CONTROLLED TESTING OF BELT TRANSMISSIONS AT DIFFERENT LOADS

JOZEF MASCENIK, SLAVKO PAVLENKO

Department of Technological System Design, Faculty of Manufacturing Technologies with a seat in Presov, Technical Universtity of Kosice, Presov, Slovak republic

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jozef.mascenik@tuke.sk, slavko.pavlenko@tuke.sk

The presented paper provides the alternative options for determining the condition of belt gear based on the testing and monitoring. In order to carry out experimental measurements, a newly developed device for testing, monitoring and diagnostics of belt drives was designed, as well as the possibility of determination of limit states by extreme loads. The designed measuring stand allows to determine the point of destruction of the belt for an extreme load. The process of the belt measurement was to set the predetermined input revolutions of the driving motor by means of the Altivar 71 (FM1) frequency inverter connected to the driving electric motor. The next step in defining the input parameters was to set the load on the driven electric motor. The load on the driven motor was achieved by the torsional moment set by means of the Altivar 71 (FM2) frequency inverter connected to the driven electric motor. In the paper, the analytical calculation is processed. The article mainly points to the innovation of the stand for testing belt transmissions.

KEYWORDS

stand, innovation, sensor, belt gear, monitoring

1 INTRODUCTION

The belt gears transfer mechanical energy for longer distance between shafts, the gear possesses good damping effect, and however, in case of the conventional belts its disadvantage rests in considerable slip, therefore the application of the precise transference number is excluded. The belt is stressed by tensile force in the belt and by centrifugal force and by bending during coiling onto the belt pulley. To allow the belts transferring of the peripheral force between the discs, they must be sufficiently pushed against the discs. Pushing is achieved by pre-stress of a tensile element. In the practice, frequent is the occurrence of incorrectly adjusted belt gear causing high vibrations which negatively influences the bearings, the shafts, and the entire machine structure. In case of the gears in questions, the most commonly occurring faults are, for instance, the following: the driving belt pulleys are not on the level with the driven ones, the belts are extremely or insufficiently tight, occurring resonance effects of the belts, wearing of the belts, the belt pulleys are not balanced or are fixed in eccentric position [Krenicky 2008].

The designed device allows determination of the belt slip expressed by the coefficient of elastic creep and specific slip along with other parameters. The device disposes of the installed sensors to record the monitored parameters which can influence the fault rate of the belt gear [Ivanov 2020].

The presented paper provides the alternative options for determining the condition of belt transmission based on the testing and monitoring. In order to carry out experimental measurements, a newly developed device for testing, monitoring and diagnostics of belt drives was designed, as well as the possibility of determination of limit states by extreme loads. The designed measuring stand allows to determine the point of destruction of the belt for an extreme load.

3D modelling and simulation Autodesk Inventor software was used in developing and structural-design stage. The program allows creation and analysis of a complete product prior to its actual manufacturing. Inventor software also enables to benefit from digital prototyping by integrating 2D AutoCAD drawings and 3D data into a single digital model [Mascenik 2015].

2 CURRENT STATE OF THE ART OF BELT GEARS

The belt gears transfer mechanical energy for longer distance between shafts, the gear possesses good damping effect, and however, in case of the conventional belts its disadvantage rests in considerable slip, therefore the application of the precise transference number is excluded. The belt is stressed by tensile force in the belt and by centrifugal force and by bending during coiling onto the belt pulley. To allow the belts transferring of the peripheral force between the discs, they must be sufficiently pushed against the discs. Pushing is achieved by pre-stress of a tensile element [Gerbert 2002]. In the practice, frequent is the occurrence of incorrectly adjusted belt gear causing high vibrations which negatively influences the bearings, the shafts, and the entire machine structure. In case of the gears in questions, the most commonly occurring faults are, for instance, the following: the driving belt pulleys are not on the level with the driven ones, the belts are extremely or insufficiently tight, occurring resonance effects of the belts, wearing of the belts, the belt pulleys are not balanced or are fixed in eccentric position [Coranic 2018].

