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The proposal of estimation method of mating between pulleys and cogbelt

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Abstract

Two estimation methods of mating (meshing) between pulleys and cogbelt of uneven-running strand transmission are presented in this work. The first one is based on the application of high speed camera, and the second one is based on CAD model and FEA software in order to determine the teeth number of pulley and cogbelt during meshing. The performed estimation allows to indicate the reasons of incorrect mating due to e.g. modelling and manufacturing of cogbelt pulleys.

Introduction

In belt transmissions with synchronous timing belts, load is transmitted as a shaped and frictional contact. The turning moment is trasmitted by the appropriate shape of the belt cooperating with the timing belt pulleys.

A transmission with a synchronous belt requires little initial tension and therefore loads shafts and bearings less than flat belts or V-belts.

To increase the drive of a transmission, the wrapping angle of the small wheel is increased by means of the tension roll. The synchronous belt is equipped with the carrying input consisting of glass fibres, steel fibres or aramid fibres. Carrying belts exibit such properties as: high resistance to stretching, little extension and high elasticity. Furthermore, fibres shall have appropriate fatigue strength. Decreasing the cross-section of a single fibre results in an increased elasticity of the belt and decreased stress in a single fibre.

The so-called 'polygonal effect' is induced in a belt transmission with a timing belts. This effect influences a non-uniform transmission of rotary motion.The phenomenon is induced by the change in the diameters of the arc of contact in the wheel. The real diameter of the wheel changes within dimentions d_{max} and d_{min} and depends on the number of cogs and the wheel graduation.

A timing belt pulley wheel is, in fact, a polygon that consists of sections of chords formed by the heads of cogs. At the moments the belt meshing and demeshing, the foot of a cog contacts the polygon and the point of contact between the cog outline and the polygon is a kinematic centre of the rotating wheel as long as it is increasing.

At meshing and demeshing of one cog in a loaded belt, the pivoting point O of the belt is situated opposite the loaded surface of the side of the belt pulley cog - points a) and b) (Fig. 1).

The lower part of Figure 1 - points c) and d) show the shift of the pivoting points O at meshing and demeshing in the strand of an unloaded belt. The pivoting point O is situated on the extended by the load surface of the belt wheel cog .

As a result of the polygonal effect, despite the constant angular velocity ω of the driving wheel, the velocities of the belt strand as well as of the driven wheel change. The ratio of velocities of wheels depends on the number of cogs. Therefore, the greater number of cogs in the wheel, the more the non-uniformity of the drive transfer is diminished and the lesser influence of the polygonal effect.

