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Monitoring of belt floating under controlled belt transmission load

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Abstract:

The paper focuses on experimental monitoring of tightening and floating of the belt at controlled loading of belt gear. In general, the belt gear is referred to as friction gear in practice the primary function of which is to transfer the performance as a consequence of frictional forces occurring between a driven belt pulley, a driving belt pulley and a flexible element. In experimental measurements, the flexible element is represented by a V-belt. The main advantages of the belt gears are peripheral speed, flexible engagement, silent running, vibration absorption and their price. Standard operation of the belt gear requires correct belt tightening which is achieved by movement of a pulley and a tension roll. At the same time, the belt tightening can be achieved by changing the spacing of the shaft axes used in experiments. In the case of belt gears use, specific principles must be observed. The principles include tightening of the belt with particular force which represents, in fact, primary condition of transmission of motion and force. At rest, the tension of both belt parts is identical. Complex analysis of belt gears was followed by experimental measurements on the stands designed for testing and monitoring of belt gears. For the purposes of monitoring of the belt floating there was a system designed which used a high precision sensor to measure distance between the belt and the sensor. At the same time, a device designed to determine the belt tightening was used as well. All measurements were analysed and collected data and facts were used to determine dependencies possible to be applied when the monitored parameters are evaluated. The results of experimental monitoring of the selected parameters at controlled loading of the belt gear can be useful in practice for designing, checking and maintenance operations.

Keywords: monitoring, belt floating, strength, belt gear, tension, load

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1. Introduction

Currently, the frequency of utilization of V-belts is higher compared to standard flat belts. The reason rests in capability to transmit higher torque. Frequently, they have of trapezoidal section which creates friction in a keyseat of the pulley on the side faces. The keyseat in the pulley must be correctly shaped to prevent the belt from reaching the bottom of the keyseat. Contrary to standard conditions, by means of the V-belts it is possible to transmit relatively high performances with considerably shorter axis distances and with higher gear ratios [1]. The gears with V-belts considerably damp strokes and flexibility of the belts. An exceptional advantage is rather silent running, soft engagement and negligible slippage. In practice, the customers are supplied with the open-ended V-belts in enclosed circle which means that the belt length is determined either by technical conditions of the manufacturer of by a respective standard. The gear containing more V-belts placed side-by-side require replacement of the entire set of the belts. In the case of such belt types, there are not any modifiers to increase the friction between the belt and pulley used.

The belt gears are commonly used in passenger vehicles as some types of vehicles are designed with a friction gearbox. The gearbox in a passenger vehicle consists of two pulleys and of axially moving bevel gear with the V-belt running in between. One of the pulleys is connected with an input shaft and the other one is connected with an output shaft. Moving the cones closer and further results in change of diameter, which the belt draws, along with gear ratio. During run-up, when the highest gear ratio or tensile force is required, the lowest diameter is set in primary pulley [2]. The belt of such gear has fixed length yet slight deformations are taken into consideration. With regards to the fact that the belt gears are frequently used in different spheres and that the precision tolerance constantly increases, it is inevitable to deal with the issue.

The belt gears are used in case of diverse industrial applications for their versatility, reliability and low costs. However, floating of the belt may occur due to different reasons such as insufficient tension, incorrect alignment, wear and tear and excessive loading. Floating of the belt may result in decreased efficiency, increased energy consumption and premature failure of the belt gear system [3].

The designed monitoring system will include measurement and analysis of frequency of the belt floating to detect and diagnose potential defects in the belt gear system. The system will use sensors to measure vibrations of the system of the belt gear and the data will be processed and analysed in order to identify frequency of the belt floating and other abnormalities. The results of analysis will be used to determine the cause of the belt floating and to provide recommendations for rectifying measures.

The monitoring system was designed to allow simple installation and maintenance and to be applicable in case of diverse types of the belt gears. The implementation of the designed system will contribute to increase efficiency and reliability of the belt gear systems, to decrease maintenance costs and to extend service life of the device [4].

