THE 7TH INTERNATIONAL CONFERENCE RESEARCH AND DEVELOPMENT OF MECHANICAL ELEMENTS AND SYSTEMS

INFLUENCE OF TORQUE VARIATION ON TIMING BELT DRIVE'S LOAD DISTRIBUTION

Ivan MILANOVIĆ
Blaža STOJANOVIĆ
Mirko BLAGOJEVIĆ
Nenad MARJANOVIĆ

Abstract: *In this paper was made a numerical analysis of timing belt drives. The subject of analysis in this paper is influence transitions of torque on distribution loads of the timing belt drives. For calculating the elements in this paper, timing belts and pulleys, with variable torque values was applied Finite Elements Analysis (FEA). Timing belt drive is exposed to different values of torque, and results indicate how the stresses change in working conditions of drives. Analysis was conducted for real timing belt drive. The analysis is performed using software package Autodesk Inventor Professional.*

Key words: Timing belt drives, Finite Element Analysis, torque, simulation, stress

1. INTRODUCTION

The timing belt drives was a relatively new conception for the power and motion transmission. Timing belt is widely used for transmission power and movements on vehicles. The main task of timing belt drives is transmitting of power and motion from driving on driven shaft.
The power transmission from driving on driven pulley is performed by direct contact belt teeth with the belt pulley teeth. The first timing belt was constructed in 1946 by Richard Case. Timing belt's construction is made so the belt groove is in the contact with apex surface of the belt. Due to transmission torque comes to the sliding of teeth across the teeth of pulley, there are frictional forces, but appearance of friction in timing belt drives and it's cosequences have not been sufficiently investigated [1,2].
It would be perfect if all the teeth in contact of timing belt pulley had the same loading, but the teeth loading values of the belt depend on the maximal torque and the teeth position on angle of pulley as well, but those conditions are almost impossible to reach.
The published papers on the theme of the analysis of the loads distribution in timing belt drives, give loads variations only in static conditions, respectively with invariable torque.
Models for the loads investigation in static conditions are from 1978 year, when *Gerbert* and *Jönson* independently developed model of timing belt drive with trapezoidal profile of teeth [3].
The first analysis of load distribution in timing belts with Finite Element Analysis (FEA) gave *Kido* 1992 [4] year, and in the next period this metod is more introduced in analysis of timing belt drives [5]. In order to reduce time and calculations in numerical analysis, timing belts and pulleys are models in two dimensional environment.

2. KINEMATICS OF THE TIMING BELT DRIVES

Load distribution of timing belt drives affects the working ability and the drives life. Considering the large number of parametars which affects on torque transmission, kinematic analysis of the coupling is extremely important, but also extremely complex process. In this paper is given a motion analysis of timing belt drives, when timing belt with pulley has a trapezoidal profile of teeth.
At the begining of the coupling between timing belt with driving pulley, belt tooth strain is maximum due to preload force. At the beginning of the coupling, the tooth top has contact with broadside surface of pulley and in that moment happens the contact per line. Due to interference, the tooth belt encroaches on the broadside surface of the belt pulley.
The timing belt pulley has a much greater stiffness than the timing belt, and then happens the belt deformation in the coupling. The process of the entering teeth belts and pulleys in the coupling was given on Figure 1.

