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Monitoring of selected parameters of the belt transmission on a specific design solution

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Abstract:

Belt drives have been used for decades to transmit power from a drive unit to an end device in a variety of applications. There is constant scientific, technical and technological progress in the production and use of belts, which has led to a variety of types and types of belts. Belt drives have several advantages over other methods of power transmission, including light weight, affordability, and the ability to be used as a slip clutch. As the requirements for V-belts increase, so does the required quality of the offered belts. When analyzing belt transmissions, it is also possible to examine their influence on other components of the machine or equipment on which they are installed. If the belt drive transmits large forces, this can have consequences on the bearings and other parts of the transmission. It is therefore essential to ensure that belt drives are optimally designed and installed to minimize potential damage to other components. On the designed specific design solution for testing belt transmissions, the actual revolutions of the input and output pulleys were monitored, the belt float was measured using high-precision distance measurement sensors, and the vibrations were measured using a magnetically fixed sensor. During the experimental measurements, parameters such as belt tension, input speed and output load were changed. The experimental measurements themselves were carried out on three A1450Lw 13x1420Li belts of the same dimensions, but manufactured by other manufacturers (Optibelt, Rubena and Gufero).

Keywords: construction, monitoring, belt transmission, load, belt tension, vibration, belt slip

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1. Introduction

Designing even specific design solutions is an active and repetitive process of innovation, while at the same time it represents a decision-making procedure. This process often requires decisions that are based on limited information and sometimes conflicting data. Like a person who has two clocks and knows what time it is but is uncertain about the two clocks, a designer often has to make decisions based on limited information [1]. Nevertheless, problem solving and decision making should be satisfying and welcome activities for the designer. Designing is an equally demanding communication process that involves the use of words and images and involves both written and oral communication. Designers must be able to communicate and collaborate effectively with professionals from different fields who have different levels of knowledge about their work. The ability to communicate effectively and collaborate with colleagues from different industries is also a key factor for a designer's success.

During the construction of new design solutions, it is important to divide the processes and phases of the life cycle of technical systems, which allow to gain an overview of their creation, functioning, maintenance and termination (Fig. 1). During the design phase, it is crucial that the designer takes into account the requirements that arise from the stages and processes that the technical system will go through during its life cycle [2]. The extent to which these requirements are included depends significantly on the awareness and knowledge of the constructor, as well as on the availability of the information system.

Due to the non-negligible position of belt transmissions in a wide range of industries, there is a need to devote attention to this type of transmissions, which is why the idea of designing a new test device arose. To contribute to this issue, a proposal for testing belt transmissions under controlled load was developed. Based on the initial designs, a 3D model was created, which was subsequently physically produced and integrated into a complex measuring system. This device is composed of three main parts: measuring, controlling and monitoring.

This newly developed test stand was built within the Center for Testing and Monitoring of Technical Systems at the Department of Design and Monitoring of Technical Systems at the Faculty of Manufacturing Technologies of TU Kosice, located in Presov. The measuring station has two uses: it serves for research in the field of testing existing and new types of belts and pulleys, and at the same time it serves as an educational aid for students to improve the quality of education in the field of technically oriented subjects.

An important aspect in the analysis of belt transmissions is their correct installation and maintenance. Belt drives can become worn or damaged due to improper tension, excessive load, and other factors. Regular inspection of the condition of belt transmissions and their necessary maintenance are therefore essential. When evaluating belt drives, it is equally important to consider their use in a particular application. There are many different types of belt drives that are designed for different purposes and applications. Therefore, it is crucial to choose the belt transmission that best suits the specific requirements of the given machine or equipment [3].

For efficient operation and durability, the correct fit and tension of the belt of belt drives is of key importance. Belt tension and tension force are key factors affecting the operation of a belt drive. Correct belt tension is essential to ensure reliable operation and minimize the risk of breakdowns. The calculation of the tensioning force of the belt depends on its size, material and application. A higher tension force can improve transmission efficiency because power transmission also depends on higher belt tension. However, excessive tensioning force can cause belt overload and premature wear. There are several methods for determining proper belt tension, including measuring its elasticity within a certain range. Tension gauges and other tools are available to check belt tension. When setting belt tension, it is important to follow the manufacturer's specifications, which determine the optimal tension for a particular belt type and application.