2. Analysis and design of the belt gears

Analysis of the belt gears deals with examination of different aspects of function and performance. Within the frame of the analysis the following factors are examined:

1. Torque capacity - it refers to the torque which can be transmitted by the gear with zero belt damaging. The factor depends on width, material and tightening of the belt.
2. Efficiency – it refers to energy being transmitted from side to side. The efficiency of the belt gears depends on many factors such as belt tightening, used belt type, belt width and gear speed.
3. Speed – gear speed depends on belt diameter, belt width and speed of shaft rotation. It is important to remember that speed must be sufficient enough to reach required performance, yet it cannot be too high to prevent belt damaging.
4. Noise level – belt gears can achieve high noise level, especially whenf using older models. Noise level depends on type and material of the used belt.

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5. Service life – service life of the belt gears depends on many factors such as type, quality, use and maintenance of the belt. Correct maintenance and regular check-ups can extend service life of the belt gears [5].

Designing and checking of the belt gears is preceded by proposal of their dimensions. Significant dimension is arithmetic diameter of the pulley referred to as "*dp*" for input pulley and "*Dp*" for output pulley. Arithmetic length is referred to as "L_p" which is applicable both for the flat belts and for the V-belts. In fact, it is the length of the tightened belts in the plane of the neutral fibre. The length of fibres remains the same at constant tension and deformation of cross-section by deflection. The arithmetic length of the belt can be expressed as follows:

$$L_p \cong 2a + \frac{\pi}{d}(d_p + D_p) + \frac{(D_p - d_p)^2}{4a} \quad (1)$$

With "a" referring to axial distance of the pulleys. Consequently, it is possible to determine approximate length based on the equation as follows:

$$L_p = 2a\frac{\alpha}{2} + \frac{\pi}{2}(d_p + D_p) + \frac{\pi\gamma}{180^\circ}(D_p - d_p) \quad (2)$$

With α referring to angle of contact of smaller pulley and the value γ can be calculated according to the following equation:

$$\gamma = \left(90^\circ - \frac{\alpha^\circ}{2}\right) = arcsin\left(\frac{D_p - d_p}{2a}\right) \quad (3)$$

Consequently, standardized belt length can be determined according to the standard and approximate axial distance of the individual pulleys can be expressed by means of the following equations:

$$a \approx p + \sqrt{p^2 - q} \quad (4)$$

Then p and q can be calculated as follows:

$$p = \frac{1}{4}L_p - \frac{\pi}{8}(d_p + D_p) \quad (5)$$

$$q = \frac{1}{8}(D_p - d_p)^2 \quad (6)$$

Initial solution for calculation of the force was its calculation in tensile F_1 and relieved F_2 branch of the belt gears (Fig. 1). In these calculations a perfectly flexible fibre was taken into consideration and at the same time the angle of contact was defined along with coefficient of friction f. When taking into consideration an elementary particle, an elementary normal dF_N, tangential dF_t tension, it is possible to opt for relations for elementary tangential F_T and normal F_N force [6].

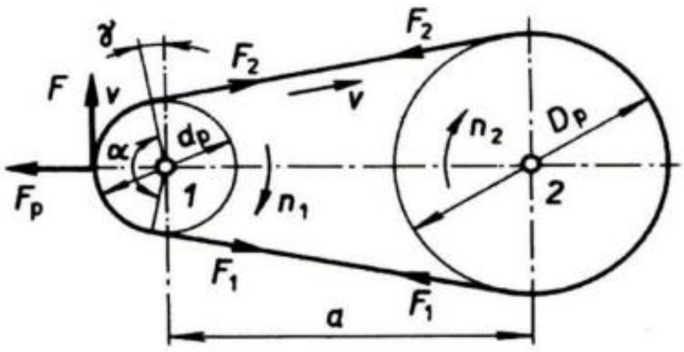

Fig. 1. Force ratio in the belt gear

Euler's formula is applicable for the forces F_1 and F_2 in relieved and tensile branch of the belt gear:

$$F_1 = F_2 . e^{f.\alpha} \tag{7}$$

with:

- α – angle of contact of small pulley,
- f – coefficient of friction stipulated by the standard,
- e – Euler's number - 2.718...