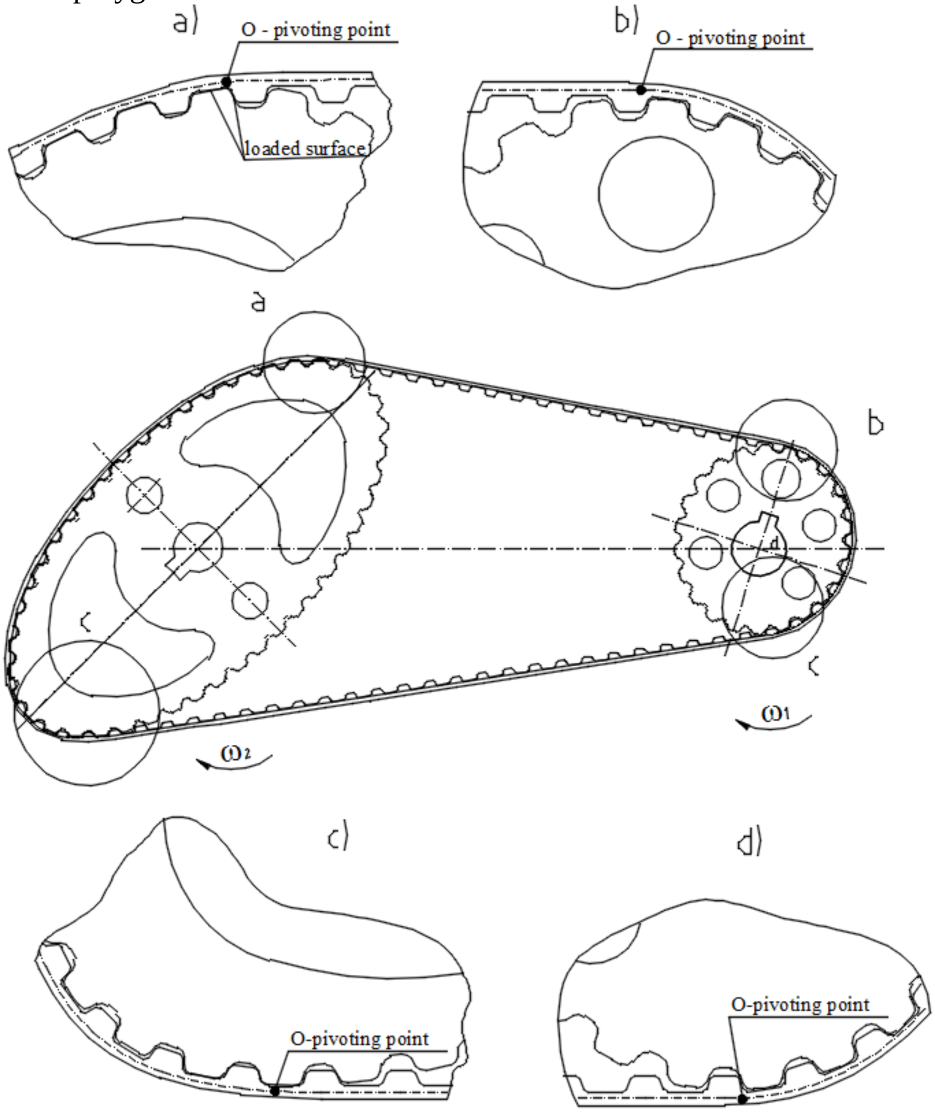

Fig. 1. The scheme of the synchronous belt meshing: a) demeshing out of the driving wheel, b) meshing with the driven wheel, c) meshing with the driving wheel, d) demeshing out of the driven wheel

This phenomenon is particularly important during mating between pulleys and cogbelt of uneven-running transmission. The characteristic feature of this type of transmission is a periodical variation of the velocity ratio during one rotation cycle due to the application of pulleys with noncircular envelope. Design and modelling problems of envelope of gears are presented in studies [1-5]. The present state of knowledge is the reason for investigation and explanation of phenomena during the transmission work – this will be done with the application of FEM.

Numerical model

The examined numerical model of a strand transmission was elaborated in the Abaqus program. The model was described as a two dimensional state of stresses. Geometrical models (solid models) of pulleys and cogbelt were prepared in AutoCAD and Autodesk Inventor programs. The transmission elements were transferred to the Abaqus program in DXF files. The initial configuration of the transmission – before assembly – is presented in figure 2. The pulleys and the cogbelt were discretizated by 4-node and 3-node finite elements for a plane state of stresses with reduced integration and linear shape functions (CPS4R and CPS3 according to Abaqus denotation).

The cogbelt reinforcement was defined as 2-node bar element with linear shape functions (T2D2 according to Abaqus denotation). The bar elements were defined on the nodes of elements of plane state of stresses. The FEM model of the transmission consisted of 18 084 elements and 18 710 nodes and had 37 418 degrees of freedom.

Aluminium was taken as a material of wheels. The material is isotropic and elastic with the following properties:

- Young's modulus – 73 GPa,
- Poisson ratio – 0,33,
- density – 2800 kg/m^3.

Hooke's classical model of elastic material was taken for material of wheels [6].

The FEM model of the cogbelt had a composite structure (two materials) – fig. 2. The rubber, which had been used as a body of the cogbelt, was described as isotropic and nonlinear-elastic material [7-10].

