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TRENDS IN DEVELOPMENT OF TIMING BELTS FOR NEW APPLICATION AREAS

The application of timing belts into new usage fields makes them more and more popular, and at the same time cause the necessity of introduction of their new construction. It became possible mainly thanks to the usage of new materials and modern production processes. The modernization of timing belts construction affects the reliability and functionality of timing belt gears. New properties allow to use the belts in successive areas of technology. Proper understanding of these conditions allows for optimal adjustment of the power transsmision belt to the machine structure. Taken into consideration parameters influencing on working of the gear is important for creation of the model of load in gear with timing belts.

Keywords: mechanical gears, belts, timing belts

1. INTRODUCTION

Toothed belts, also called synchronous belts, cooperate with the pulley by a friction geometrical linking [2]. For many years, the primary use of transmission belts were synchronous motion transfer from the crankshaft to the camshaft in an internal combustion engine [13]. In modern cars from a few up to several gears with timing belts may exis: in motor systems, steering and brake systems and in systems improving passenger and driver comfort [4]. In a year 2004 a Swiss manufacturer of watches produced a model for famous sportsmen, that uses three timing belts (Fig. 1). Currently, the most intensive development of power transmission occurs in industrial applications and automatical production systems [9, 10]. They can by find in all kinds of mechanical devices: numerically controlled machines, manipulators, automatic systems, storage, transportation and installation, plotters, printers, etc. [9]. Timing belts are used in the most demanding

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systems, like infusion pumps, buildings elevators, as well as aircraft and space technologyes. Timing belts are meant for use in micro- drives, where they can work with large ratios such as 1:20 000 Cyclobelt. Another range of belts application is heavy machinery drive, where they successfully replace chains [3]. In many devices one may find drives with toothed belts such as multi-shaft, tangential and open end belt, that connect shafts parallelly and diagonally [5, 12].

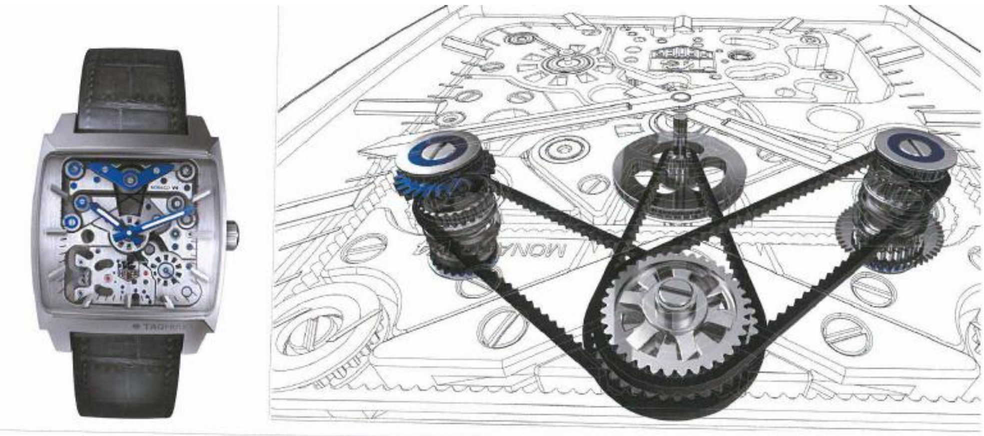

Fig. 1. Watch Tag Heuer Monaco V4 [1]

Over the years basic elements of the toothed belt construction underwent many modifications (Fig. 2). Belt's tooth have different structures in different sizes, in relation to the notch and different shapes. Firstly, geometrical form of the teeth refleceted teeth of pulleys used in helical gear units that had a bad impact on the kinematics of movement in timing belt gears. In fist designe of belts teeth no other parameters were analyzed, as the meaning of the volume of the tooth, the belt pitch and the shape of the tooth flank. Chevron teeth structures and curved shape were introduced only in order to reduce the emission of noise in the transmission, without solving the problem of axial separation belts.