Checking the force ratios requires calculation of circumferential force of the small pulley according to following equation:

$$F_o = \frac{2. Mk_1}{d_p} \tag{8}$$

Then the torque can be defined according to the following equation:

$$Mk_1 = \frac{P_1}{\omega_1} \tag{9}$$

Consequently, based on resultant force balance of the selected belt the following relationship can be detected:

$$F_o = F_1 - F_2 \tag{10}$$

The following relation is then applicable for force F_1:

$$F_1 = F_o \frac{e^{\alpha.f}}{e^{\alpha.f} - 1} \tag{11}$$

Consequently, it is inevitable to calculate the belt tightening during installation. The respective tightening is necessary to derive adherence force between the belt and the pulley. The following relation is applicable:

$$F_p = \frac{F_1 + F_2}{2} \tag{12}$$

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Consequently, it is suitable to select actual prestress to increase prevention of slippage according to the equation as follows:

$$F_{ps} = (1{,}2 \div 1{,}6).F_p \tag{13}$$

Resultant of the individual forces will be geometrical sum according to the equation as follows:

$$F_v = \sqrt{F_1^2 + F_2^2 + 2.F_1.F_2.\cos\gamma} \tag{14}$$

So angle γ is possible to be calculated according to the equation as follows:

$$\gamma = 90° - \frac{\alpha}{2} \tag{15}$$

The aforementioned force causes transverse stress of the shaft.

3. Floating of the belt

Vibrations of the belt gear can cause diverse problems including increased noise, premature wearing of the belt and of the pulley and decreased efficiency [7]. As regards the belt drives different types of the floating can occur (Fig. 2) including the following phenomena:

1. Torsional floating occurs when the belt and pulleys are incorrectly adjusted which causes torsional deflection of the belt. The slippage of the belt, excessive wearing and noise can be caused by torsional vibrations.
2. Transverse floating to sides caused by excessive stress, incorrect adjustment or resonance is referred to as transverse vibrations. Excessive wear of the belt, of the pulley and of the bearings as well as increased noise level can be caused by transverse vibrations.
3. Axial floating occurs when the belt moves back and forth along its axis which is frequently caused by insufficient tightening or incorrect adjustment. Axial floating can result in excessive wear and noise of the belt and pulleys.

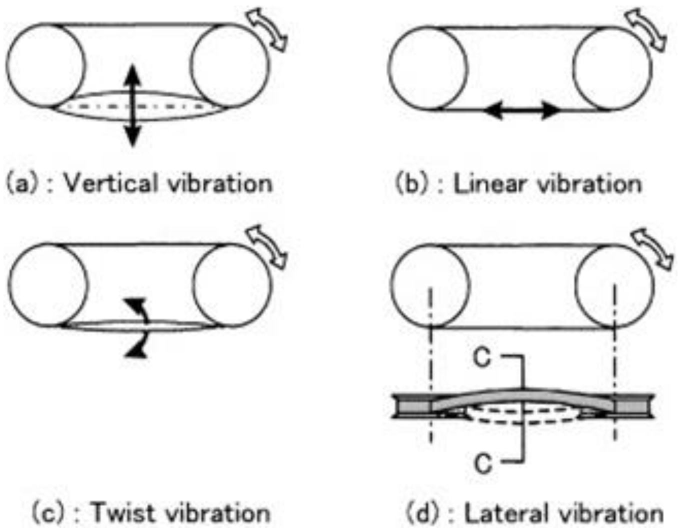

Fig. 2. Types of the belt floating

Floating of the belt drive can be caused by different causes such as incorrect tightening, incorrect adjustment, worn out or ruptured belts, damaged pulleys or bearings and resonance. Correct tightening and adjustment are indispensable to minimize vibrations and preservation of optimal performance of belt and pulleys.

