transmitter are not still fully investigated. At timing belt power transmitters, contacts are between metal and non-metal or two non-metal surfaces, differently from other power transmitters (gears, chain transmitters, Cardan transmitters and so on) where contacts are between two metal surfaces [4-6].

The basic tribomechanical systems at timing belt transmitter are (Fig. 3):

1. Belt teeth – pulley teeth,
2. Side surface of belt – pulley rim,
3. Inter-teeth belt space – head of pulley teeth.

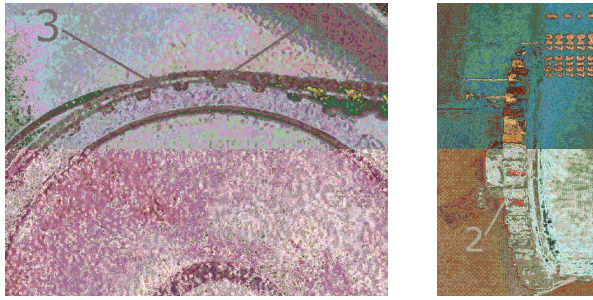


Figure 3. Timing belt power transmitter with basic tribomechanical systems

The motion types at those tribomechanical systems are presented at Tab. 1.

Table 1. Tribomechanical systems and motion type at timing belt power transmitter

Tribomechanical system	Motion type
teeth of timing belt-teeth of pulley	impact sliding rolling
side surface of belt – pulley rim	impact sliding
inter-teeth belt space – head of pulley teeth	sliding rolling

#### 4. TRIBOMECHANICAL SYSTEM AT INTER-TEETH OF TIMING BELT AND HEAD OF PULLEY TEETH

During motion of the timing belt at envelope arc, its flexion and strains are caused. Timing belts flex at multi-angle profile, differently from flat belts which flex at continual and smooth curve. Flexures of the timing belts caused internal losing and fatigue of timing belt, means its tension element. Flexion and strains of the belt at envelope arc caused deformation of the belt.

Besides that, load at teeth of the timing belt decrease from higher value that act at come in meshing to lower value that act when come out of meshing. The highest value of load is at first tooth that is in mesh, so this tooth is highly deformed. Due to different load at each tooth, the different deformations are caused along envelope arc. Difference of deformations caused relative motions, primarily, at tangential direction. Also, timing belt came in mesh with maximal strains and come out of mesh with decreased load. Those motions caused relative motions in relation to pulley at direction of envelope arc. Friction occur along whole envelope arc between inter-teeth and head of pulley teeth. Relative motions of timing belt across envelope arc,

which are caused due to its deformations and differences of load at its teeth, caused sliding type of friction (Fig. 4). Value of this force can be determined by following relation:

$$F'_{ti} = c_K \cdot \Delta k ,$$

Where is:

$c_K$  - Rigidity of timing belt and

$\Delta k$  - Deformation of timing belt at envelope arc

During motions of timing belt, changing of directions and values of friction forces is caused. The changings of forces along envelope arc caused changings of timing belt pitch. At driving pulley pitch of timing belt is higher at active zone, which caused sliding of timing belt in direction of its rotation, so friction forces act in direction of tension force at inactive zone of the belt (Fig. 4). At driven pulley and belt zone that is not active, pitch is lesser that pitch of the pulley, while it is higher at its active zone. Those differences caused that friction forces at active zone act in opposite direction of rotation, means in direction of force at zone of belt that is not active.

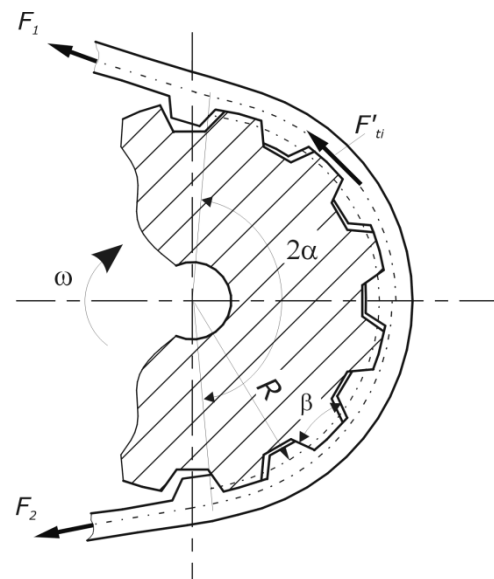


Figure 4. Friction force at timing belt inter-teeth and head of pulley teeth

Direction of friction force  $F'_{ti}$ , in general case, depend on sign of total deformation along envelope arc. The highest values of friction forces are caused in case when high difference of force distribution along envelope arc is present, means in case when high difference of forces between active and inactive

zone of belt is present and number of teeth in mesh are small. All this lead to conclusion that direction and value of friction force is changing along envelope arc in relation to current position. Changing of friction forces is present when changing of its pitch is present. The entire explanation, that is presented, is related to driving pulley, while at driven pulley, things are in reverse [3-7].

## 5. TESTING OF TIMING BELTS

Experimental testing of timing belt is done at custom design and made testing device. The testing device operate as open power loop [8-10]. As this experimental testing belong to group of testing with simulation of exploitation conditions, it is important to define demands and limitations at process of device design in order to obtain relevant testing results.

