EXPERIMENTAL MONITORING AND DIAGNOSTICS OF BELT GEARS IN TESTING DEVICE

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Constant development in mechanical engineering increasingly employs machines with high frequency revolutions requiring high efficiency and noiseless running and thus qualitative demands laid for belt gears increase as well. A new device for measuring and diagnostics of belt gears was designed to realize experimental measurements. Measurements can determine, for instance, slip of a V-belt expressed by the coefficient of elastic creep and of specific slip. Measurements regarding the designed device can be performed when input revolutions of the electric motor and torque of the belt gear are constant and tensioning force of the belt gear varies or when input revolutions of the electric motor and tensioning force are constant and output torque varies. The monitored parameters are assessed by particular software solutions.

KEYWORDS

belt gear, monitoring, diagnostics, device

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 influence the bearings, the shafts, and the entire machine structure [Bicejova 2013a,b,c, Cacko 2014]. 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 [Bicejova 2016a,b].

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 [Krenicky 2011]. Parameter monitoring is performed by the PC technique and by the suitable software [Mascenik 2014a, Novakova 2008].

2 NEWLY DESIGNED TESTING STAND

The designed testing and monitoring device of belt gears features three parts:

- measurement node with belt gear,
- control panel,
- monitoring and assessing part.

The measurement node with belt gear represents the principal part of the entire stand consisting of asynchronous electric motor Siemens (1LA7090-2AA10ZA11 1.5KW 2900/min 400V Y 50Hz IMB3 PTC thermistor), which serves as a drive in the belt gear. The gear outlet includes the same asynchronous electric motor referred to as a system load factor. Device control is assured by switchers and frequency converters of the control panel. Frequency converters of the input electric motor are used for adjustment of, for instance, revolutions and load at the outlet can be varied by variation of electric motor torque. A supporting frame of the device features adjustable elements with electric motors. The adjustable parts can be shifted away from each other by turning a screw rod by means of which the belt is tensioned. Monitoring and assessing part is represented by a PC with respective software solutions. Following fig. 1 shows the control panel [Mascenik 2014b, Novakova 2008].

Figure 1. Control panel of testing device

Frequency converter is a device that converts electric current of one frequency to electric current of another frequency. A frequent reason for frequency converter installation is a need of continuous regulation, e.g. of revolutions of asynchronous electric motor [Novakova 2008].

Electric motors are controlled by frequency converters Altivar 71 of ATV71HU15N4, ALTIVAR 3x400V/1.5kW type designed by Schneider Electric with the possibility of a full momentum open-loop control. It is the converter with properties and simple adjustment that predetermine the use in more complicated applications with performance of up to 500kW. The following characteristics of this frequency converter rank among the main ones: - regulation of speed or momentum with vector control even in case of rather low revolutions, - possibility to control high revolution motors up to 1000Hz (over 37kW of up to 500Hz), - possibility of control at zero revolutions and open-loop control of synchronous motors, - controlled braking and momentum control on the basis of weight, - possibility of diverse braking methods with option of energy recuperation to the DC power network [Puskar 2012]. Connection between frequency converters and the computer is assured by a connecting cable with transducer USB/RS485. Following figure 2 shows thermal properties for current of the converter as a thermal function and switching frequency according to type of installation [Mascenik 2014b].

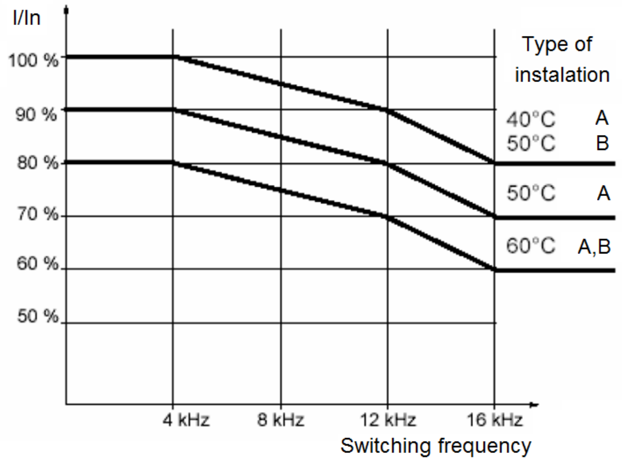

Figure 2. Thermal frequencies of frequency converter Altivar ATV71HU15N4

The frequency converters applied to control electric motors are connected according to the following figures. Figure 3 shows connection of frequency converter to control driving electric motor.[Gaspar 2013] Figure 4 shows connection of frequency converter to control output electric motor. Input electric motor is used and adjusted by torque so that it is a system load factor [Novakova 2008].