Except for the aforementioned facts, a selection of high-quality belts and pulleys, regular lubrication and maintenance, and also a prevention against resonance risk can forestall floating in the belt drive. Regular check-ups and monitoring can contribute to an identification of possible problems with vibrations before making them more complicated.

Floating in the belt drive can be caused by other factors apart from aforementioned types of vibrations. Those can include the following cases:

- Belt resonance occurs when inherent frequency of the belt is identical with operating frequency of the system which results in increased amplitudes of floating. Belt resonance can be decreased by changing the belt tightening or by using different belt material.
- Bearing resonance occurs when inherent frequency of the bearing is identical with operating frequency of the system which results in increased amplitudes of floating. Bearing resonance can be decreased by using better bearings or by extending the system by absorption.
- Toughness of the belt: contrary to softer belts, the stiffer ones are more prone to floating. Selection of the belt with accurate toughness is crucial for the respective application.
- Eccentricity of the pulley: Eccentric or diverging pulley can cause the floating of the belt. It can be eliminated by changing the adjustment of the pulley or by using a new one [8].

Generally, a reduction of floating in the belt drives is crucial for improving the performance and for decreasing maintenance costs. Regular check-ups and maintenance can help detect possible problems and prevent excessive wearing and damaging of the system.

4. Design of belt floating monitoring system

While designing the belt floating monitoring system with highly precise sensor of distance, it is indispensable to deal with different issues influencing performance and reliability.

1. The first factor includes a determination of correct positioning of the distance sensor. The sensor should be positioned to be able to detect floating of the belt in both motors and at the same time it should be isolated from external influence such as vibration or impacts.
2. The second aspect is a selection of suitable distance sensor with broad range of measurement and high precision.
3. The third aspect is to build an algorithm for processing input data collected by sensor and for determining the belt floating. The algorithm should be able to process the input data in real time and to pre-set data related to belt floating in easily applicable interface [9].
4. The system should be designed to provide easy assembling and dismantling.

5. Measurement and evaluation of the belt floating

Procedure of the belt floating measurement in the belt gear by means of highly precise distance sensor includes the following stages:

1. Preparation of the measuring system (Fig. 3): prior to measurement it is necessary to prepare the measuring spot. It is recommended to conduct the measurement in clean space, adequately illuminated by light, with minimal disturbance. At the same time, it is important to ensure correct installation and calibration of the sensor.

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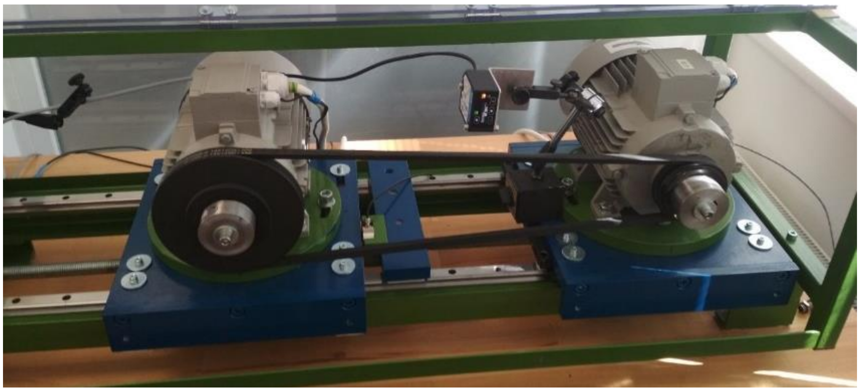

Fig. 3. Measuring system designed for the belt gear testing

2. Removal of the gear cover: installation of the sensor on the belt must be preceded by a removal of the gear cover. Safety measures must be observed when removing the cover.
3. Installation of the sensor SICK OD2000-0501T15 (Fig. 4): the sensor must be positioned on one side of the gear by means of universal magnetic stand and must be parallel with the belt. The distance must be minimal. Installing of the sensor will ensure precise measurement of the floating of the belt in the belt gear. It is recommended to position the sensor in the proximity of the centre line of the belt which should enable a more precise measurement.