The designed device allows determination of the belt slip expressed by the coefficient of elastic creep and specific slip along with other parameters. The device disposes of the installed sensors to record the monitored parameters which can influence the fault rate of the belt gear. Parameter monitoring is performed by the PC technique and by the suitable software.

In case of belt gears, the terms of creep and slip of the belt must be defined. *Creep of the belt* is a phenomenon occurring if the belt is loose, i.e. insufficiently tight [Husar 2019]. By means of required tightening the creep can be excluded. *Slip of the belt* (specific slip) is a phenomenon occurring even if the belt is correctly tightened and with the increasing tightening of the belt the slip becomes more extensive. The slip cannot be prevented due to operation conditions of the belt drives. The belt slip represents the subject of our measurement.

To avoid the creep on the small belt pulley during the run, the adequate tightening after fitting the belt on the pulley should be assured. The extent of prestress in case of the V-belts should be as follows:

$$F_p = \frac{F_1 + F_2}{2} \tag{1}$$

To avoid the creep of the belt the actual prestress is selected

$$F_{ps} = (1.2 \div 1.6).F_p \tag{2}$$

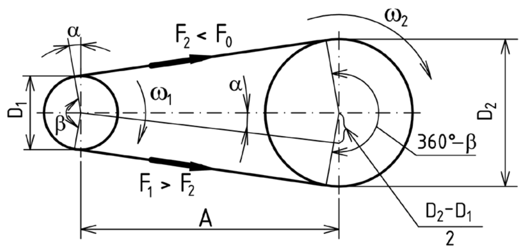

Figure 1. Distribution of forces in case of the belt gear

The prestress, especially of the new belts is substantially more extensive in case of which the elongation during the period of the running-in must be taken into consideration. With regard to actual prestress of the belt, in the individual strands during the run, the action of forces F_1, F_2 is observed, which are bonded in reference to the following relation:

$$F_1 = F_2.e^{f\alpha_1}, \tag{3}$$

with

F_1 - force (tension) in converging strand,

F_2 - force (tension) in diverging strand,

f - coefficient of friction in the key seat,

α_1 - angle of wrap of small pulley [Krenicky 2010].

Their difference determines maximal driving force F_{max} which with the respective force relation can be transferred by the belt without the creep on the small belt pulley.

$$F_{o1} = F_1 - F_2 = F_2(e^{f\alpha_1} - 1) \tag{4}$$

In a similar way maximal driving force of the big belt pulley can be determined.

$$F_{o2} = F_2.e^{f\alpha_2} \tag{5}$$

As $\alpha_2 > \alpha_1$, so $F_{o1} > F_{o2}$. Driving force F_{o1} is given by the transferred torque as follows

$$F_{o1} = \frac{2M_{k1}}{D_1} \text{ [Gaspar 2021].} \tag{6}$$

In case of higher peripheral velocities the effect of centrifugal force can also be observed

$$F_{cv} = \rho.S.v^2 = q.v^2, \tag{7}$$

with

S - cross-sectional area of the belt [m^2]

q - weight of 1m of the belt length [kg.m^{-1}]

v - peripheral velocity of the belt [m.s^{-1}]

ρ - specific weight [kg.m^{-3}].

Gradual decrease of force (tension) F_1 in the belt from the *A* point to force F_2 in the *B* point of the driving belt pulley (see fig. 1) causes shortening of the belt by corresponding value of Δl [Jacyna 2015].

The proportional shortening expressed by the relation

$$\varepsilon = \frac{\Delta l}{l}, \tag{8}$$

is referred to as specific slip of the belt. The belt is elongated (it creeps) on the driven belt pulley by the same length with the increase of force (tension) in the *C* point to the value of F_1 in the *D* point (fig. 1). Coefficient ψ defined as $\psi = (1 - \varepsilon)$ is referred to as the coefficient of elastic creep [Balta 2015].

Peripheral velocity of the small belt pulley is as follows:

$$v_\eta = \frac{\pi.D_1.n_1}{60} = \frac{D_1}{2}\omega_1 \tag{9}$$

Elastic deformation of the belt causes lower peripheral velocity of the driven belt pulley contrary to peripheral velocity of the driving pulley.

