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INFLUENCE OF TORQUE VARIATION ON STRESS OF TIMING BELT

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Abstract: The influence of torque variation on the stress value of the teeth of timing belt is shown in the paper. Tests were performed on timing belt drive with trapezoidal profile of teeth. Analysis of the results shows that the stress changes depending on the position of the belt teeth on a wraparound arc. Also, the size of torque affects the value of the stress. The highest stress values occur in the first teeth in the mesh, while the lowest stress values occur on value of 6th and 7th tooth. Stress analysis was performed using Finite Element Analysis (FEA) using Autodesk Inventor Professional 2016 and Ansys Workbench 2013.

Key words: timing belt drives, Finite Element Analysis, torque, stress

1 INTRODUCTION

Driving systems have very significant role in the mechanical industry thanks to very extensive researches and experiences; nowadays, it is possible to perform an optimal selection of the driving machine, as well as, the way of its adaptation to the working machine. The transfer of the mechanical energy, from the driving machine to the working one, is performed by means of transmission shafts, coupling and transmissions [1-3].

A timing belt drive is a relatively young drive designed by Richard Case in 1946, as a drive for a sewing machine [4,5]. It was a rubber belt with trapezoidal teeth profile which had replaced the belts with metal clips.

Timing belts drives where the torque is transmitted by meshing of the belt teeth and belt pulley, causes the disability of elastic sliding, as well as, the need for previous straining. They have a number of good features: small sliding, constant speed, small mass, high degree of efficiency, cheap maintenance, small load of bearings, etc... Timing belt drives are used starting with computing machines, computers, and instruments, along with machine tools, pumps, and compressors, to heavy industrial facilities. The best known application of the timing belt drives is in the automotive

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industry and the industry of IC engine's camshaft drive. The popularity of the timing belts in the automotive industry has accelerated their use in the other industries [6-9].

2 KINEMATICS OF MESHING OF TIMING BELT DRIVES

Transmission of power and motion, by using timing belt, is made by shape and friction. At power transmission, the belt teeth enter the meshing with belt pulley's belt groove, where lateral and radial clearances occur. At mashing belt teeth and belt pulley's teeth, it comes to displacing the belt towards the tangential, radial and axial direction. These displacements occur due to the torque, previous tension, circumferential force, radial force, centrifugal force, deformation of the belt due to its bending and straining, air, construction of the belt, tensile member and belt pulley, accuracy of production and assembly work, etc. It is obvious that, due to a large number of influential parameters, kinematic analysis represents a very complex and complicated process [2,6,10].

The belt tooth enters the meshing with the driving pulley, maximally strained due to previous tension. During entering the meshing, the apex of the belt tooth contacts the flank of the belt pulley tooth. At that moment, a line contact occurs. Due to interference, the belt tooth cuts into the flank surface of the belt pulley tooth. Due to the elastic properties of the belt and large stiffness of the belt pulley, a deformation of the belt tooth occurs (Figure 1, position 4). The deformation of the belt tooth increases, while at the same time, the contact surface of the belt and the belt pulley increases, as well. A contact point between the belt tooth and belt pulley moves from the apex of the belt pulley toward its root.

The maximum deformation of the tooth occurs in the position 2 (Figure 1). The reduction of deformations occurs due to the action of internal stresses and turning of the belt and the belt pulley. And then, a contact over surface occurs. The process of entering the belt teeth into the meshing with the belt pulley is followed by the relative sliding of their flanks, with appearance of the friction force. The value of nominal force changes according to parabolic law, which leads to a variation of the friction force. The greatest value of the nominal force and friction force occurs at the root of teeth.