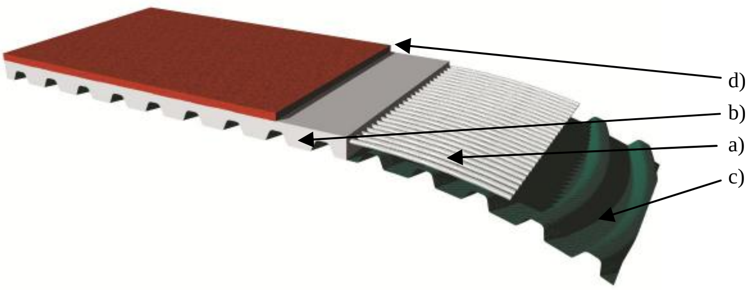

Fig. 2. Basic elements of a timing belt: a) cord, b) teeth on running side, c) fabric on the teeth, d) additional layer on back side [6]

Latest structural solutions are based on change the positions of teeth on the belt width (Fig. 3). Changes started in a year 2000 by introducion of the belt type N10 with conical teeth, then teeth underwent further development like: arched tooth - type BAT, chevron packings - called Eagle, offset - SFAT and oblique.

a)
b)
c)
d)
e)

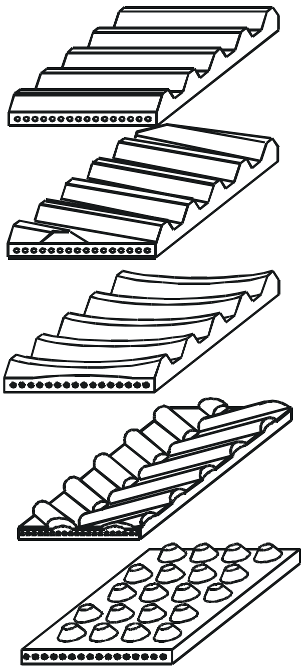

Fig. 3. Timing Belts with different tooth distribution on the belt width:
a) simple, b) oblique, c) arc, d) attached, e) cone

A variety of polymers with different load characteristic, conected with their rheological properties are used in the belts production. Such phenomena as: creeping, stress relaxation, elastic recovery, strong internal friction and dissipation of energy, orientation of the internal structure and its mechanical stabilization, storage of materials, chemical relaxation, change of properties and change of construction of the internal structure under the influence of ambient temperature, have a positive or negative influence on exploitation properties of timing belts [12]. The internal intermolecular forces, called Van der Waals forces, have a fundamental impact on the rheological and mechanical properties. It forces depends on their maximum tensile strength and elastic modulus values of the variable polymers. The material properties affect belt tooth and pulley coupling as well as power distribution within the cord at the arc of contact. In the belts made of various materials it is important to transmit the circumferential force caused by the belt coupling with the pulley. During examination of cyclic deformation of the belt cross-section while bending on pulleys it appeared it had a significant impact on the of energy loss value due to internal friction in the material and on the increase of temperature at the waist. The largest losses were observed in layers below the neutral axis [14].