When using belt transmissions, it is also important to define terms such as belt slippage and slippage. Belt slippage occurs when the belt is loose or under-tensioned, and this can be eliminated by proper tensioning [4]. Belt slip, also known as measured slip, exists even with proper belt tension, increasing as belt tension increases. Slippage itself cannot be excluded from the operating conditions of belt drives, and that is why belt slippage was also the subject of my measurements.

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2. Specific technical solution of the measuring device

The measuring system as a device for testing belt transmissions is designed as universal and easily modifiable, allowing the addition or replacement of individual components. With this device, it is possible to change the drive and driven pulley, exchange belts, change input and output parameters, and the like. For example, the replacement of pulleys is often performed in order to modify the transmission ratio between input and output, which corresponds to the objectives of testing belt transmissions as part of innovative research in this field [5].

Autodesk Inventor 3D modeling and simulation software was used during the development and design phase. This program makes it possible to create and examine the entire product before its physical production. Inventor makes it possible to combine the advantages of digital prototyping and integrate 2D drawings from AutoCAD software and merge 3D model data into one model [6].

The newly designed system includes a basic frame on which the driving electric motor and the driven electric motor are placed, which serves as part of the braking system. The shafts of the driving electric motor and the driven electric motor are fitted with pulleys and connected by a V-belt, creating a belt transmission. Siemens asynchronous electric motors (type 1LA7090-2AA10ZA11, 1.5 kW, 2900 min^{-1}, 400 V, Y, 50 Hz, IMB3, PTC thermistor) are slidably located on the frame, while the V-belt tension can be adjusted. The driven electric motor, which is controlled by a frequency converter, serves as a brake, and its braking effect can be adjusted as needed. This braking effect creates corresponding forces in the belt in the loaded and unloaded branches, which leads to a pulley slip that is measurable [7]. The tension of the belt and the displacement of the drive electric motor are controlled through a tensometric sensor of the pressure force by means of a threaded rod and a pressure bracket. The quantities needed to calculate the slip are sensed and analyzed by a computer through sensors of the actual revolutions of the driving and driven electric motors. Belt tension values are evaluated via PC. Figure 1 shows a 3D model and a real manufactured system for monitoring belt transmissions and testing different types of belts.