According to the aforementioned facts the following can be proved:

$$v_2 = v_1(1-\varepsilon) = v_1.\psi \tag{10}$$

The gear ratio of the belt gear is given by the following relation:

$$i = \frac{n_1}{n_2} = \frac{\omega_1}{\omega_2} = \frac{D_2}{D_1.\psi} \tag{11}$$

The value ψ ranges usually from 0.98 to 0.99. The slip becomes extensive with the gear ratio, with velocity, and with the belt tension [Straka 2020b].

The measured parameters monitored on the device and transferred directly through a digital-to-analogue converter into the computer represent the actual revolutions of the driving belt pulley of the electric motor n_{1s} and the actual revolutions of the driven belt pulley (brake) n_{2s}. On the basis of the data, the software calculates inevitable quantities the outcome of which is determination of the resulting slip of the belt gear.

<u>The measured and the calculated parameters of the measurement of the belt slip are as follows:</u>

n_{1t} – card revolutions of the electric motor – driving machine,

n_{1s} – actual revolutions of electric motor with loading of the driving part and with the given tensioning force F_H,

n_2 – revolutions of the driven machine without the slip,

$$n_2 = \frac{n_{1s}}{i_t}, \tag{12}$$

i_t - theoretical gear ratio,

$$i_t = \frac{D_p}{d_p}, \tag{13}$$

n_{2s} - actual measured revolutions of the driven machine with the slip,

Δn_2 - slip revolutions $\Delta n_2 = n_2 - n_{2s}$,

T - measured time of slip revolution [s],

ξ - specific slip,

$$\xi = \frac{60}{T.n_{1s}}.i_t, \tag{14}$$

ψ - coefficient of elastic creep $\psi = 1 - \xi$,

i - gear ration of the belt gear,

$$i = \frac{D_p}{d_p.\psi} \tag{15}$$

and thus

$$i = \frac{i_t}{\psi} \text{ [Lubarda 2015].} \tag{16}$$

3 PRIMARY MEASURING DEVICE OF THE BELT SLIP

The device consists of the basic frame containing a drive electric motor and a brake. The belt pulleys mounted on the electric motor shaft and the brakes are connected by the V-belt and thus together they form the belt gear. The electric motor fixed on the frame is adjustable with the option of the V-belt tightening. The brake effect, the extent of which can be controlled proportionally induces inevitable torque in the electric motor along with the respective forces of the belt in its converging and diverging strands. The difference causes the belt pulley slip needful to be measured. Tightening of the belt and the respective shift of the electric motor are performed through a proving ring by a tightening screw and by a thrust bracket. The quantities inevitable for calculation and for the slip are monitored and assessed by a computer through sensors of the electric motor revolutions and of the brake. The values of electric motor input power and of intensity of tensioning force of the proving ring are read directly off the measuring devices.

The following figure 2 shows the scheme of the designed device and in figure 3 the actual designed measuring device of the belt gear slip is shown.

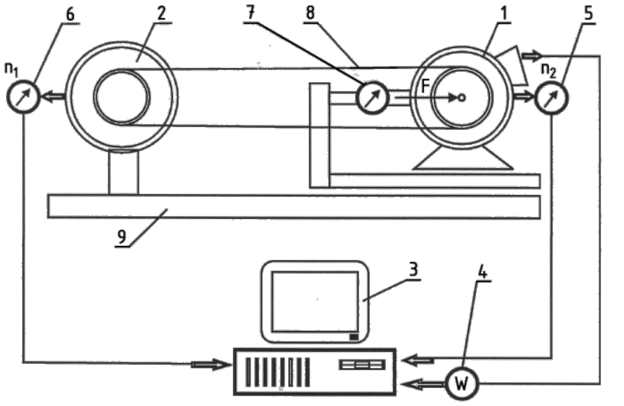

Figure 2. Scheme of measuring device of the belt gear slip: 1 – Electric motor, 2 – Brake, 3 – Computer, 4 – Sensor of output, 5 – Sensor of revolutions n_1, 6 – Sensor of revolutions n_2, 7 – Proving ring with deviation meter, 8 – Belt, 9 – Frame