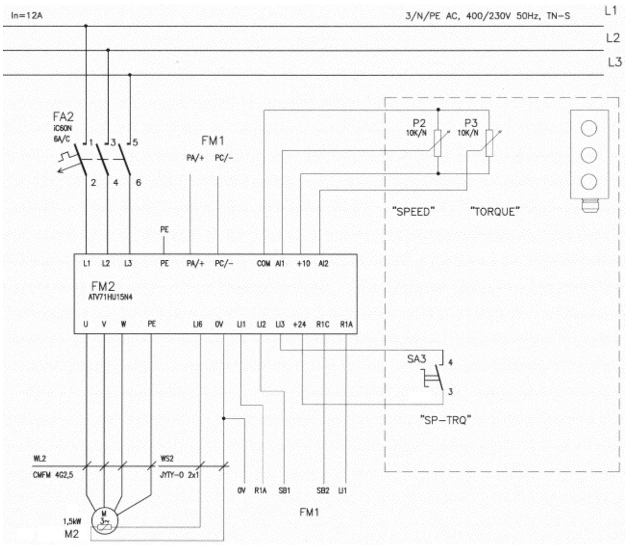

Figure 3. Connection of FM1 to control driving electric motor

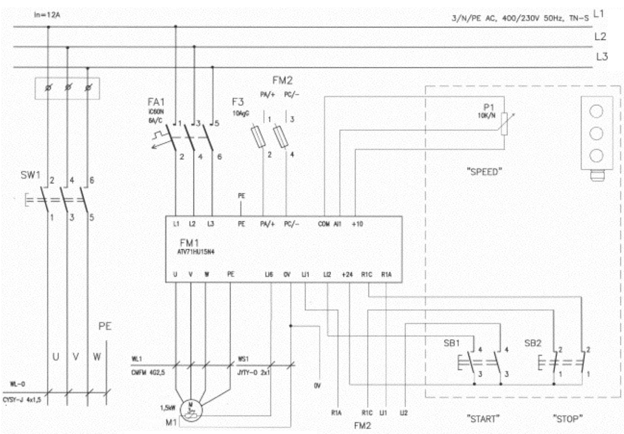

Figure 4. Connection of FM2 to control driven electric motor

2.1 *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. By means of required tightening the creep can be excluded [Litecka 2010]. *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. Right 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:

$$F_p = \frac{F_1 + F_2}{2} \qquad (1)$$

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

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

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 run the action of forces F_1, F_2 is observed, which are bonded in reference to the following relation:

$$F_1 = F_2.e^{f\alpha_1}, \qquad (3)$$

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.

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.

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

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

$$F_{o2} = F_2.e^{f\alpha_2} \; . \qquad (5)$$

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

$$F_{o1} = \frac{2M_{k1}}{D_1} \; . \qquad (6)$$

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

$$F_{cv} = \rho.S.v^2 = q.v^2 \; , \qquad (7)$$

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 force F_2 of the driving belt pulley causes shortening of the belt by corresponding value of Δl.
The proportional shortening expressed by the relation

$$\varepsilon = \frac{\Delta l}{l} \quad (8)$$

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) to the value of F_1. Coefficient ψ defined as $\psi = (1 - \varepsilon)$ is referred to as the coefficient of elastic creep.
Peripheral velocity of the small belt pulley is as follows:

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

Elastic deformation of the belt causes lower peripheral velocity of the driven belt pulley contrary to peripheral velocity of the driving pulley [Murcinkova 2013].
According to the aforementioned facts the following can be proved:

$$v_2 = v_1(1-\varepsilon) = v_1.\psi \quad (10)$$

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

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

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.

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 [Halko 2013]. 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.