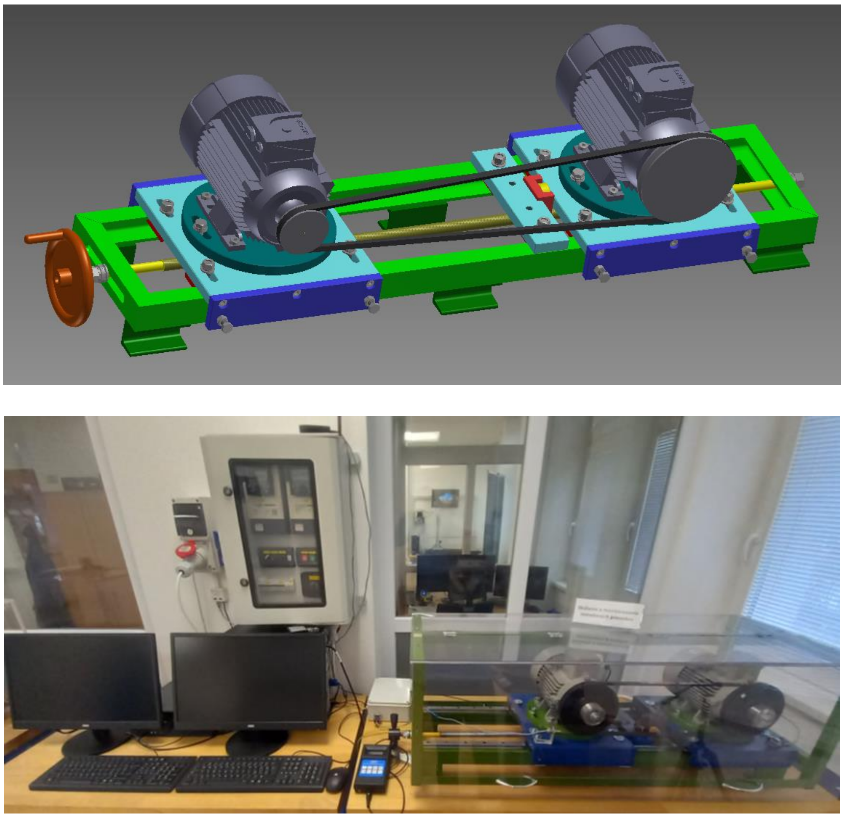

Fig. 1. 3D model and real measuring and monitoring equipment

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3. Measurements and results

3.1. Measurement of belt transmission slip

When monitoring the slippage of the belt transmission, the speed of the electric motor, the theoretical transmission ratio indicated on the label, together with the values of the belt tension and the torque are considered as input parameters [8]. These values are obtained directly from the sensors located on the device. The measured parameters, which are obtained from the device and then transferred to the computer using an analog-digital converter, represent the real revolutions of the drive pulley of the electric motor n1s and the real revolutions of the driven pulley (brake) n_{2s}. These data are subsequently processed by the "*Motor*" software to calculate the necessary values, the result of which is the determination of the final slip of the belt transmission.

The belt slip measurement parameters are:

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

n_{1s} – the actual revolutions of the motor under the load of the driven part under the given conditions of the tension force *F*,

n_2 – revolutions without slippage on the driving machine,

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

i_t – theoretical gear ratio

$$i_t = \frac{D_p}{d_p} \tag{2}$$

n_{2s} – measured (actual) revolutions of the driven machine with slip,

Δn_2 – slip revolutions

$$\Delta n_2 = n_2 - n_{2s} \tag{3}$$

T – measured (actual) time of slip revolution [s],

ξ - relative slip

$$\xi = \frac{60}{T.n_{1s}}.i_t \tag{4}$$

ψ - coefficient of elastic slip

$$\psi = 1 - \xi \tag{5}$$

i - gear ratio in a belt drive

$$i = \frac{D_p}{d_p.\psi} \quad \text{so} \quad i = \frac{i_t}{\psi} \tag{6}$$

The "Motor" software is designed directly for the monitoring system, while it is necessary to enter the set input and output revolutions and gear ratio at the beginning. The measurement can be carried out in two different ways:

- at constant speed of the electric motor and brake load (same torque), it is necessary to obtain the values of ψ and ξ for at least five different values of tensioning force, both during loading and unloading of the transmission. Based on these obtained values, it is possible to process graphs of the dependence of the coefficient of elastic slip on the value of the tension force and include these values in the data table [9].
- when maintaining constant values of the input speed of the electric motor and tension force, it is necessary to measure the elastic slip coefficient ψ at least five different values of the torque

on the electric motor. The value of the torque is obtained from the measured input power of the electric motor according to the following procedure:

Power of the electric motor P_e:

$$P_e = P_{ke}.\eta_e \tag{7}$$

where: P_{ke} – measured power with a wattmeter,

η_e – the efficiency of the electric motor specified in the technical specifications.

Subsequently, the torque on the pulley can be calculated:

$$M_{ke} = \frac{P_e}{\omega_{1s}} \quad \text{whilst} \quad \omega_{1s} = \frac{2\pi n_{1s}}{60} \tag{8}$$

where: n_{1s} – real (actual) revolutions of the driven pulley obtained from the "*Motor*" program.