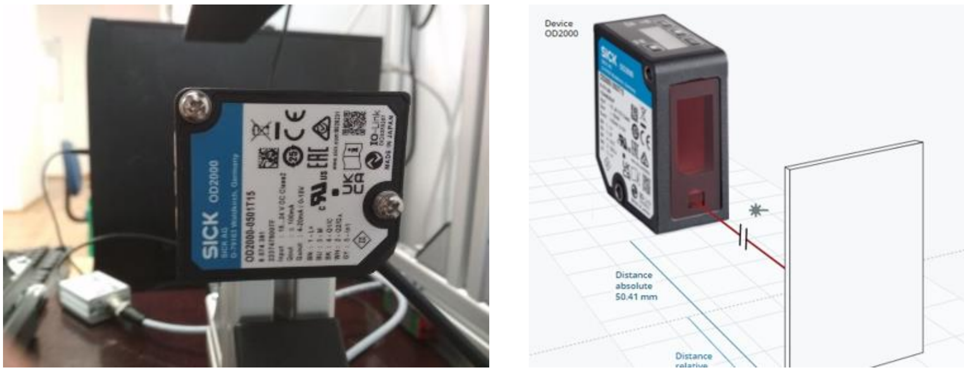

Fig. 4. Sensor SICK OD2000-0501T15

4. Fixation and adjustment of the distance sensor: the sensor should be firmly fixed on its position to minimize influence of vibrations or of other external factors on the measurement.
5. Tightening of the belt by a tightening pulley to the first value of 105 N. The required value is set by the belt tension meter SKF PHL FM10/400/A (Fig. 5).

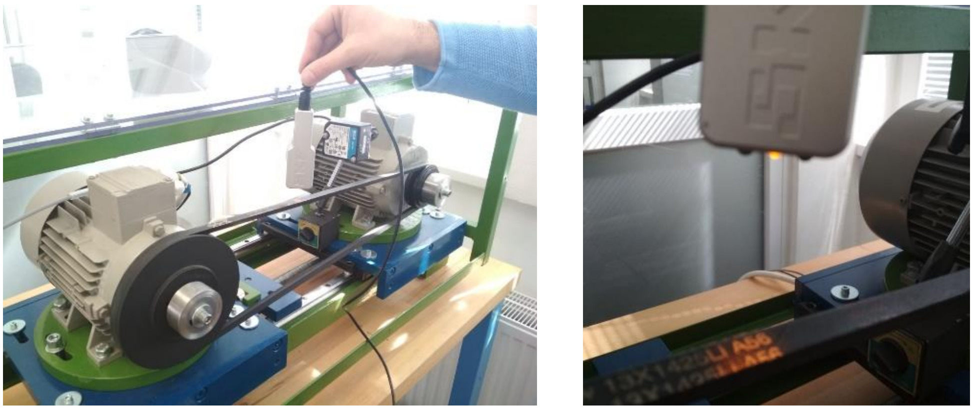

Fig. 5. Adjustment and tightening of the belt by means of contactless belt tension meter SKF

6. Preparation of the table environment to record the measured values: rotations with the values are 500 rev/min, 1000 rev/min,1500 rev/min, 2000 rev/min, 2500 rev/min. Selected tightening is approximately 100 N, 200 N, 300 N.
7. Measurements: by means of the distance sensor the values of the belt floating are obtained. The results should be recorded in real time along with all relevant data [10].