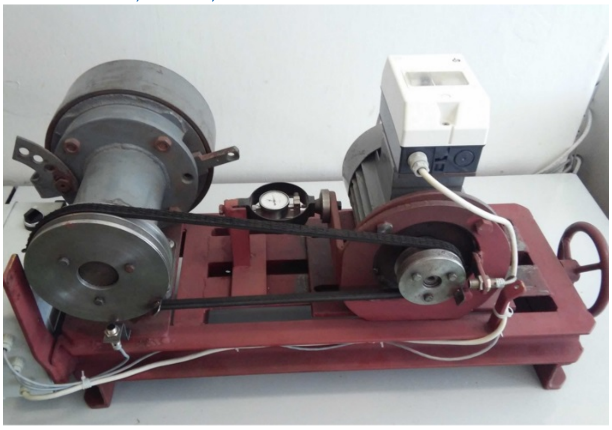

Figure 3. Measuring device of the belt gear slip

To allow actual measurement as mentioned afore, the device must contain the sensors out of which a signal is sent to the computer and consequently the monitored state of the belt gear is assessed. The following figure 4. shows the sensors of a small (driving) and of a big (driven) belt pulley.

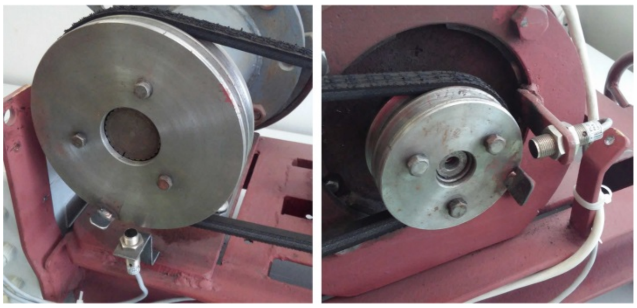

Figure 4. Fixed sensors for measurement of revolutions

The device in question intended for measurement of the belt gear slip is designed as a universal device in case of which a simple adjustment allows adding or changing of the individual components. The device enables change of the small or of the big belt pulley as well as the change of the belts and of input or output parameters, etc. [Gaspar 2017]. For instance, the change of the belt pulleys is carried out for the purpose of change of the gear ratio between input and output, which also represents the intention within the frame of the research innovation in the sphere of the belt gear testing.

4 INNOVATED MEASURING DEVICE OF THE BELT SLIP

The newly designed device consists of the basic frame containing a drive electric motor and a driven electric motor, which is included into the assembly as a brake. The belt pulleys mounted on the electric motor shaft and on the driven electric motor are connected by the V-belt and thus together they form the belt gear [Mascenik 2011]. The asynchronous electric motors Siemens (1LA7090-2AA10ZA11 1.5KW 2900 rpm, 400V Y 50Hz IMB3 PTC thermistor) fixed on the frame are adjustable with the option of the V-belt tightening. The driven electric motor controlled by a frequency converter is set up as the brake the extent of which can be controlled proportionally and in the electric motor its brake effect induces respective forces of the belt in converging and diverging strands [Rewers 2018]. Yet, the difference causes the belt pulley slip that can be measured. Tightening of the belt and the respective shift of the electric motor are performed with a tensometric sensor of thrust, a screw rod and thrust bracket. The quantities inevitable for calculation and for the slip are monitored and assessed by a computer through sensors of actual revolutions of both the driven and driving electric motors. The values of intensity of tensioning force are assessed by a PC [Bun 2018]. Figure 5 shows the 3D model and figure 8 shows the scheme of the designed device and in figure 7 the actual designed measuring device of the belt gear slip is shown.