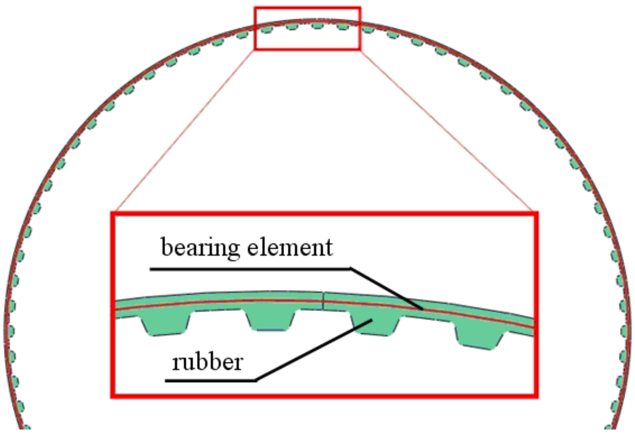

Fig. 2. Composite structure (two materials) of the cogbelt

The exemplification of the transmission work was done in two steps:

1) cogbelt stretching,
2) a simulation of the transmission work. This process has a quasi-static character.

In first step, a kinematic excitation (horizontal displacement) was applied to the reference nodes of the rigid body constraints of both pulleys – this excitation caused a displacement of the pulleys in order to get the specified force in the cogbelt, i.e. 150 kN.

The speed of a vertical displacement and a rotation on axis were excited as zero. The simulation of this process lasted 2 seconds (fig. 3). The diagram of the energy balance for the first step confirms the quasi-static character of the process (fig. 4). This figure shows that after selection of a backlash (ca 1.5 s), most of the work of external forces is transferred to the system in a form of the internal energy (initial stresses in the cogbelt) and is partially dissipated because of friction between the pulleys and the cogbelt. The kinematic energy gets a small value (< 20 mJ) mainly due to the cogbelt vibrations which are excited by a given excitation.

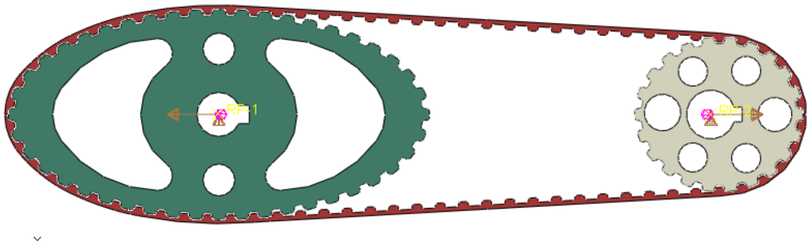

Fig. 3. Kinematic excitation (horizontal displacement – brown arrows) which stretches the cogbelt

The second step is a simulation of the transmission work. The following two analysis were conducted:
- Z1 – excited rotation of the pulley K1 during a free rotation of the pulley K2,
- Z2 – excited rotation of the pulley K1 during the pulley K2 braking with a torque of 10 N·m.

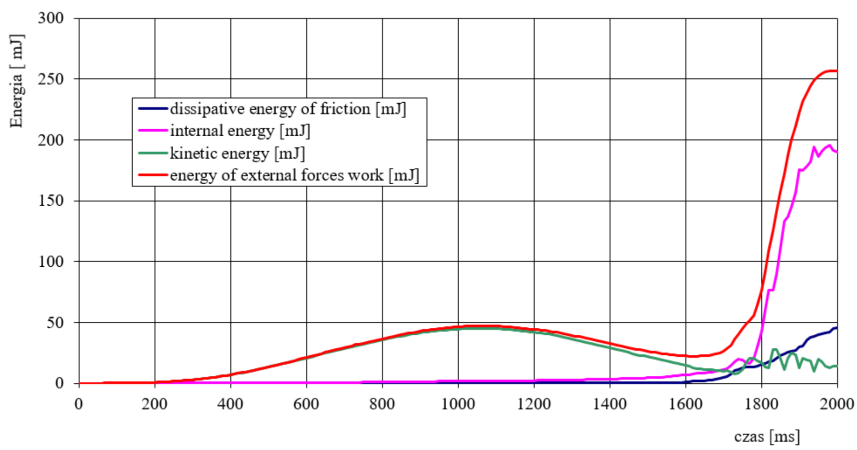

Fig. 4. Energy balance for the first step (cogbelt stretching)

Contact modelling with FEA

Contact was defined as a system of two pairs of contact surfaces between:
- tooth surfaces of wheel K1 and cogbelt,
- tooth surfaces of wheel K2 and cogbelt.