2.2 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 [Puskar 2013].
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 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,

$$n_2 = \frac{n_{1s}}{i_t}, \quad (12)$$

i_t – theoretical gear ratio,

$$i_t = \frac{D_p}{d_p}, \quad (13)$$

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,

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

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

$$i = \frac{D_p}{d_p.\psi} \quad \text{and thus} \quad i = \frac{i_t}{\psi}. \quad (15)$$

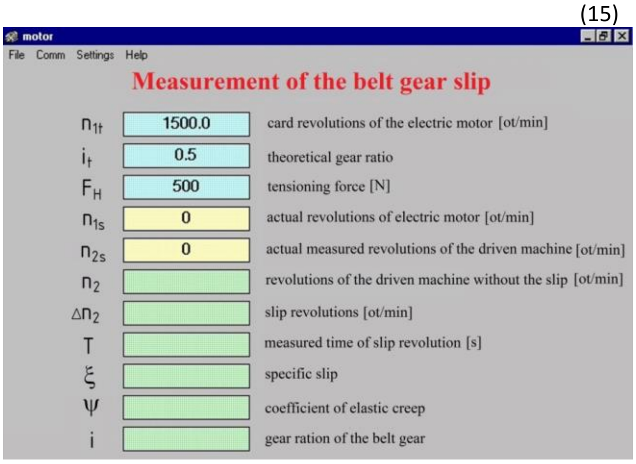

Figure 5. Work area of the software "Motor" for measurement of the belt gear slip

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:

$$P_e = P_{ke}.\eta_e \quad (16)$$

with P_{ke} – output read off the wattmeter "4"

η_e – electric motor efficiency specified by technical data of the motor.

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

$$M_{ke} = \frac{P_e}{\omega_{1s}} \quad \text{and} \quad \omega_{1s} = \frac{2\pi n_{1s}}{60} \quad (17)$$

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 the 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.

The results of given calculations and measurements are assessed by the "Motor" program through sensors fixed in proximity of both belt pulleys. The sensors monitor actual input and output revolutions of belt gear. Adjustment and monitoring of electric motors through the SoMove software can be performed by including the frequency converters into the assembly [Mascenik 2012].

SoMove software is used for configuration and adjustment of parameters of Altivar frequency converters, of Lexiujm synchronous drives, TeSys motor starters. 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). 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. Following figure 6 demonstrates working environment of SoMove program.

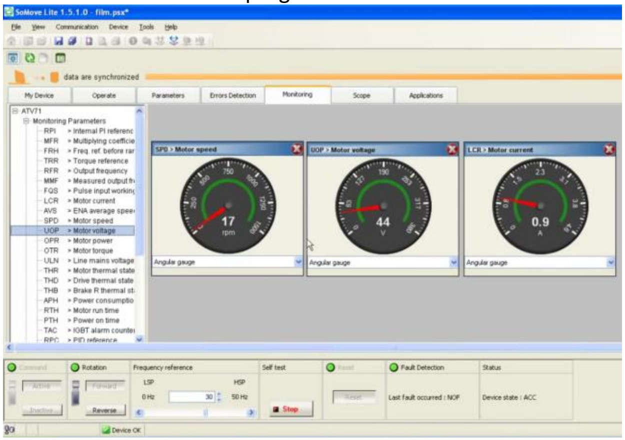

Figure 6. Work area of monitoring and adjusting software of SoMove

3 CONCLUSION

To assure that V-belts perform their function, they must be constantly forced into the grooves in every belt pulley, i.e. they must be constantly tightened to avoid creeping. As the belts get tightened during operation after certain period of time, the belt gear must be fitted with a suitable tightening device. For instance, axial distance of both belt pulleys can be prolonged or the belt might be tightened by a sheave. Under the influence of constantly increasing demands laid even on belt gears, the quality improvement of belts and of belt pulleys requires closer attention to be paid to. The main intention of the measuring device is to determine limiting conditions or to specify a point of destruction of the belt by means of extreme loading [Mascenik 2011]. The device can measure, for instance by the installed sensors, the actual revolutions of belt pulleys which are compared with the ones set up for frequency converters. 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.

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REFERENCES

[Bicejova 2013a] Bicejova, L., Pavlenko, S., Mascenik, J. Abrasive Granularity Impact on Water Jet Technology Head Vibrations During Cutting Steel, Applied Mechanics and Materials, 2013, pp. 304-309, ISSN 1660-9336

[Bicejova 2013b] Bicejova, L. Abrasive kind and granularity changes affects to water jet technology head vibration during cutting HARDOX material thickness alternation process. In: Applied Mechanics and Materials. Vol. 308 2013, pp. 75-79. ISSN 1660-9336

[Bicejova 2013c] Bicejova, L. Water jet technology head vibration generation due to selected technology parameters fluctuation effect during alloy cutting. In: Applied Mechanics and Materials. Vol.308 2013, pp. 81-86. ISSN 1660-9336