Table 1. Measured values

Revolutions [rpm]	Tension [N]	0%			25%			50%			75%		
		MAX	MIN	STR	MAX	MIN	STR	MAX	MIN	STR	MAX	MIN	STR
500	105	-0.5	-1.4	0.9	-0.5	-1.5	1.1	-0.7	-1.9	1.2	-0,6	-2,2	1,6
	202	2	1.3	0.7	1.8	1.3	0.5	1.9	0.8	1.1	1.9	1.1	0.8
	306	2.4	1.7	0.8	2.3	1.6	0.7	2.4	1.4	1	2.3	1.5	0.9
1000	105	-0.3	-1.5	1	-0.2	-2.2	2	-0.7	-1.9	1.4	-0.8	-2.2	1.4
	202	2.1	1.2	0.9	1.9	1.2	0.7	2	1.2	0.8	2.2	0.8	1.3
	306	2.4	1.5	0.9	2.3	1.5	0.8	2.2	1.7	0.6	2.2	1.5	0.7
1500	105	-0.3	-1.6	1.5	-0.5	-1.8	1.3	-0.6	-2	1,4	-0.5	-2.2	1.7
	202	2	1.4	0.6	2.1	1.3	0.8	2.1	1.2	0,9	2.2	1.1	1.1
	306	2.8	1.2	1.6	2.6	1.2	1.4	2.4	1.6	0,7	2.2	1.7	0.6
2000	105	1	-2.6	3.6	2.7	-1.7	4.4	1.8	-0.1	1,9	2.4	-0.7	3.1
	202	2	1.2	0.8	2.1	1.1	1	4.1	-0.9	5	3	0	3
	306	2.5	1.7	0.8	2.4	1.7	0.8	2.5	1.6	1.1	2.8	1.3	1.5
2500	105	2.9	-0.7	3.6	1.3	0.3	1	1	0.3	0.7	0.8	0.2	0.6
	202	5.3	-2	7.3	2.2	0.8	1.4	2.5	0.5	2	2.3	0.7	1.5
	306	2.4	1.5	0.9	2.3	1.6	0.8	2.2	1.5	0.8	2.3	1.5	0.8

8. Repetition of the measurements: the measurements are repeated using different values of tension such as 105, 202 and 306 N (Table 1), or using different values of rotations and motor loading.
9. Data processing.

6. Data analysis

Measurement 1 – Input rotations 500 rev/min

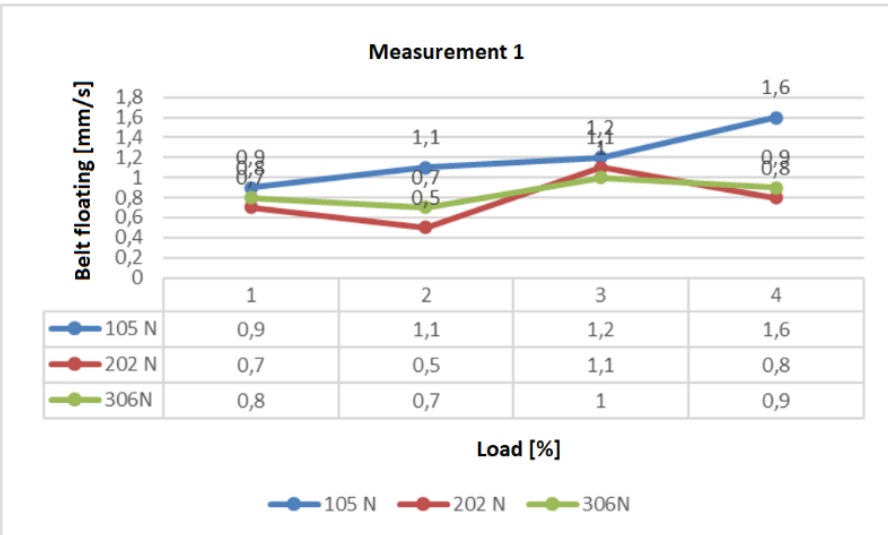

Fig. 6. Dependence of the belt floating on gear loading and the belt tightening at 500 rev/min

Fig. 6 shows that at 500 rev/min and with the belt tightening to 105 N and with increasing percentage value of the motor loading (ranging from 0 to 75%), the value of the belt floating increases. Furthermore, it is obvious that in the case of the belt tightening to 202 N and 306 N and with increasing gear loading, the belt floating decreases.