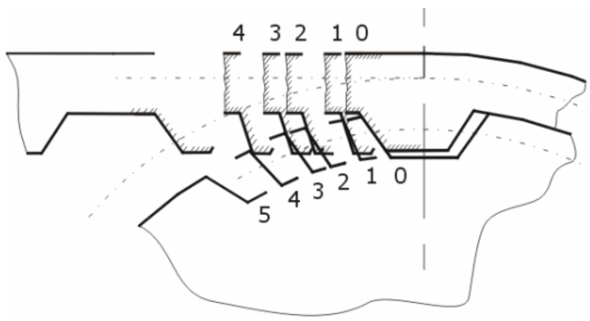

Fig. 1. Tooth belt and pulley in the coupling

The deformation of the belt teeth increases, and at the same time the contact surface of the belt and pulley increases. The contact point between teeth belt and pulley moves from the pulley top to his root. The maximum tooth deformation ocures in position 2, marked on Figure 1. Because of the action of interior stresses and belt swinging, occures the decreasing of deformation. In the position 0 happens the complete overlaping of the broadside surfaces of the timing belt and pulley and in that time comes to the contact on the surface.
The entering process of the belt teeth in the coupling with pulley is followed by relative sliding of the broadside surfaces and the appearance of the force of friction. When it comes to the contact, the match between the belt internal surface and the outvard belt surface lasts highly short. The coupling and deformation of teeth belts in contact is significantly influenced by the teeh number which are in contact [6].
Increasing of the teeth number of driving pulley conducts to the decreasing of the tooth deformation. During this it's necessary to be careful, because the teeth number of driving pulley which are in the coupling with timing belt should be major then six.
If the number of the teeth in the coupling with the belt is less than six, occures the multiple increasing of deformations, which can lead to the large wearing of belts. During the movements of timing belt, along the angle between tensile branch and spare branch of pulley comes to bending and straining of belts. The belt strain supplay to internal dissipation and belt fatigue. Considering that during the coupling of the timing belt and pulley, the contact is polygonal, then it comes to the belts bending in mutual start and, respectively, exit from the coupling. Figure 2 shows the tooth belt in the coupling with the pulley tooth.

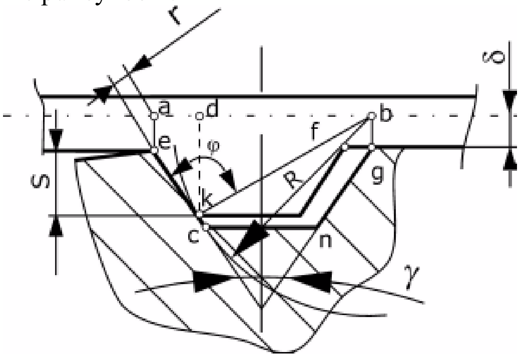

Figure 2. The coupling at tooth belt with pulley tooth

At entry and exit from the coupling, tooth belt performs swinging around points a and b. Swinging lasts until last subtense ab coincidences with subtense on peak circle in this points, due to what the line ek defines the circle of the radius R.
The coupling entry and the exit without the interference happens if $R < bc$ or $\varphi > 90°$. Length ab is equal as breadth along the angle between tensile branch and spare branch of pulley k_t (1) on peak circle diameter, and it's equal to [7]:

$$k_t = ad + db \geq \frac{2s}{\sin\gamma} \qquad (1)$$

where : s - height of the timing belt tooth,
γ - is the angle of the pulley profile.

3. NUMERICAL MODEL OF TIMING BELT DRIVE

In the last few decades, the method of Finite Element Analysis (FEA) enabled the development of the large number of softwares for load analysis. Numerical methods with simulations are used to calculate and anticipate object performance, with much more accuracy then earlier. Today, the modern software packages provide a possibility that all the calculations, due to variable loads kinds we can perform fast and easy. The analysis of the influence of variation of the torque on load distribution of timing belt drives in this paper is analysed with FEA integrated in the software package *Autodesk Inventor* [8]. In mentioned software package was performed complete modeling and numerical analysis of timing belt drives in 3D environment. The model of timing belt with pulley, analized in the paper, is given on Figure 3 [9]. To determine the stress change on timing belt due to variable torque values, is used the mesh with spatial finite elements.

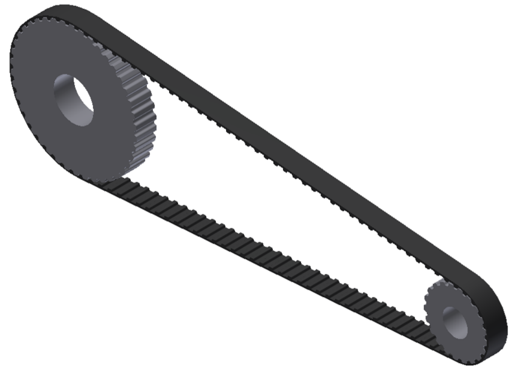

Fig. 3. Model of timing belt drive

Pulley material is much more rigid than the timing belt, and that is the steel with performance in Table 1. Timing belt material is rigid rubber with the characteristics also in Table 1.