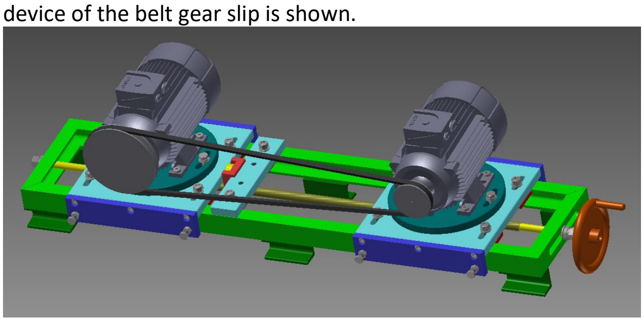

Figure 5. Newly designed stand for belt gear testing

Monitoring and adjustment of the belt tightening is directly connected via force tensometric sensor of EMSYST EMS50. A membrane sensor features bridge interconnection in case of small dimensions and measurement is carried out in direction of pressure. Force measurement ranges from 0.1 up to 10 kN. The sensor can serve for industrial as well as for laboratory purposes. The position of the sensor is shown in Fig. 6.

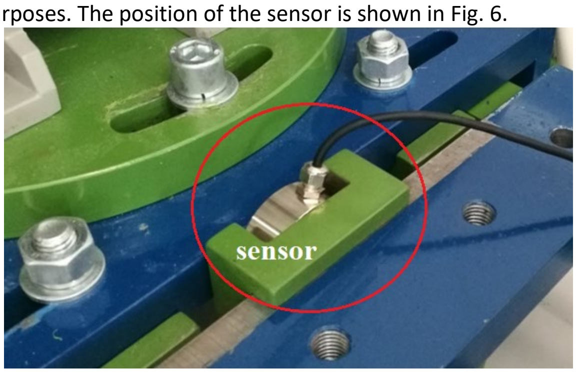

Figure 6. Monitoring of belt tightening with tensometric sensor of thrust

The test device consists of three basic interconnected and working units, namely:

• measuring unit with belt transmission,
• control and regulate unit,
• monitoring and evaluation unit.

The measuring unit (Fig. 9) of the device consists of a base metal frame on which the components necessary for the measurement are mounted. A pair of electric motors is placed on the slides mounted on the base frame. The necessary belt tension is provided by the sliding of the electric motors. The belt tension is possible to control by means of a tensioning screw located at the bottom of the base frame, passing through the internal thread. One of the electric motors serves as a driver of gear, the other one serves as a brake to be used as a load of gear.

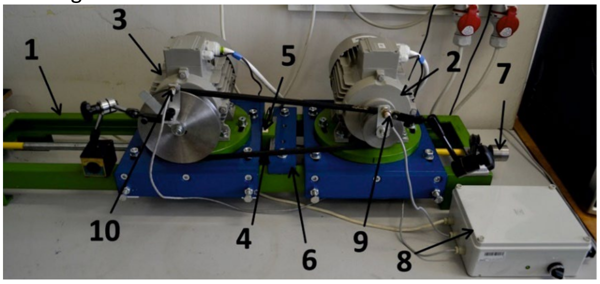

Fig. 7. A device for the belt transmission characteristics measuring. 1 - base metal frame, 2 - driving electric motor, 3 - driven electric motor, 4 - tested belt, 5 – tensometer EMSYST EMS50, 6 - tensioning plate, 7 - tensioning screw, 8- converter, 9- sensor of actual revolutions of driving belt pulley, 10 - sensor of actual revolutions of driven belt pulley.

The three-phase asynchronous electro motors Siemens (1LA7090-2AA10ZA11 1.5kW, 2900 rpm, 400V, 50Hz) are used in the assembly of the measuring stand. The electro motors are designed to drive industrial equipment such as ventilators, pumps, machine tools etc.

The transfer of the rotary motion between the pulleys located on the shafts of the electric motors is provided by means of a wedge-shaped belt. The measuring stand makes it easy to replace the pulleys on the electric motor shafts for testing the different belts or straps [Mascenik 2016a].

Following fig. 8 shows a scheme of the device designed for measuring of belt gear slip or for testing of new belt types. The device assembly consists of the following: 1 – driving electric motor, 2 – driven electric motor as the assembly brake, 3 – monitoring and assessing computer, 4 – belt, 5 – sensor of the actual revolutions of input belt pulley, 6 – sensor of the actual revolutions of output belt pulley, 7 – tensometric sensor of thrust, 8 – supporting frame, FM1 – frequency converter to control the driving electric motor, FM2 – frequency converter to control the driven electric motor.