Measurement 2 – Input rotations 1000 rev/min

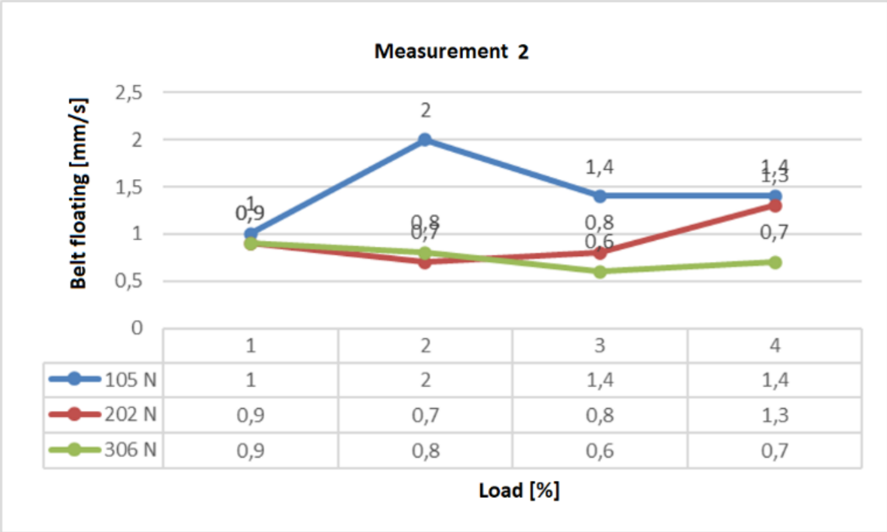

Fig. 7. Dependence of the belt floating on gear loading and the belt tightening at 1000 rev/min

Fig. 7 shows that floating vibrations decrease with increasing values of tightening and loading of the motor. For instance, in the case of tightening to 105 N for percentage loading of 0%, the belt floating is 1 mm/s. In the case of percentage loading of 75% the belt floating is 1.4 mm/s. In the case of tightening to 306 N, the belt floating is 0.9 mm/s for percentage loading of 0%. In the case of percentage loading of 75% the belt floating is 0.7 mm/s.

At the same time, it can be seen that the value of the belt floating for each tension differs in relation to percentage representation of tightening [11]. For instance, when tightening is 202 N, the belt floating value is of 0.7 m/s for percentage representation of 25%, yet the belt floating value of 1.3 mm/s is typical for percentage representation of 75%.

Measurement 3 – Input rotations 1500 rev/min

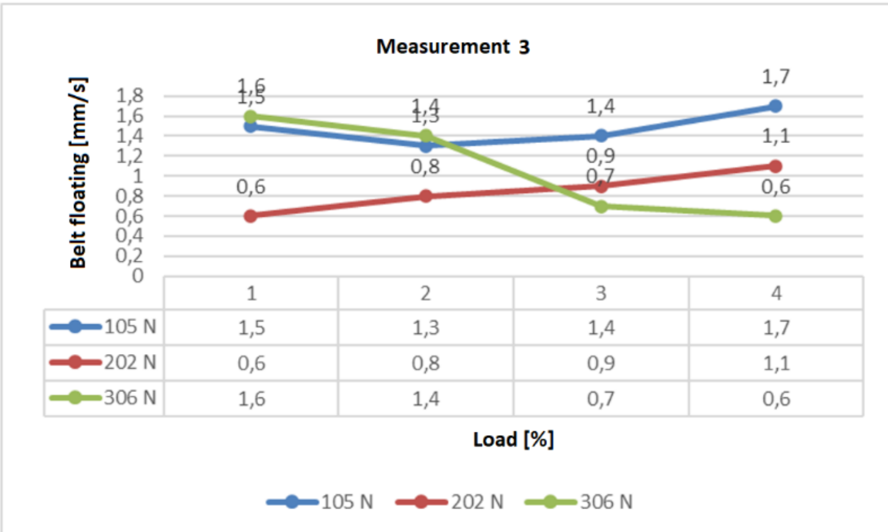

Fig. 8. Dependence of the belt floating on gear loading and the belt tightening at 1500 rev/min

Fig. 8 shows that the amplitude of the belt floating increases when tightening reaches 105 N and 202 N and it also increases with increasing percentage loading of the motor.