Those demands can be defined as:

- Compact and rigid design,
- Wide load range,
- Simple changings of load level,
- Ability to control load parameter ( $M_{opt}, n$ ),
- Ability to obtain highly controlled working regime with precision and reliability,
- Ability of testing device to be connected with output peripherals (graphical output devices, computer...).

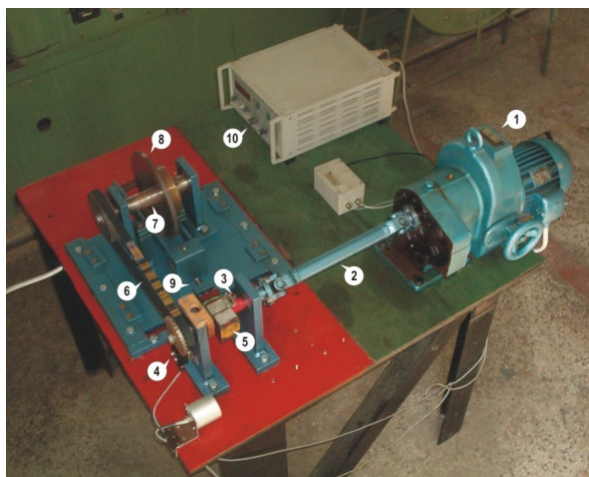


Figure 5. Device for timing belt testing

Basic elements of testing device are:

1. Driving unit,
2. Cardan transmitter,

3. Input shaft with measuring devices,
4. Sensor for input shaft number of rotation,
5. Torque sensor on input shaft,
6. Considered power transmitter (timing belt pulley),
7. Output shaft,
8. Mechanical brake,
9. Tension mechanism and
10. Signal amplifier.

Configuration of basic elements of device for testing of timing belt power transmitter is presented at Fig. 5.

Driving unit, type KR-11/2C (37-180 rpm<sup>-1</sup>) – producer "Prva petoletka" OOUR Devices and elements, Brus, consists of electromotor (1) type ZKT90S-4 (totally enclosed single phase asynchronous motor with cage rotor with thermal protection, size 90L, 4-pole type), friction power transmitter, and gear reductor.

Design solution provides automatic regulation of pressure between friction discs and compensation of axial gap due to wear. Changing of number of rotations per minute is done manually, by rotation of wheel that by coupling of gear and bar, radially (vertically) move electromotor with conical friction disc from friction wheel. Driving unit (1) and input shaft (3) are connected by Cardan shaft (2).

Input, measuring, shaft (3) is design in the way to be elastically deformed under maximal torque load. Inductive sensor of number of rotations per minute (4), type MA1 is placed on measuring shaft, so as torque transducer (5) that is formed of strain gauges and signal transmitter MT2555A that is mounted by special adapter with battery compartment BK2801A.

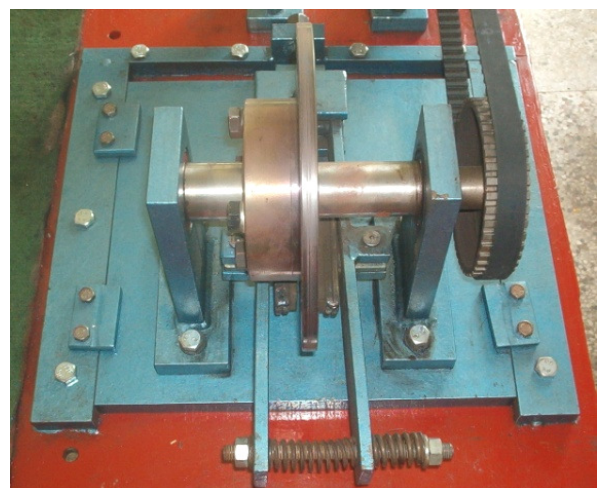


Figure 6. Mechanical Brake

Input and output shafts (7) are connected by considered power transmitter (6), means timing belt - pulley system. Tension of timing belt is done by the tension mechanism (9) with external threaded spindle. By spindle rotations the movements of plate with output shaft and mechanical brake are done.

Mechanical brake is specially designed for open power loop (Fig. 6). Breaking is done by acting of breaking pads on both sides of the disc. Regulation of force and torque is done manually by the means of spring and screw.

Mechanical brake obtain certain braking torque, means load torque on output shaft of timing belt – pulley power transmitter. Value of torque is presented on digital display of the signal amplifier that gets signal from measuring device on shaft by signal transmitter EV2510A. The number of rotations per minute of input shaft is also displayed on amplifier gain that gets signal from inductive sensor and impulse receiver DV2556. By that, working regime at input shaft is obtained and regulated.

By adaptations of joining elements with driving unit from one side and output shaft equipped with measuring devices, testing of various types of power transmitters can be done with limitations in dimensions and load regime.