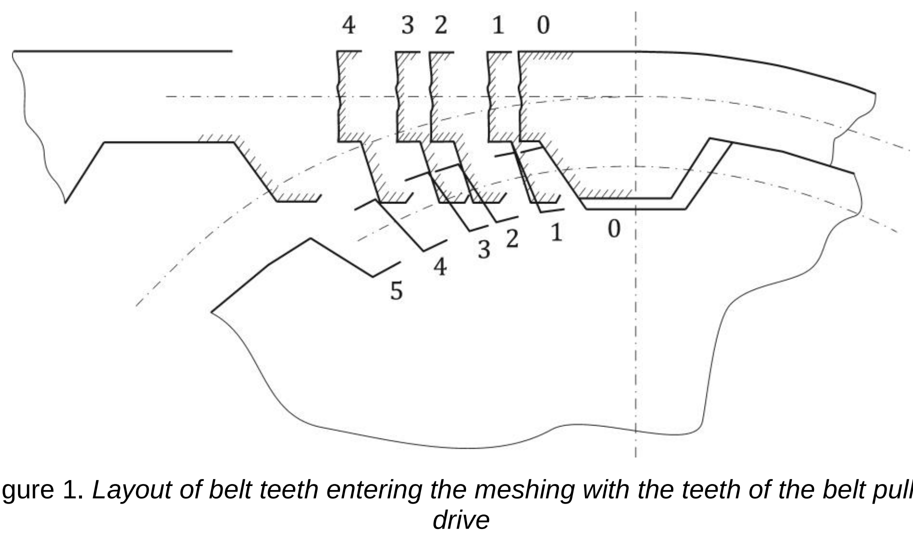


Figure 1. *Layout of belt teeth entering the meshing with the teeth of the belt pulley drive*

3 MODEL OF THE TIMING BELT DRIVE

The timing belt drive, representing the subject of the analysis, is the transmission that is widely used with passenger cars with engine performance of 1124 cm^3. The basic technical data of the timing belt are given in the Table 1.

Table 1. *Technical characteristics of the timing belt drive*

Parameter	Value
Teeth number (driving pulley)	$z_1 = 21$
Teeth number (driven pulley)	$z_2 = 42$
Teeth number of timing belt	$z_k = 116$
Belt index	L
Belt pitch	$p = 9.525$ mm
Belt width	$b = 19.05$ mm
Angle of the teeth belt profile	$\beta = 40^\circ$

The tests of tribological characteristics of this timing belt have been done on a specially designed test workbench at the Faculty of Engineering in Kragujevac [11].

Input data of the timing belt drive for numerical analysis, correspond to the testing conditions on the worktable:

- Torque M_1=7.504 Nm,
- Input number of revolutions: n_1=1400 min^{-1}.

Timing belt, for its complex structure, consist of several elements (teeth, backing surface, tensile member and outside fabric) which are made of different materials. Considering these facts, and because that there is no corresponding data in the software package, the new material has been made and its characteristics are given in the Table 2 [12-14].

Table 2. *Basic characteristics of the timing belt material*

Name	New material for belt	
General	Mass Density	0.93 g/cm^3
	Yield Strength	82.75 MPa
	Ultimate Tensile Strength	27.6 MPa
Stress	Young's Moduls	10 GPa
	Poissin's Ratio	0.35 ul
	Shear Moduls	0 GPa
Stress Thermal	Expansion Coefficient	0.000000000558 ul/c
	Thermal Conductivity	0.14 W/(m K)
	Specific Heat	450 J/(kg c)
Part Name(s)	Synchronous Belt	

A steel, with characteristics given in the Table 3, has been selected for the material of the timing belt.

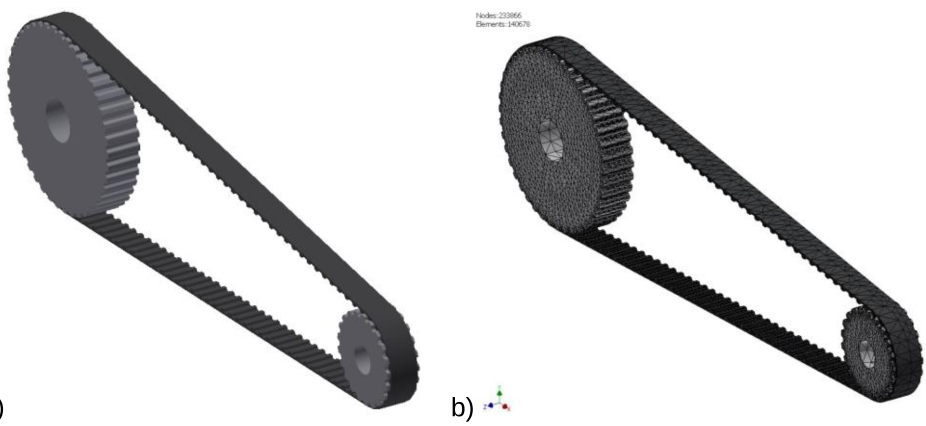
Table 3. *Characteristics of the timing belt pulley material*

Name	Steel	
General	Mass Density	7.85 g/cm^3
	Yield Strength	207 MPa
	Ultimate Tensile Strength	345 MPa
Stress	Young's Moduls	210 GPa
	Poissin's Ratio	0.3 ul
	Shear Moduls	80.7692 GPa
Stress Thermal	Expansion Coefficient	0.00000000012 ul/c
	Thermal Conductivity	56 W (m K)
	Specific Heat	460 J/(kg c)
Part Name(s)	Synchronous Pulley 1 Synchronous Pulley 2	

4 ANALYSIS OF THE INFLUENCE OF VARIATION OF THE TORQUE ON STRESS VALUES OF TIMING BELT

Based on the technical characteristics of belt and belt pulley given in the Tables 1, 2, and 3, the modelling of the timing belt drive in the software package Autodesk Inventor Professional 2016 [15] has been performed. The model of the timing belt drive is presented in the Figure 2a.