For instance, in the case of tightening value of 105 N and percentage ratio of 0%, the amplitude of the belt floating reaches 1.5 mm/s and in the case of percentage ratio of 75%, the tightening value is 1.7 mm/s. In the case of tightening of 202 N and percentage ratio of 0%, the amplitude of the belt floating reaches 0.6 mm/s and in the case of percentage ratio of 75%, the belt floating amplitude reaches the value of 1.1 mm/s.

However, in the case of tightening of 306 N, the values of the belt floating decrease with the increasing percentage loading of the motor. For instance, in the case of tightening of 306 N and percentage ratio of 0%, the belt floating amplitude reaches 1.6 mm/s and in the case of percentage ratio of 75% the values reach 0.6 mm/s.

Following the aforementioned facts, it is clear that the more tightened the belt is, the lower the floating value drops.

Measurement 4 – Input rotations 2000 rev/min

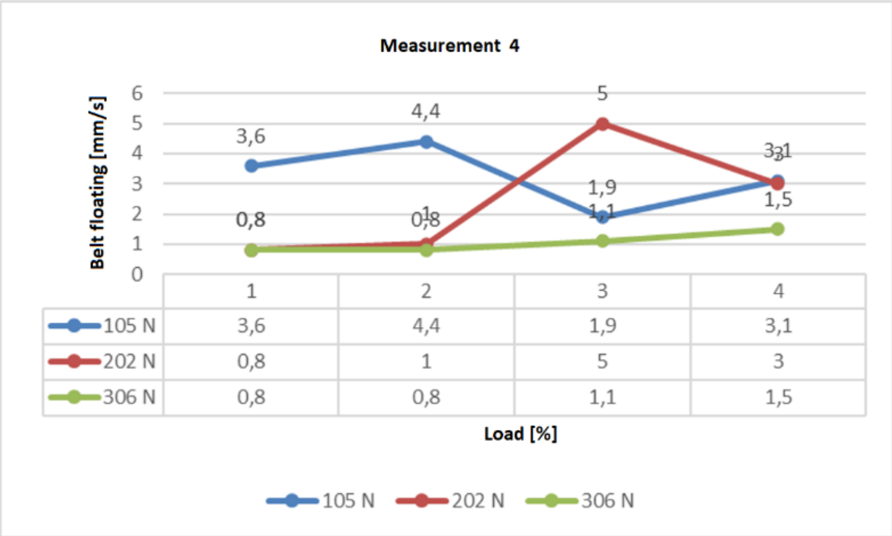

Fig. 9. Dependence of the belt floating on gear loading and the belt tightening at 2000 rev/min

Measurement 5 – Input rotations 2500 rev/min

Fig. 10. Dependence of the belt floating on gear loading and the belt tightening at 2500 rev/min

According to the aforementioned measurements (Fig. 9, 10), it is possible to evaluate the results of the belt floating measurement when changing the rotations, the belt tightening and loading at the output by adjusting the load torque.

7. Conclusion

The paper points out that the design of the monitoring system for the belt floating in the belt gear represents an important prevention tool of potential defects and failures of the motor. The system uses sensors for measuring vibrations and temperature of the belt and for their processing by means of algorithms applied to detect the belt floating. The designed system was verified by means of experimental devices and the results proved its efficiency in detection of the belt floating as well as options of further use in present gears. In the future, the system could be improved by using automatic control of the belt tightening based on obtained data and thus its reliability and efficiency might increase as well.

The design of the monitoring system for the belt floating in the belt gear has high potential in the field of machine and device operation as it allows the operators to prevent an occurrence of serious failures and to increase efficiency of operation. As regards the fact that the belt floating in the belt gear represents one of the main factors causing wear of the belt as well as of other gear elements, it is important to have a reliable and precise system for monitoring this parameter.

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