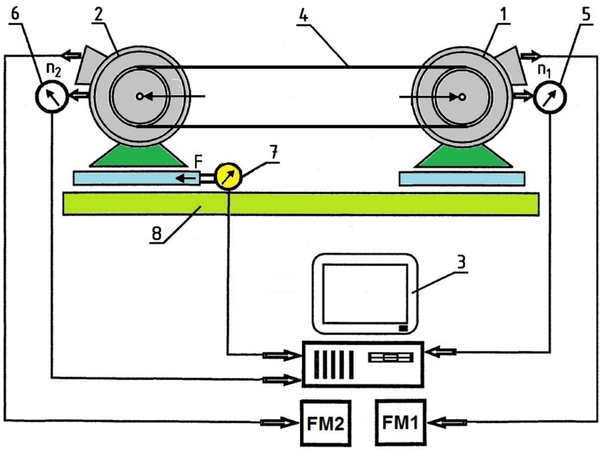

Figure 8. Scheme of device designed to test the belt

Monitoring and adjustment of the belt tightening is directly connected via force tensometric sensor of EMSYST EMS50. Membrane sensor features bridge interconnection in case of small dimensions and measurement is carried out in direction of pressure. The range of force measurement is from 0.1 up to 100 kN. The sensor can serve for industrial as well as laboratory purposes [Husar 2021].

For the purpose of controlling and regulation of the electric motor's operation, the test stand is equipped with a primary control unit (Fig. 9) consisting of a pair of frequency converters and a connecting cable with a USB/RS485 converter enabling the interconnection of the frequency converters with the computer [Krenicky 2012].

Frequency converters can be controlled and monitored when the entire assembly is connected to the PC through monitoring and adjusting SoMove software. SoMove software is used for configuration and adjustment of parameters of Altivar frequency converters, of Lexium synchronous drives, TeSys motor starters.

Figure 9. Control panel with frequency converters

SoMove program features a unique option of off-line mode which allows access to any parameter of the adjusted device (prior to connection to a superior system) [Straka 2020a]. Its output is a configuration file that can be archived, printed or exported to Excel. The created configuration can be read by multi-Loader which, apart from other, allows copying of parameters without use of personal computer.

5 CONCLUSIONS

One of the aims of the measuring device design is to determine limiting conditions or to define a destruction point through extreme loadings of the belt. The stand design stemmed from the essential technological and structural knowledge gained from technical literature, available materials and practical advice offered by the experienced professionals [Coranic 2021]. The selection of the most suitable alternative was preceded by a proposal of several alternatives and their detailed analysis by means of virtual model. Through application of the installed sensors the device allows measuring of the actual revolutions of belt pulleys which are compared with the ones set up for frequency converters. Monitoring of the inevitable parameters to determine for example the belt gear slip is carried out by means of the sensors installed at pre-defined places the data from which are processed by the PC [Mascenik 2016b]. When the device is placed on a damping or rubber pad the vibrations of conversion can be measured. The results and knowledge of research measurements could contribute to the sphere of development of new types of belt gears.

The main goal of this paper was to point out the innovation of the test equipment of belt transmissions. The original device was a measuring set with a mechanical brake at the output. The new device is designed to be more sophisticated and the load can be regulated at the output of the belt drive using a frequency converter. The upgraded device is designed as a universal device for monitoring multiple parameters.

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CONTACTS

M.Sc. Jozef Mascenik, PhD., prof. M.Sc. Slavko Pavlenko, CSc.
Technical Universtity of Kosice
Faculty of Manufacturing Technologies with a seat in Presov
Department of Design and Monitoring of Technical Systems
Bayerova 1, Presov, 080 01, Slovak Republic
+421 51 772 6337, +421 55 602 6466
jozef.mascenik@tuke.sk, slavko.pavlenko@tuke.sk, www.tuke.sk