Measurements were made with the gear under load and unloaded. The results of the measurements were displayed in the form of the dependence of the quantity ψ on the torque with the given additional parameters. All these dependencies were recorded and tabulated. Instead of measuring power, we can use the measurement of electrical quantities such as voltage and current or measure the electrical power directly on the driving (driven) devices. The purpose of this measurement was to demonstrate how slip affects the efficiency of the belt transmission, while the efficiency of this transmission is defined by the well-known relationship [10].

$$\eta = \frac{P_2}{P_1} \cdot 100\% \tag{9}$$

Subsequently, the efficiency with slip acceptance is expressed by the following mathematical relationship:

$$\eta_s = \frac{P_2}{P_1 \psi} \cdot 100\% \tag{10}$$

Laboratory determination of power with the help of electrical quantities must be completed by physically connecting and expanding the monitoring software with power quantities and determining the accuracy of the power measurement with the gradual determination of the observed efficiency of the belt transmission according to the given relationships [11]. Experimental monitoring of selected type A belts was carried out by changing the tensioning force of the belt, which was selected and set based on the tabular value of the optimal tension of this type of belt to a value of 254 N.

Table 1. Table of specific weights and values of belt tension

	mm		rpm		N	N	kg/m	
Z	40	60	1 000	2 500	104	69	0,051	n/a
			2 501	4 000	121	81		
	61 over		1 000	2 500	174	116		
			2 501	4 000	174	116		
A	75	90	1 000	2 500	332	222	0,115	0,150
			2 501	4 000	254	169		
	91	120	1 000	2 500	391	261		
			2 501	4 000	332	222		
	121	175	1 000	2 500	469	313		
			2 501	4 000	411	274		

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Due to the optimal value of the belt tension (see Table 1) given by the manufacturer, the belt tension values of 50 N, 250 N and 450 N were proposed for the experiment. The following Figure 2 shows the dependence of the resulting values of the elastic slip coefficient on the changed values of the revolutions on the input drive pulley and the output load on the driven pulley by changing the torque when the belt is tensioned to 50 N. The adjustment of the output load change is possible by connecting the output electric motor via the FM2 frequency converter. The values of the elastic slip coefficient were read from the "*Motor*" program, which simultaneously monitored the actual revolutions on the driving and driven pulleys [12]. The optimal belt tension is at 254 N, which is taken into account in the measurements and the results are shown in Figure 3, and the overload above the table value is shown in Figure 4 when the belt is tensioned at 450 N.

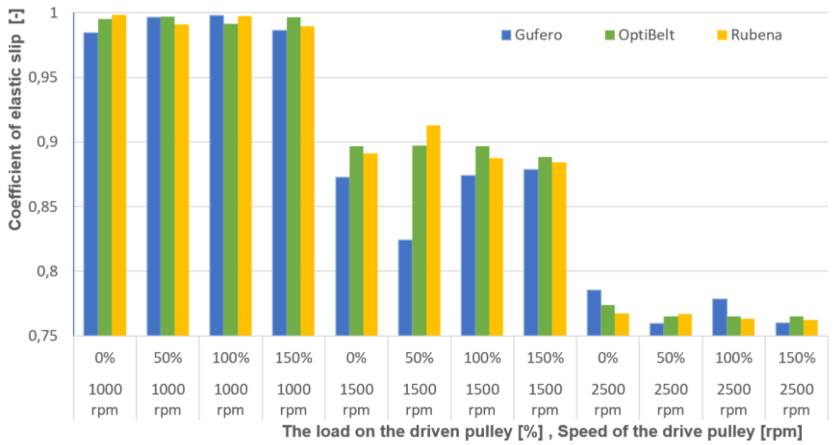

Fig. 2. Graph showing the dependence of the coefficient of elastic slip on the input speed and the load at the output of the belt transmission with a belt tension of 50 N