[Bicejova 2016a] Bicejova, L., Pavlenko, S., Mascenik, J. Measuring, processing and evaluating of technology head water jet vibration signal. In: Key Engineering Materials: Operation and Diagnostics of Machines and Production Systems Operational States 3. Vol. 669, 2016, pp. 205-211. ISBN 978-3-03835-629-5. ISSN 1013-9826

[Bicejova 2016b] Bicejova, L., Pavlenko, S. Experimental investigation and determination of abrasive granularity change impact to technology head vibration generating during awj technology steel cutting. In: Key Engineering Materials: Operation and Diagnostics of Machines and Production Systems Operational States 3. Vol. 669 2016, pp. 220-227. ISBN 978-3-03835-629-5. ISSN 1013-9826

[Gaspar 2013] Gaspar, S., Pasko, J. Influence of technological factors of die casting on mechanical properties of castings from silumin, 2013. In: Lecture Notes in Electrical Engineering. Vol. 240, pp. 713-722. ISSN 1876-1100

[Halko 2013] Halko, J., Mascenik, J. Differential with an integrated, newly - developed two-stage transfer, In: Applied Mechanics and Materials: Materials Engineering for Advanced Technologies ICMEAT 2013. Vol. 510 2014, pp. 215-219. ISSN 1662-7482

[Cacko 2014] Cacko, P., Krenicky, T., Dobransky, J. Impact of an excessive wear of bearing on the mechatronic devices. In: Applied Mechanics and Materials. Vol. 460 (2014), pp. 99-106. ISSN 1660-9336

[Krenicky 2011] Krenicky, T. Implementation of Virtual Instrumentation for Machinery Monitoring. In: Scientific Papers: Operation and Diagnostics of Machines and Production Systems Operational States: Vol. 4, RAM-Verlag, Lüdenscheid, 2011, pp. 5-8. ISBN 978-3-942303-10-1

[Litecka 2010] Litecka, J., Fecova, V. The latest trends in the gear production area by hobbing. In: Internet Journal of Engineering and Technology for Young Scientists. Vol. 1/1 (2010), p. 21-24, ISSN 1338-2365

[Mascenik 2011] Mascenik, J., Gaspar, S. Experimental Assessment of Roughness Changes in the Cutting Surface and Microhardness Changes of the Material S 355 J2 G3 after Being Cut by Non-Conventional Technologies, 2011. In: Advanced Materials Research. Vol. 314-316, ISSN 1022-6680

[Mascenik 2012] Mascenik, J. The evacuation of pressure moulds as progressive developments of die casting process, 2012. In: Acta Technica Corviniensis: Bulletin of engineering. Vol. 5, no. 3 (2012), pp. 25-26. ISSN 2067-3809

[Mascenik 2014a] Mascenik, J., Pavlenko, S. Aspects of alternative dispute creating bolted joint technology flowdrill, In: Applied Mechanics and Materials: 2nd International Conference on Mechanical Structures and Smart Materials, 2014, Kuala Lumpur, Malaysia. Vol. 680 (2014), pp. 186-189. ISSN 1660-9336

[Mascenik 2014b] Mascenik, J., Pavlenko, S. Determining the exact value of the shape deviations of the experimental measurements, In. Applied Mechanics and Materials, Vol. 624, 2014, pp. 339-343, ISSN 1660-9336

[Murcinkova 2013] Murcinkova, Z., Krenicky, T. Implementation of virtual instrumentation for multiparametric technical system monitoring, In: SGEM 2013: 13th International multidisciplinary scientific geoconference: Informatics, geoinformatics and remote sensing, 2013, Bulgaria - Sofia: STEF92 Technology, p. 139-144, ISSN 1314-2704

[Novakova 2008] Novakova, M., Pavlenko, S. Comparison of production parameters in cutting of material by laser and plasma. In: Management of Manufacturing Systems: 3rd Conference with international participation. Presov: FVT TU, 2008 pp. 276-278. ISBN 9788055300696

[Puskar 2012] Puskar, M., Bigos, P. Method for accurate measurements of detonations in motorbike high speed racing engine, In: Measurement. Vol. 45, no. 3 (2012), p. 529–534. ISSN 0263-2241

[Puskar 2013] Puskar, M., Bigos, P., Balazikova, M., Petkova, V. The measurement method solving the problems of engine output characteristics caused by change in atmospheric conditions on the principle of the theory of optimal temperature range of exhaust system, In: Measurement: Journal of the International Measurement Confederation (IMEKO). Vol. 46, no. 1 (2013), p. 467–475, ISSN 0263-2241

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