In Abaqus contact constraints are automatically defined for nodes which are placed on surfaces of contact pair. Contact conditions are forced with the application of penalty method. The friction is defined with the use of classical Coulomb’s friction law – the value of 0.3 was taken for the friction coefficient. In Abaqus/Explicit contact conditions (penetrations and contact reactions) are checked in every increment. For each successive form of deformation the contact constraints are taken as a result of constraints which are imposed to calculations of velocity and acceleration. Contact reactions are calculated during determining the vector of nodal, external forces *P*. The procedure of explicit integration of equation of motion does not demand the application of iterative algorithm – this allows to solve effectively strong discrete and complex contact algorithms such as dynamic simulation of transmission work. This criterion was decisive during selection of calculation method for dynamic simulation.

Figures 5 and 6 present number of teeth in wrap and contact in function of angle of rotation for driving and driven wheel.

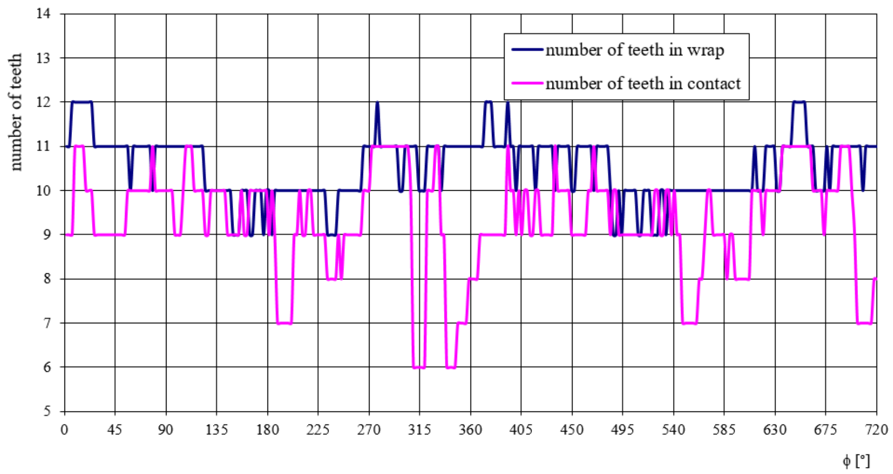

Fig. 5. Number of teeth of small wheel in wrap and contact (FEA method)

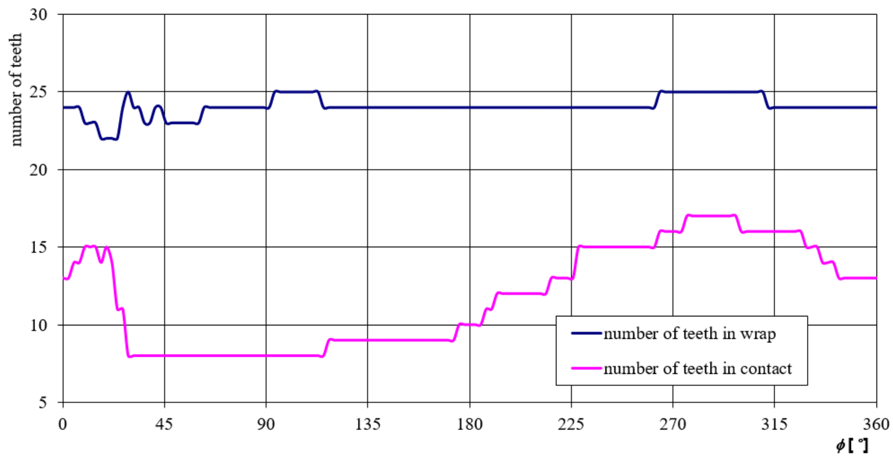

Fig. 6. Number of teeth of elliptical wheel in wrap and contact (FEA method)