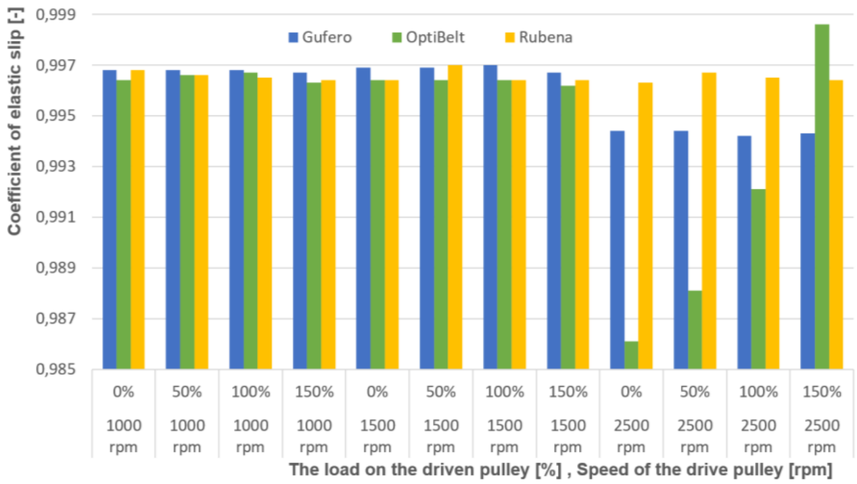

Fig. 3. Graph showing the dependence of the coefficient of elastic slip on the input speed and the load at the output of the belt transmission with a belt tension of 250 N

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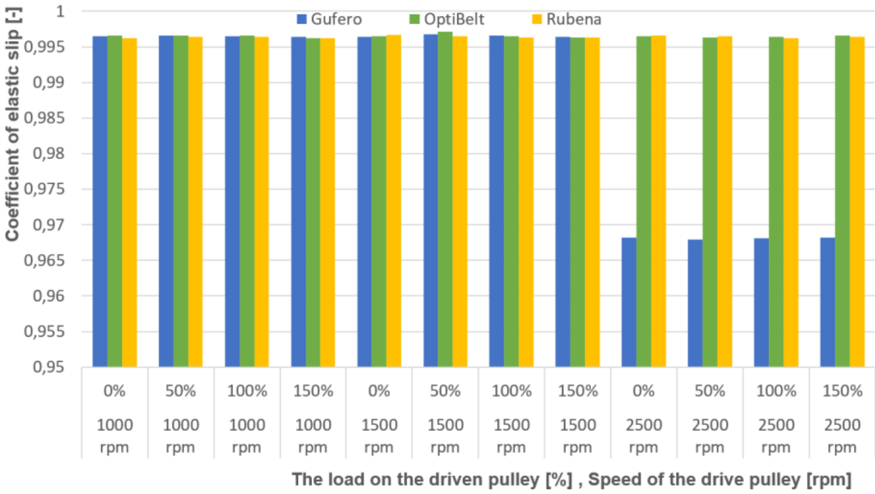
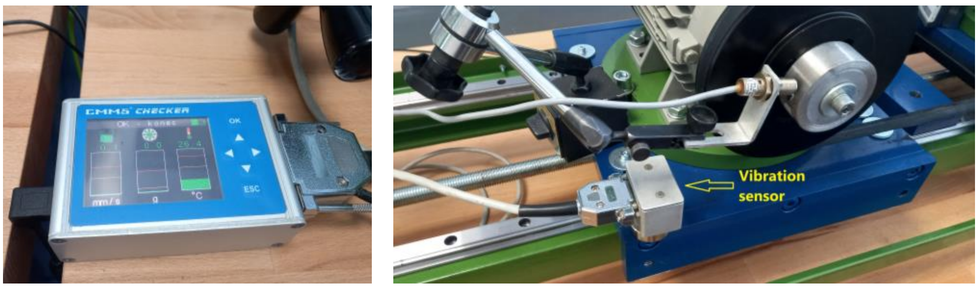


Fig. 4. Graph showing the dependence of the coefficient of elastic slip on the input speed and the load at the output of the belt transmission with a belt tension of 450 N

3.2. Measuring vibration velocity from a belt transmission

Due to the emerging vibrations on devices with a belt transmission, and thus the connection with belt floating, it is important to address this issue. Since it is possible to controllably change the belt tension of the belt transmission on the newly designed test device by changing the axial distance of the pulleys, it also allows us to monitor the change of vibrations in selected places [13, 14]. From practical experience, due to the resulting vibrations, there is a high possibility of shortening the service life and at the same time damaging the storage of the pulley shafts in the bearings. Therefore, it is appropriate to point out the influence of the vibration value depending on the change in the input speed of the drive pulley and at the same time the change in the load on the output drive pulley.