It is necessary to define the type of the contact also by defining and imposing constrains, loads, and materials in Autodesk Inventor. In this case, it is about the contact that is realized in the meshing of belt teeth and belt pulley teeth. After determining parameters, the network of finite elements has been defined as well, i.e. the type and the size of the network. The model with all entered parameters and included network of finite elements have been presented in the Figure 2b [14].



a) b)

Figure 2. *a) Model of the timing belt drive, b) Model of the timing belt drive with the network of finite elements*

Infliction of the load is done by placing the torque on the place of the driving pulley. By calculation, the torque on the drive pulley is $M_1 = 7{,}504\ Nm$. The stress condition of the timing belt at the given torque value has been presented in the Figure 3.

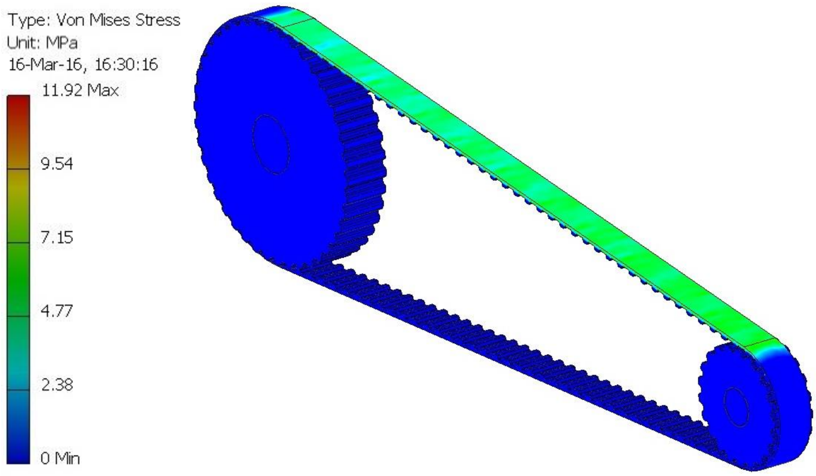


Figure 3. *Stresses in the belt at the load torque M=7500 Nmm*

The analysis of the value of Von Mises stresses in the teeth of timing belt along the wraparound arc has been performed for different torque values 5 Nm, 7.5 Nm, 15 Nm and 30 Nm.

The Figure 4 presents the values of Von Mises stresses for all teeth in the meshing and different torque values [14].

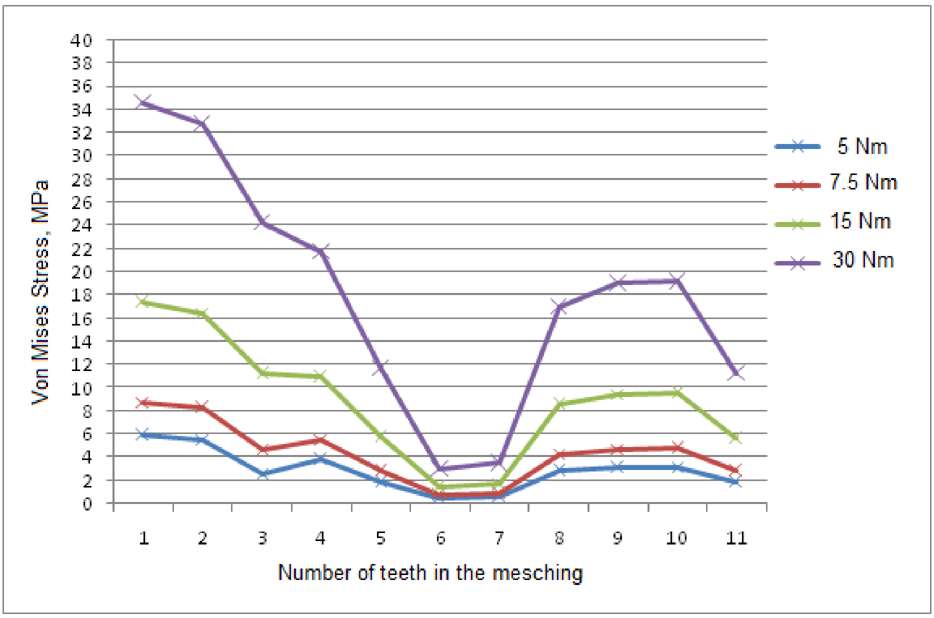


Figure 4. *The plot of influence of torque variation on the stress values in the belt teeth*