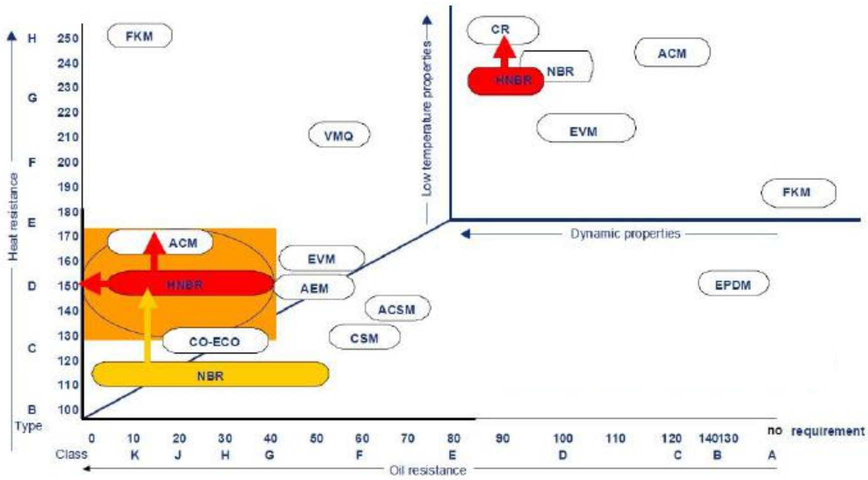

Fig. 4. Choice of belt material to working conditions Goodyear training data

The deformation of the tooth depends in the considerable degree on its shape but also on such features as: the belt's material, additional layers one running side together with composite of cord layer. Proportion of timing belt pitch to timing belt pulley is also meaningful for this process and it depends on preliminary force of timing belt. Another and probably one of the most important parameters used in estimation of the gear pitch diameter is the height of belts cord layer.

2. DESCRIPTION OF THE MECHANICAL PROPERTIES OF THE GEAR WITH TIMING BELT

The geometrical features of the toothed pulley have to provide the best conditions of coupling process. The shape of the notch of the pulley is not the simple reflection of the shape of tooth of the belt. When the belt coupless with the pulley, it is squeezed, curved and after it, it he slides on the pulley. These processes are the fundamental cause of deformation and the wear-off the teeth of the belt.

One should take into account dynamic strengths connected with accelerations and delays in the transmission together with linear speed.

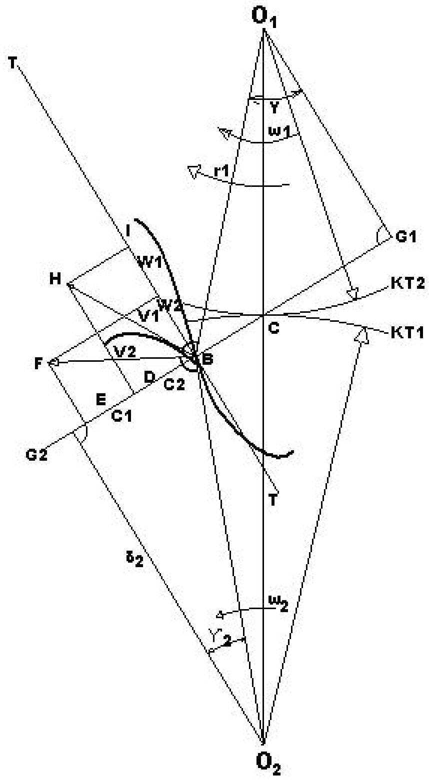

Fig. 5. The principle of engagement of the gears

Uniformity transfer of rotary motion requires preserved the main principles of engagement in mechanical gear (Fig. 5). Straight line perpendicular to the side of the tooth at the point where the gear teeth cooperate must pass through the contact point of the pulley rolling on the belt (Fig. 6). The transmission ratio should be constant, this means that the position of the centers of rotation should be constant, as well as the pulley rolling ratio. The contact point of pulleys rolling is called the focal point of engagement. During the movement of a number of consecutive points in the contact plane, the contact lines (meshing) are created. The central point in the gear meshing with the toothed belt is located at the intersection of the neutral axis of the cord. The symmetry axis of the active pulley is perpendicular to the cord layer . This point is the pivot point of the place of engagement that influences pulley and belt teeth in the coupling process, behind this point coupling is completed. A similar process occurs in a decoupling point on the passive pulley. Depending on the pitch and diameter of the pulley in the coupling process a different number of teeth take part, causing instantaneous variability of the number of teeth belt being coupled with the pulley.

