Experimental Measurements of Belt Gears in Newly Developed Device

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***Abstract* – The paper deals with the alternative of determination of state of the belt gear. To realize themeasurements a newly developed device was designed for measurement and diagnostics of the belt gears. The main task is to detect the V-belt slip expressed by the coefficient of elastic creep and of specific slip with a measuring device. The measurements regarding can be performed if input revolutions of the electric motor and torque of the belt gear are constant whereas the tensioning force of the belt gear changes. It is also possible to perform the measurement if the input revolutions of the electric motor and the tensioning forces are constant and the torque changes.**

***Keywords* – measurement, belt gear, slip, output, revolutions.**

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. [5] 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.

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.

2. 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 [1]. 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 shows the scheme of the designed device and in figure 2. the actual designed measuring device of the belt gear slip is shown.

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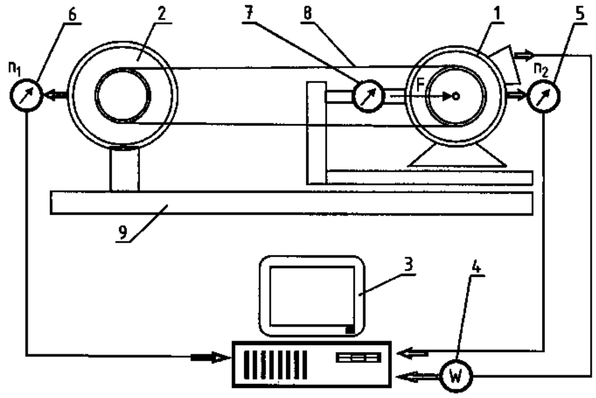

Figure 1. Scheme of measuring device of the belt gear slip: 1 – Electric motor, 2 – Brake, 3 – Computer, 4 – Sensor of output, 5 – Sensor of revolutions n_1, 6 – Sensor of revolutions n_2, 7 – Proving ring with deviation meter, 8 – Belt, 9 – Frame

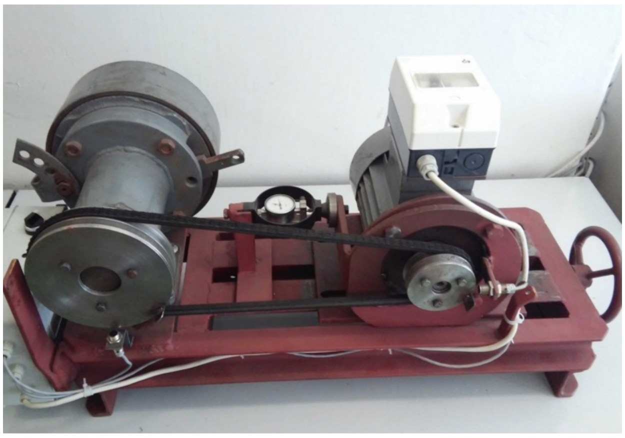

Figure 2. Measuring device of the belt gear slip

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 3. shows the sensors of a small (driving) and of a big (driven) belt pulley.

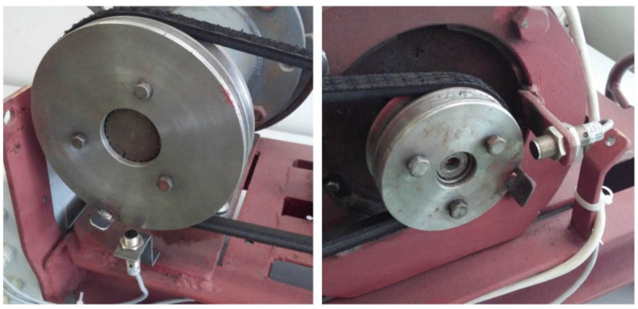

Figure 3.Fixed sensors for measurement of revolutions

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. 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 [9].

3. Calculation and Measurement of the Belt Gear

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 [2]. 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 [11]. 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:

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

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

$$F_{ps} = (1.2 \div 1.6).F_p \quad . [7]$$

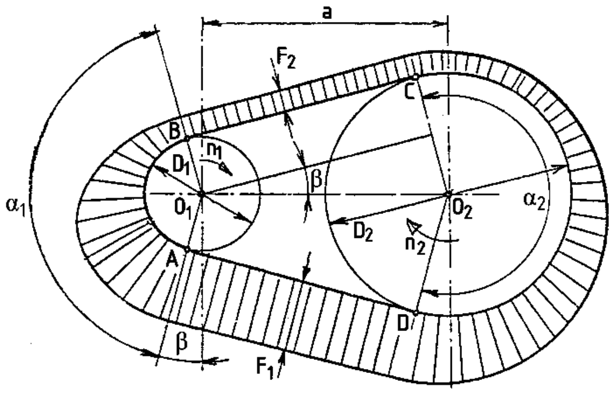

Figure 4. Distribution of forces in case of the belt gear

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:

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

with F_1 - force (tension) in converging strand,

F_2- force (tension) in diverging strand,
f - coefficient of friction in the keyseat,
α_1- angle of wrap of small pulley [3].