Test stand and measurements

A measuring set with CMOS camera High Speed Star 5 series (LaVision manufacturer) was applied to register a coupling process between cogbelt and noncircular cogbelt pulley. This device allows to register directly high speed processes such as fuel injection and load motion (Fig. 7). The photos can be done with the speed 250 000 frames per second (fps), but only for reduced resolution of matrix CMOS 128×16 pixels. The spatial resolution was the main priority for the research measurements, so it was decided to set the speed to the value of

3000 fps and it was sufficient value for the research tests. Maximal resolution of camera is equal to 1024×1024 points for the speed 3000 fps (it responds to physical resolution of matrix for detector size of 17×17 micrometers). The chosen camera allows to register monochrome images and works in spectral range from 380 to 800 nm. For applied configuration the camera was equipped with lens with focal distance 50 mm. In order to get optimal (maximal) filling of view field of camera, it was necessary to set the camera in a distance from several to ca. 30 cm from the investigated objects. This causes observable distortions of view which can make difficulties in the analysis of image and can introduce some errors into measured quantities.

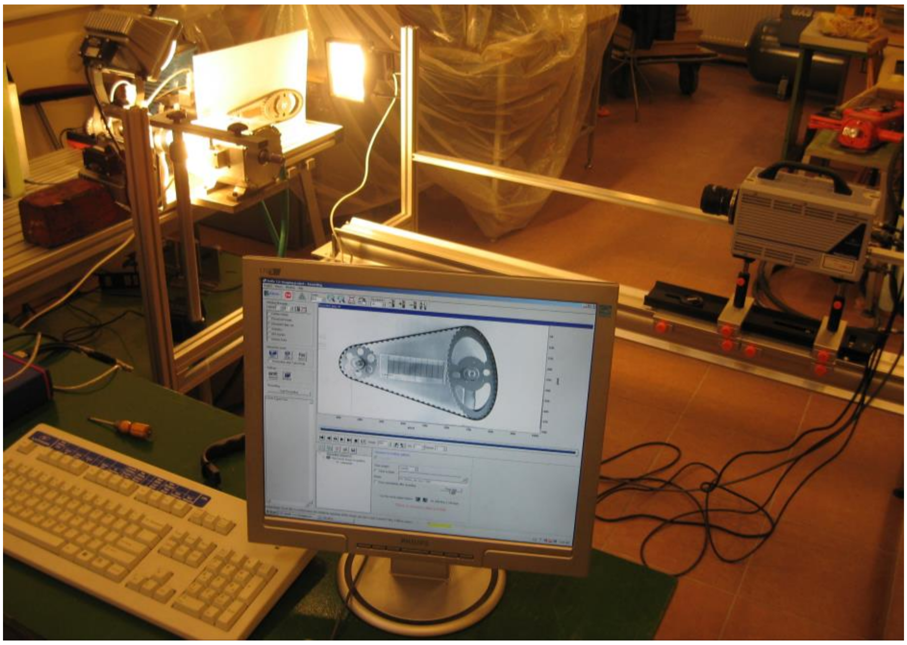

Fig. 7. Test stand for image acquisition of work of uneven-running strand transmission with cogbelt

The investigated transmission was illuminated with two halogen lamps – each one with the power of 500 W. The lamps were set together in order to minimalize the presence of shadow in the field of view.

Methodology of image processing and analysis

From the point of view of image processing and analysis the proposed approach should be defined as model based recognition, because the essential element of elaborated algorithms is the assumption of model accessibility of recognized object. This model is directly imported by software from AutoCAD files.

In elaborated process of image analysis the following assumption was made: the processing of each frame of video stream is independently done.

This process consists of two main stages:

– CAD model and image fitting,
– estimation of chosen variables for state of investigated object (cogbelt pulley): angle of rotation, rate of misfit.

The elaborated software was implemented with the application of known library of image analysis and computer vision OpenCV [11, 12]. This is very universal and the most applied environment for developing the image applications – it is accessible within a framework of open license software.