Table 1. Basic characteristics of materials

Material	Young`s modul	Poisson coef.
Č (pulley)	210 GPa	0,3
Rigid rubber (belt)	10GPa	0,3

In the analysis are used the timing belt without the tensile element, and therefore, the rigid rubber of extremely high strenght is used as a material.

4. EXPERIMENTAL ANALYSIS OF DRIVE

The timing belt with all the previously mentioned tehnical characteristics is exposed to different values of torque and then the stress variations during the coupling of the belt teeth and pulley are monitorized. In drives, the driving pulley is smaller the pulley. In order to make the drives conditions closer to the real conditions, it's necessary to impose certain constrains on model. It is necessary to restrict radially end wise motion of driving pulley, which prevents egrees from plane due to torque. This type of the constraints of driving pulley is obtained with PIN. Since, it is static analysis, the translation of driven pulley is fixed for all three directions and the constraint FIX is used.

In the working conditions of timing belt drives, values of the basic parameters are torque on input shaft $M = 7{,}504\ Nm$, until number revolution on input shaft is $n = 1400\ o/\min$ [6,7]. The basic tehnical informations of timing belt drives are given in Table 2.

Table 2. Basic tehnical informations of timing belt drives

Parameter	Value
Teeth number (driving pulley)	$z_1 = 21$
Teeth number (driven pulley)	$z_2 = 42$
Teeth number of timing belt	$z_k = 112$
Belt index	L
Belt pitch	$h = 9{,}525\ [mm]$
Belt broadness	$b = 19{,}050\ [mm]$
Angle of the teeth belt profile	$\beta = 40°$

Except the constraints setting and loads on model, software package *Inventor* allows the definition of several types of contacts in the coupling belt teeth and pulley. For analysis of timing belt drive *Separation* contact is defined, where the contact of characteristic parts of timing belt and belt pulley and their separation is implied. The material elements are assigned and transmission drive is ready for static analysis in the mentioned software package. In investigation of the influence of variable torque on load distribution in timing belts, torque values are in interval between $5\ Nm$ and $30\ Nm$ [8].

5. RESULT ANALYSIS

Tension stress of the teeth belt obtained by the simulation is shown below. Tension stress of belts changes depending primarily on the torque values. Stress values and distribution are show on Figures 4 and 5.

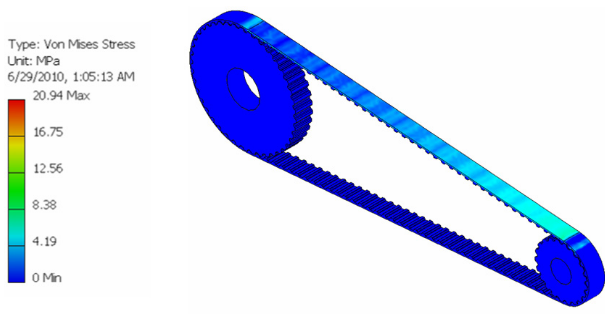

Fig. 4. Load distribution of timing belt ($M = 7{,}5\ Nm$)

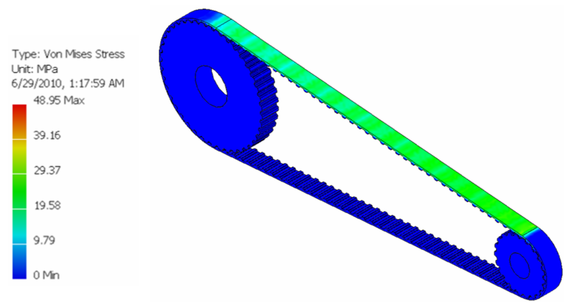

Fig. 5. Load distribution of timing belt ($M = 30\ Nm$)

On Figure 4 is shown the stress distribution for torque value $M = 7{,}5\ Nm$ that is the calculated value, and on Figure 5 is shown the load distribution for a considerably higher values of torque, for $M = 30\ Nm$.

From tension stress figures is evident a difference which is made due to the change / increasing of torque. Timing belt is significantly stressed and stresses are significantly higher. Analysis shows that stresses values are biggest in the tensile branch, and with belt motion to the spare branch the values decrease. The most stressed are the first three teeth in the coupling, what is shown on figures 6 and 7.