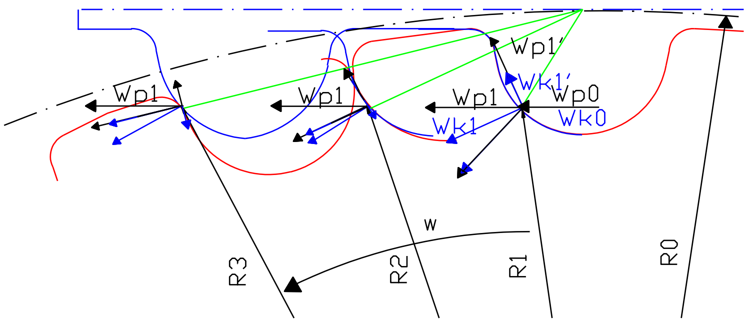

Fig 6. Meshing process of timing belt with pulley

It has been empirically confirmed that the periodical deformation of the belt cross-section during bending at the pulley, significantly influences the energy loss value due to internal friction in the belt is material and rises the belt's temperature [7]. The highest value of internal friction and energy dissipation occurs in the compressed layers of the belt, below the neutral axis (bearing level) (Fig. 7). Main friction types between the toothed belt and the pulley are associated with belt's movement within the tooth space as well as the coupling and decoupling process. The above mentioned conditions contributed to the new interpretation of phenomena taking place during combined shape - friction coupling as well as to the directions of the toothed belt structure development.

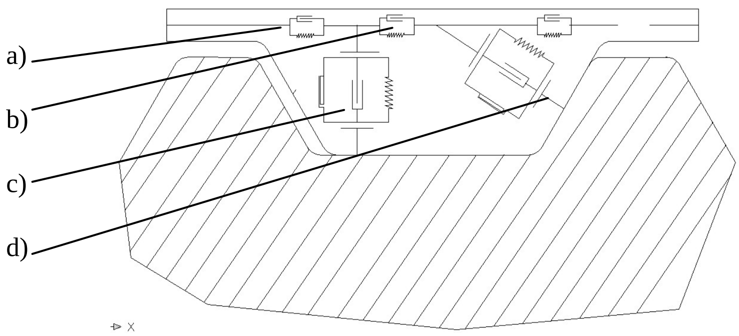

Fig. 7. Tooth model: a) cord elongation between teeths, b) cord elongation inside tooth, c) tooth deformation caused by friction, d) tooth deformation caused by geometric coupling.

Processes taking place inside the belt tooth depend on the geometry of timing belt pulley tooth. The phenomena occurring inside the belt, have an impact on its efficiency and durability (Fig. 8).

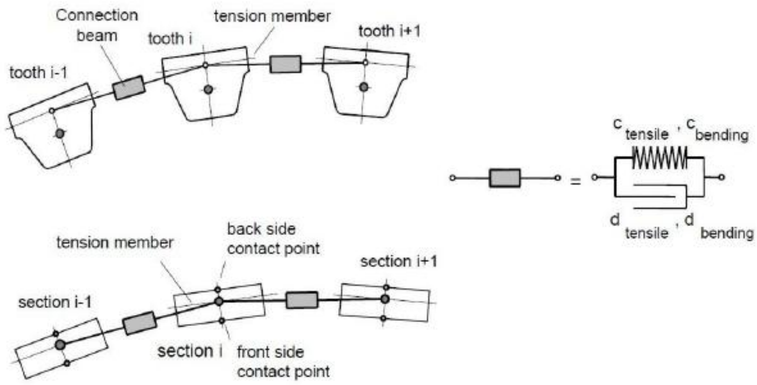

Fig. 8. Rigid body representation of timing belt and non-toothed belt [14]