Due to the possibilities within the experiment, vibration measurement was performed by the contact method using a handheld device for measuring and diagnosing machines CMMS Checker (Figure 5a). This measuring system allows for the display of faults also on color machine diagrams generated on the display. A vibration sensor was connected to the measuring unit, which was attached to a predetermined location with a magnet (Figure 5b).



a) b)

Fig. 5. Measuring unit CMMS and sensor for vibration velocity monitoring

The following Fig. 6 shows only minor changes in vibration velocity values when changing a belt of the same type "A" but from different manufacturers. More pronounced changes in vibrations can be observed at higher revolutions, which in our case of the experiment were set to a value of 2500 rpm. At lower speeds of 1000 and 1500 rpm, there were not so many differences. From the results of experimental vibration measurements, it is possible to state and, based on this, to present further recommendations for the general public and users of this type of belts [15, 16]. Fig. 6 shows the change in vibration velocity at the optimal belt tension of 250 N, while experiments were also carried out at 50 N and 450 N tension.

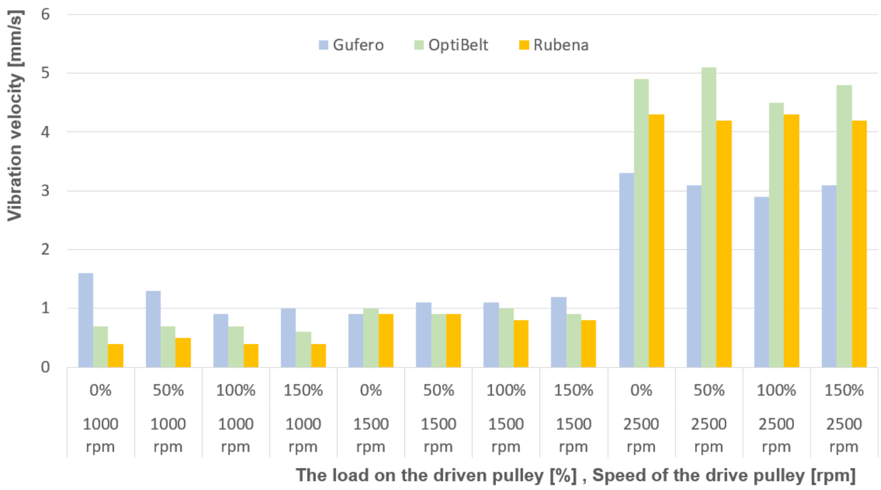


Fig. 6. Graph showing the dependence of vibration velocity on the input speed and the load at the output of the belt transmission at a belt tension of 250 N

After processing the measured values of vibrations at the selected place of the stand, we can evaluate that with different types of belts and at input speeds of 1000 and 1500 rpm, the values are not as large as at increased speeds to a value of 2500 rpm.

4. Conclusion

This article presents a specific design solution as an alternative for monitoring, determining and verifying key parameters affecting the operation and lifetime of various devices and systems using belt transmission. When designing new structural solutions, the economic costs have the greatest impact on the design and development stage and not the production itself, while the construction itself has a great impact on the functionality and reliability of the product.

The presented design solution is modular and at the same time implemented within the framework of the development of laboratories, the professional training of students within the educational process and the creation of final theses, or the solution of tasks in the field of design, control and testing of belt transmissions. If the results of the presented article inspired the expansion of the investigation of the given issue, then it can be concluded that the newly designed system and the results of its measurements are also important in practice.

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