From the Figure it can be seen that the highest stress is in the tensile branch of the first two teeth, and then the stress decreases at the transition towards the tensile branch. However, the minimum values of stresses are in the 6th and 7th tooth. Afterwards, the stress value increases again and the maximum values occur in the 9th and 10th tooth. This stress distribution is in accordance with kinematic analysis by which it is confirmed. The minimum stress value occurs in the teeth which are located in the middle of wraparound angle (arc), primarily due to discharging, but also due to difference in the deformation of certain teeth. The clearances, occurring due to deformation, as well as, the values of normal and friction forces, change their directions and values after half way of wraparound arc, which has been confirmed by static analysis.

The values of Von Mises stresses increases with the increase of torque, as expected. However, it has been noticed that the size of finite elements has very small influence on the stress value (approximately 1.5%) (Figure 5) [14].

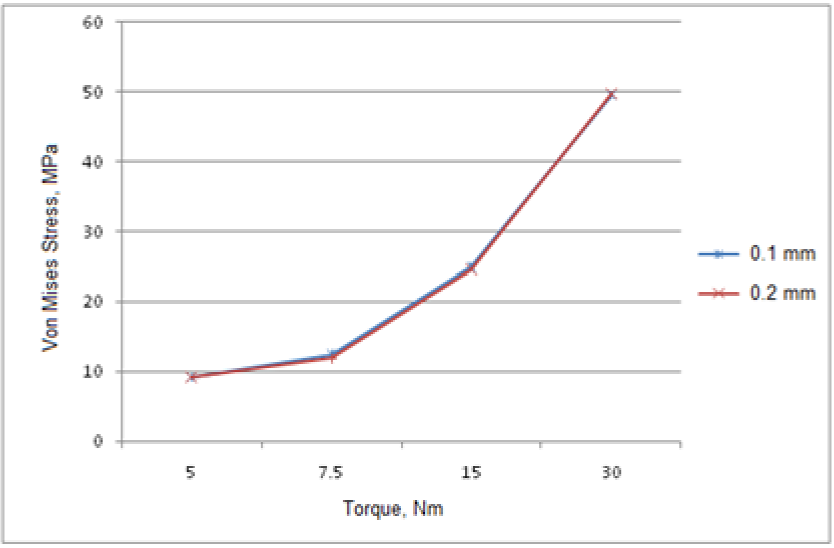


Figure 5. *The plot of influence of size variation of finite elements*

5 CONCLUSION

Based on conducted timing belt stress analysis with trapezoidal tooth profile by using finite elements it has been noticed that the maximum stress values occur on the first teeth in the mesh. It has also been noticed that the stresses change depending on the position of the belt teeth or the minimum stress values occur on the teeth which are located in the middle of wraparound angle. During the belt displacement along the wraparound angle of the belt pulley, it come to bending and straining of the belt. Unlike flat belts, where the bending of timing belts is done along the unified curve, the bending of timing belts is done along the polygonal profile. The bending of the belt leads to internal losses, as well as, the belt fatigue, or tensile member. The bending and straining of the belt along the wraparound angle lead to belt deformation. In addition, the load of the belt teeth decreases from entering of belt teeth in the mesh with the belt pulley to its exit from the mesh. The first tooth in the mesh, where the maximum deformations occur, is the most loaded one. Considering the different teeth loads, it comes to formation of uneven deformations of belt teeth along the wraparound angle. The difference of deformations leads to relative displacement of the first row of the belt toward tangential direction. Besides that, the belt enters the mesh maximally strained, and it leaves the mesh with belt pulley unballasted. Due to these displacements of the belt, it comes to a relative movement of the belt in comparison to the belt pulley along the wraparound angle. The torque value affects the stress value in the way that the stress value increases with the increase of torque. The size of the finite elements has a small influence on the stress value.

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NOMENCLATURE

z teeth number (driving pulley),

p belt pitch, mm

b belt width, mm

M torque, Nm

n input number of revolutions, min^{-1}

Greek symbols

β angle of the teeth belt profile, °

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