The main method for designing toothed belts is to select an appropriate belt and cord materials. The cord extension value on the arc of contact is determined by the angle of the arc of contact over which the belt teeth are deformed. The number of deformed teeth depends also on the value of the pitch [17]. To develop a qualitative model of the geometric coupling between the toothed belt and pulleys, it is necessary to consider deformation and the number of coupled belt teeth. If only the geometrical meshing between belt and pulley is taken into consideration the model of meshing can by represented with formula:

$$\frac{S_1}{S_2} = f\left(\sum_{z=1}^{z_o} \frac{\Delta lz}{p}\right) \tag{1}$$

where ΔL_z is the deformation of tooth on contact arc with timing pulley and – p is pitch of belt. This type of cooperation between belt and pulley is similar to chain and typical for old types of gears. Belt is supported by top of head of pulley teeth, where is very thin layer of material. This is a reason why deformation of material between cord and pulley is not taken to model. Different high of cord on arc of contact above pulley is not described. Now in a standard cooperation in gear with timing belt, a belt is supported by space between pulley teeth. The surface of cooperation is larger, so it is necessary to consider friction in this area in meshing model.

$$\frac{S_1}{S_2} = f\left(\sum_{z=1}^{z_o} \frac{\Delta lz}{p}\right) + e^{\mu\varphi_a} \tag{2}$$

With use of elements from the classical Euler's model $e^{\mu\varphi_a}$, where *a* is arc of contacts where power is transferred from belt to pulley.

3. DESCRIPTION OF TIMING BELT MATERIAL

The belt coupling model takes into account deformation of all coupled teeth. The model considers different phenomena occurring in the driving and in the driven pulley. Teeth deformation depends on the belt's material as well as on both volumetric and energetic wear of teeth [8]. Ishihara, Hashitsume and Tatiana extended the Rivlin-Mooney's model by nonlinear part [12]. The already existing three constants were experimentally verified by Zahorski, who certified good correspondence between thoeory and experiment [13]. In order to describe the bouncy properties theory of hyperelastic materials it is often applied. The model is frequently polynominal:

$$W = \sum_{i,j=1}^{N} C_{ij}(I_1 - 3)^i (I_2 - 3)^j + \sum_{k=1}^{N} \frac{1}{d_k}(J - 1)^{2k} \tag{3}$$

With use of:

$$I_1 = \lambda_1^2 + \lambda_2^2 + \lambda_3^2 , \quad I_2 = \lambda_1^2\lambda_2^2 + \lambda_2^2\lambda_3^2 + \lambda_3^2\lambda_1^2 , \quad I_3 = \lambda_1^2\lambda_2^2\lambda_3^2 \tag{4}$$

For *i*=1, *k*=1 it is new Hooke's model, for *i*=1, *j*=1 first Mooney-Rivlin's model for *i*, *j*, *k* =1 it is modified Odgen's model in ABAQUS system called superfoam [8, 15]. The main method for designing timing belts is to select an appropriate belt and cord materials. The cord extension value on the arc of contact is determined by the angle of the arc of contact over which the belt teeth are deformed (Fig. 9).

The number of deformed teeth depends also on the value of the pitch. To develop a qualitative model of the geometric coupling between the toothed belt and pulleys, it is necessary to consider deformation and the number of coupled belt teeth.

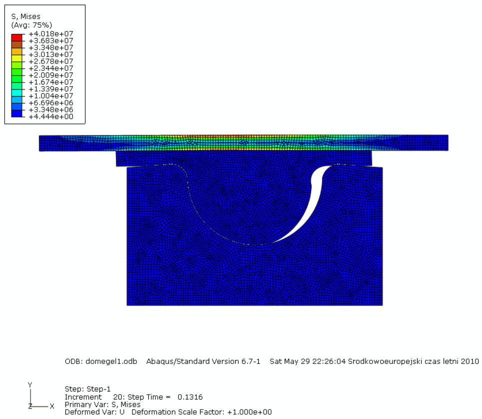

Fig. 9. Contact approach for timing belt with pulley

4. DEMANDING APPLICATIONS OF TIMING BELTS

Choosing to design a belt, it seems that the only limitation is thetransmitted power value. In many new applications the limitation is also the quality of the belt.