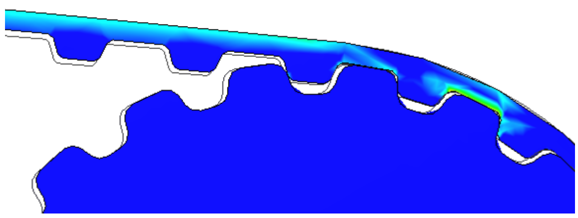

Fig. 6. Tension stress of first three tooth belts in the coupling ($M = 7{,}5\ Nm$)

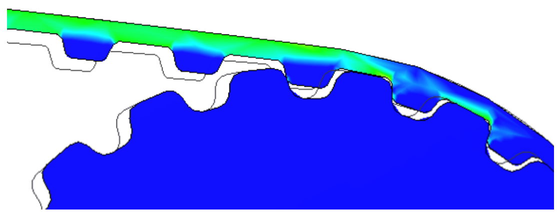

Fig. 7. Tension stress of first three tooth belts in the coupling ($M = 30\ Nm$)

Based on belt torque variation for given stresses values on teeth was formed the diagram on, Figure 8. Stress variation in timing belt drive, which is analised for real works conditions, on diagram is shown with green curve ($M = 7{,}5\ Nm$).

In the shown diagram it is evident that most loaded teeth are on tensile branch, the first three teeth, while on the teeth 4, 5 and 6 the stress decreases. When belt passes a half of angle between tensile branch and spare branch of belt, that is from tooth 6, it comes to stress increment due to straining or belts straining. Stresses then increase to the tenth belt in the coupling, and then belt teeth starting with exit from the coupling which leads to the decreasing of the stresses on timing belt. The release moment of belt teeth from the coupling is observed on diagram as a belt tooth discharging, i.e his return in zero position. On the diagram is also observed, with torque increasing, stress values skipping and droping along the angle between tensile branch and spare branch occure on indentical locations.

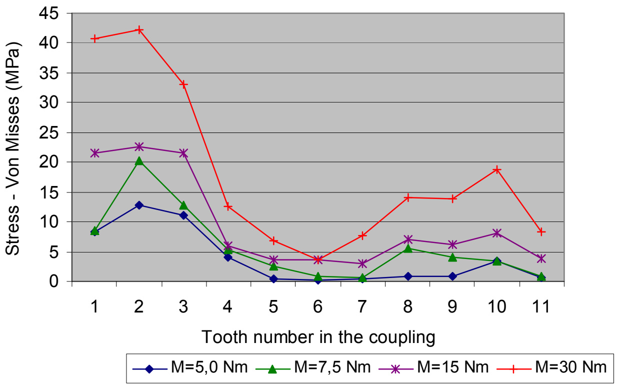

Fig. 8. Influence variation of torque on stress values

6. CONCLUSION

The knowledge of the load distribution on teeth in the coupling is very important for analysis of timing belt drives. Each belt tooth is exposed to a certain load, and load depends on springing and tribological characteristics of timing belt drives. To make the coupling ideal it is necessary that the load distribution between teeth is approximately equal. The analysis shows that the most loaded are the belt teeth in tensile branch, and with belt motion of branch to the spare tensile, the load values decrease. With increasing of the values of torque, the stresses along the belt also increase.

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CORRESPONDANCE

Ivan Milanović, M.Sc., PhD student
University of Kragujevac
Faculty of Mechanical Engineering
Sestre Janjić 6
34000 Kragujevac, Serbia
ivanmasinac@gmail.com

Blaža Stojanović, M.Sc., teaching assistant
University of Kragujevac
Faculty of Mechanical Engineering
Sestre Janjić 6
34000 Kragujevac, Serbia
blaza@kg.ac.rs

Mirko Blagojević, Ph.D., assistant professor
University of Kragujevac
Faculty of Mechanical Engineering
Sestre Janjić 6
34000 Kragujevac, Serbia
mirkob@kg.ac.rs

Nenad Marjanović, Ph.D., full professor
University of Kragujevac
Faculty of Mechanical Engineering
Sestre Janjić 6
34000 Kragujevac, Serbia
nesam@kg.ac.rs