Figures 8 and 9 show quantitative list of teeth of noncircular cogbelt pulleys which are in wrap and contact.

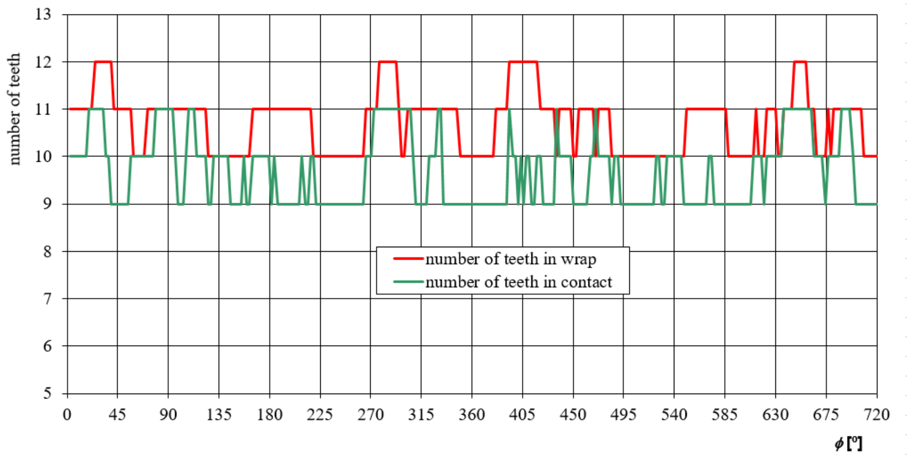

Fig. 8. Number of teeth of small wheel in wrap and contact (optical method)

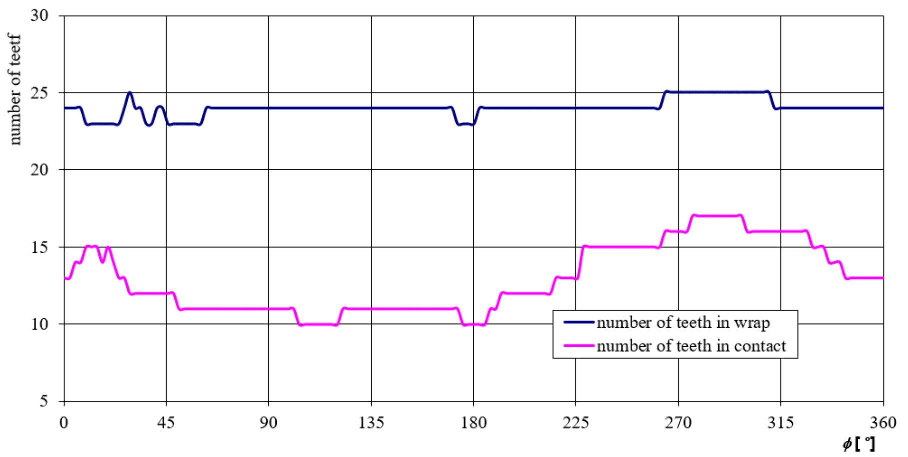

Fig. 9. Number of teeth of elliptical wheel in wrap and contact (optical method)

On the basis of diagrams one can show the angles of rotation of wheels for which the number of teeth is excessively reduced and this can results in very high load of cogbelt and uneven-running motion of transmission.

Conclusions

A proper mating between pulleys and cogbelt in strand transmission is a base to apply full loading of such type of drive.

On the basis of performed analyses of images one can conduct the quantitative estimation of the number of teeth in wrapping angle and meshed teeth i.e. the number of loaded teeth. The accepted method of estimation requires improvements, but after some corrections it can be applied to estimate strand transmissions with noncircular cogbelt pulleys and classical strand transmissions. The aim of research with the application of finite element analysis was the quantitative and qualitative analysis of operation of strand transmission with noncircular cogbelt pulleys. The operation of cogbelt during transmission work was analysed. On the basis of this analysis the following parameters were evaluated: the number of cogbelt teeth in wrapping angle and number of meshed teeth of pulley and cogbelt.

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