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.

$$F_{o1} = F_1 - F_2 = F_2(e^{f\alpha_1} - 1) \quad . [4]$$

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

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

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

$$F_{o1} = \frac{2M_{k1}}{D_1} \quad . [6]$$

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

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

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. 4) causes shortening of the belt by corresponding value of Δl.

The proportional shortening expressed by the relation

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

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.4). Coefficient ψ defined as $\psi = (1 - \varepsilon)$ is referred to as the coefficient of elastic creep. [8]

Peripheral velocity of the small belt pulley is as follows:

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

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:

$$v_2 = v_1(1-\varepsilon) = v_1.\psi .$$

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

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

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 [10].

The Belt Gear Efficiency

The loses ranging from 2 up to 5% are predominant in case of the transferred output due to the belt resistance against bending, the belt friction in the belt pulley grooves, air resistance, and friction in the shaft bearings. The efficiency of the belt gear depends on peripheral velocity of the driving belt pulley, belt thickness, diameters of the belt pulleys, shape and quality of the belt pulley grooves, and type of the shaft fixation.

4. Experimental Measurement of the Belt Gear

In measurement of the belt gear slip, the input parameters are represented by card revolutions of the electric motor and theoretical gear ratio. Input parameters include also the values of tensioning force and of torque which are read off the measuring device directly onto the device.

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.

The measured and the calculated parameters of the measurement of the belt slip are as follows:

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,

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

i_t - theoretical gear ratio,

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

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,

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

ψ - coefficient of elastic creep $\psi = 1 - \xi$,
i - gear ration of the belt gear,

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

and thus

$$i = \frac{i_t}{\psi}. [14]$$

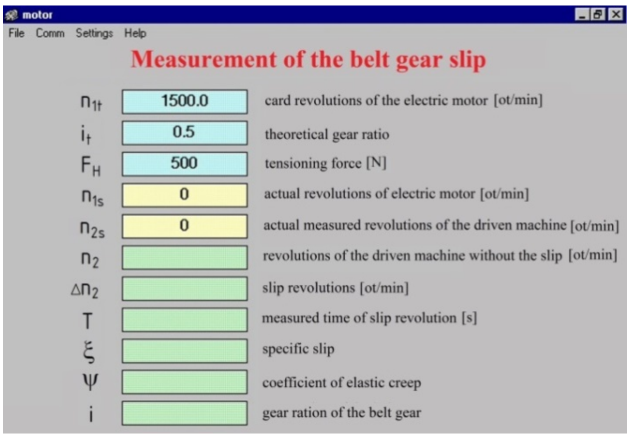

Figure 5. Work area of the software for measurement of the belt gear slip

Figure 5. presents the work display of the software showing clearly which values are entered, measured, and calculated. The measurement can be performed with two alternatives as follows:

- with constant revolutions of the electric motor and with constant loading by the brake (by constant torque) it is inevitable to detect the values of ψ and ξ with the minimum of 5 diverse values of tensioning force. The measurement should be performed with loading and unloading of the gear. On the basis of the acquired values, the graph with dependence of the coefficient value of elastic creep of the tensioning force value should be elaborated. The respective values must be presented in the data table.

- with constant values of input revolutions of the electric motor and of tensioning force the coefficient of elastic creep ψ with at least 5 diverse values of torque of the electric motor should be measured. The value of torque can be determined according to the value of the measured input power of the electric motor as follows:

Electric motor output P_e:

$$P_e = P_{ke}.\eta_e.$$

with P_{ke} - output read off the wattmeter “4”
η_e -electric motor efficiency specified by technical data of the motor [13].

Consequently, torque of the belt pulley of electric motor is calculated as follows:

$$M_{ke} = \frac{P_e}{\omega_{1s}}$$

and

$$\omega_{1s} = \frac{2\pi n_{1s}}{60}.$$

with_n_{1s}- actual revolutions of the driven belt pulley read off the computer display.

The measurements must be performed with the loading and with unloading of the gear. The result of the measurement is presented as dependence of ψ on torque with other given parameters. All the dependence values are entered into the table of values.

5. Conclusion

The main intention of the testing of the belt gears of the newly developed device is determination of recommendations regarding the decrease of fault rate of the belt gears as in the practice.During the belt gear operation the faults occur in the form of rapid belt wear, decrease of revolutions of the driven belt pulley, overheating of the belt under influence of external effects, cross-sectional ruptures in the bottom part of the belt, longitudinal ruptures, and wear of the upper part of the belt [12].

Contemporary gears with the V-belts represent powerful drive; however, the optimal output shall not be achieved without, for instance, correct tightening and layout. High output is given by a multi-year research and development carried out by the engineers and by the technicians heading towards the refinement of materials and processes. Although the belt gear represents rather obsolete component of output transfer, the current belt gear is exceptionally powerful means of the output transfer between the driving machine and other device.

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