## 6. TESTING RESULTS AND EVALUATION

Measuring of geometrical dimensions are done at ZASTAVA TOOL FACTORY, Department for Quality Providing. In order to obtain relevant results about changing of considered dimensions, measuring were done at eight teeth of timing belt. During experimental testing following values were measured (Fig. 7):

- Pitch ( $h$ ),
- Belt width ( $b$ ),
- Height at inter-teeth of the belt ( $t_1$ ) and
- Total belt height ( $t$ ).

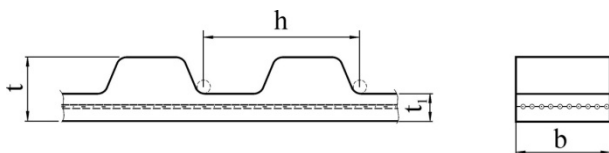


Figure 7. Dimensions of timing belt

In this paper, the changing of timing belt height at inter-teeth is considered. Timing belt height at inter-teeth is distance between internal side of inter-teeth

and back side of belt. The device DIGIMAR that is used for measuring of timing belt height at inter-teeth is presented at Fig. 8.

Changing of belt height at inter-teeth ( $\Delta t_1$ ) during experimental testing can be calculated as:

$$\Delta t_1 = t_{1o} - t_1$$

Where is:

$t_1$  - Value of belt height at inter-teeth measured during experimental testing and

$t_{1o}$  - Belt height at inter-teeth before testing.



Figure 8. Device for measuring of geometrical dimensions – DIGIMAR

Measuring results of changing of timing belt height at inter-teeth, during exploitation, for eight considered teeth are presented at Tab. 2 and Fig. 9.

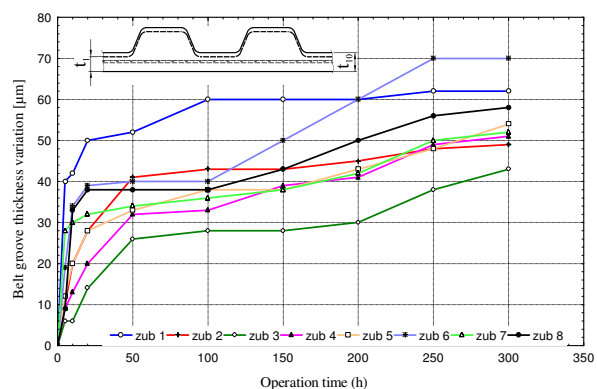


Figure 9. Changing of timing belt height at inter-teeth

Table 2. Changing of timing belt height at inter-teeth

$$\Delta t_1 = t_{10} - t_1 [\mu\text{m}]$$

Exploitation time (hours)	$\Delta t_1$							
	Tooth of timing belt							
	1	2	3	4	5	6	7	8
5	40	10	6	9	12	19	28	9
10	42	20	6	13	20	34	30	33
20	50	28	14	20	28	39	32	38
50	52	41	26	32	33	40	34	38
100	60	43	28	33	38	40	36	38
150	60	43	28	39	38	50	38	43
200	60	45	30	41	43	60	42	50
250	62	48	38	49	48	70	50	56
300	62	49	43	51	54	70	52	58

The conducted analysis showed that height of timing belt at inter-teeth continually decrease during exploitation period. During running-in period, that lasts for approximately 20 hours, this changing is very significant and it is happening on all of considered eight belt tooth. The changing during running-in period is caused by deformations of the belt, its pitch and width decrease. During period of normal wear timing belt height at inter-teeth continue to decrease. During period of 20 hours to 50 hours of exploitation this changing is significant. After 50 hours of exploitation till 200 hours of exploitation, changing of timing belt height is not significant. The highest plastic deformations are present during running-in period. Due to the fact that those deformations are small during period of normal wear, cylindrical wear of tooth head are not significant, so changings of belt height at inter-teeth are small. After 200 hours of exploitation changings of belt height at inter-teeth are significant for all considered eight teeth. By further evaluation of those values it can be concluded that all values do not have same trend of changing. But, it can be concluded that total belt height have larger changings than belt height at inter-teeth. This process caused reduction of active teeth height that is in contact with teeth of the pulley. If reduction of timing belt width after 150 hours of exploitation is considered, it can be concluded that nominal side surface of belt teeth is, also, caused. As timing belt power transmitters, transmit power by contact of profiles and friction, enlargement of belt pitch and reduction of nominal surface of teeth caused failures during exploitation of those power transmitters.

## 6. CONCLUSION

During contact of timing belt teeth with teeth of the pulley, radial and axial movements of belt are

caused. Those movements are caused by torque, circumferential force, pre-tensioning, radial force, centrifugal force, air, belt deformation due to flexion and strain, timing belt design, tension element and pulley, production tolerances and installation properties, quality of surfaces, and so on. It is obvious that kinematic of meshing at timing belt transmitters is very complicated. As consequence of friction and wear, reduction of timing belt height at inter-teeth is caused, so reduction of total height of timing belt is, also, directly, caused. By that, nominal contact surface of timing belt teeth and pulley teeth is reduced. After 300 hours of exploitation, the height of timing belt at inter-teeth is reduced by ~2%, averagely, in relation to starting value. The consequences of those changings are unbalanced operation, increase of noise, vibrations, and significant reduction of timing belt working life.

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