Fig. 10. Belt with pitch accuracy correction at the periphery in control system

The knowledge of characteristics and production technology allows the introduction of improvements in a power transmission or a job performance with increased accuracy. The first step in choosing the transmission system for control system is the choice of a gear that is limited baclash or “backlash-free”. Depending on a production technology, timing belts are affected with pitch errors. In particular belts made of thermoplastic material, moulded around the cord, an inaccuracy is associated with a local warming of the cord layer at the start of molding. One method of decrease the pitch error is a separation along the belt, relative shifting of separated pieces to each other, and re-welding (Fig. 10).

Fig.11. Belts cut from the same sleeve in parallel conveyor

The belts produced as extruded form have problem with the proper performance of the cord layer. Each wire must have a feed system with the regulation of preload force. If the tension is different for different wires, curved belt's are produced. If the force decreases in a production process, pitch alongside the belt will be heterogeneous. The solution is to use belts cut from the one sleeve as sets (Fig. 11).

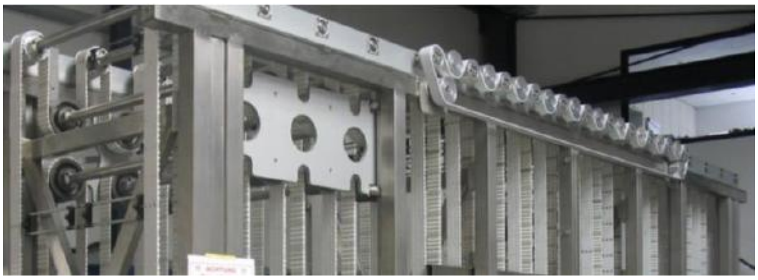

Fig. 12. Additional belt for displacement correction of carrier webs in stock vials

In systems such as storage systems very long strips are used (50-100 meters). In such applications, there are displacement, an inaccuracy caused by the flexibility of belts, backlash and execution inaccuracy. Therefore, additional belts are used to improve the accuracy of displacement, ensure that each vial is in permanent motion (Fig. 12).

5. CONCLUSIONS

The phenomena associated with the contact between the toothed belt and the pulley can be divided into categories. The first category includes phenomena occurring inside the belt and is associated with a load transfer from the belt's material to the cord as well as effects occurring between respective belt and pulley surfaces. Numerical methods and experimental verification shows that the most important for mechanical parameters of gear is proper selection of material. This is especially important on the arc of contact on the belt's pulley. Inside the belt exist an internal and external friction. Analysis of those effects constitutes the grounds for individual attitudes to design and operation of toothed belt transmission gears. The value of initial stress force is essential in the work inequality process of the gear. There are significant differences depending on mechanical and material properties of the belt that are important for the quality estimation of coupling of timing belt and timing pulley. The new application areas show another problems which face the designer of timing belts. In this way, new applications are forced to create new belts and these allow to overcome next barriers of machines design.

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TENDENCJE ROZWOJU PASÓW ZĘBATYCH DO NOWYCH ZASTOSOWAŃ

Streszczenie

W artykule poruszono problemy związane z poszukiwaniem nowych rodzajów pasów zębatych do nowych zastosowań konstrukcyjnych. Nowe typoszeregi powstają gównie z wykorzystaniem nowoczesnych materiałów i procesów produkcyjnych. Pasy zębate zaczynają być stosowane w mikromechanizmach i systemach sterujących. Osiągają trwałość porównywalną z łańcuchami. Z uwagi na właściwości materiału pasa jego cechy geometryczne (zaczerpnięte są z przekładni zębatych walowych) wymagają optymalizacji. Wraz z modernizacją pasów i kół pasowych zmieniają się warunki sprzężenia, co wpływa na niezawodność i funkcjonalność przekładni. Nowe właściwości pasów wymagają nowego opisu sprzężenia pasa z kołami i dalszych badań.