

## EXPERIMENTAL DETERMINATION OF THE BELT TRANSMISSION SLIP

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### Abstract:

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 main objective of the experimental measurement was to determine the slip of the wedge-shaped belt. The slip was evaluated by the coefficient of belt creeping and the specific belt slip by means of the measuring stand. The measurements on the proposed device can be made when the input speed from the electric motor and the transmitted torque of the belt gear are constant while the tensioning force of the belt drive is changing or the measurements can be made when the tensioning force and input speed of the belt drive are constant and the torsional moment changes. The monitoring of specified parameters for determining the belt gear slip is made by means of sensors located at predetermined locations from which data is processed by a PC. In the paper, the analytical calculation is processed, from which the values are compared with the values measured on the proposed device.

**Key words:** belt gear, calculation, measurement, slip

### INTRODUCTION

In the present, the belt transmission provide the opportunity to use a wide range of applications where some kind of motion transfer is needed. With the continuous technical and technological development in fields using belt drives, there is a demand for continuous improvement and new innovations in this area applied to the manufacturers. The available technological equipment and processes enable producers of belt transmission components to produce the ever higher level gear belts of the highest quality [15].

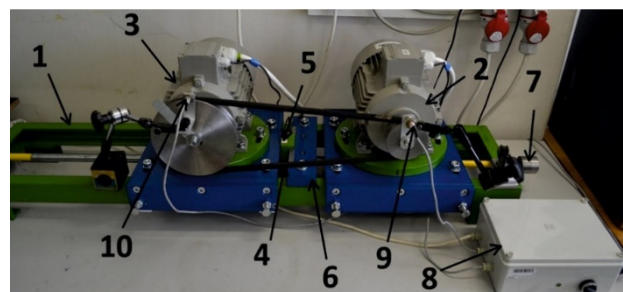
The parameters affecting the gear efficiency are the undisputed factor that has to be taken into account, especially when designing a belt transmission for application in a device requiring the greater precision. The paper focuses on the performance parameters that include the slip of the belt transmission. It is a phenomenon affecting the efficiency of the belt transmission which cannot be eliminated in any way [18].

### DESIGNED STAND FOR TESTING THE BELT TRANSMISSION

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. 1) 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 [14]. 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 [21].



**Fig. 1** 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 EMS550, 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.

An important factor influencing the correct belt measurement and testing is an appropriate belt (strap) tension. The stand is equipped for this purpose with the tensometer sensing element EMSYST EMS50 which is located between the tensioning plate and the sliding bed of the electric motor. It is a diaphragm bridge sensor of relatively small dimensions and the measurement is performed in the direction of pressure. For the purpose of controlling and regulation of the electric motors operation, the test stand is equipped with a primary control unit (Fig. 2) 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 [12].



Fig. 2 Control and regulate unit:

1 – frequency converter of the driving electric motor, 2 – frequency converter of driven electric motor, 3 – box with modular breakers, 4 – central power switch, 5 – controlling regulators

The electro motors of the measuring stand are controlled by a pair of Altivar 71 type ATV71HU15N4 frequency inverters from Schneider Electric. It is a frequency inverter which regarding its properties and ease of use is designed for use in more difficult and complicated applications with power ranges of up to 500 kW. The basic characteristics of the Altivar 71 frequency inverter include the speed and power control capability with vector control even at low speed [3]. It has many features such as PID controller, brake control suitable especially for conveyor systems, strokes and other applications. The Altivar 71 frequency inverter does not have its own display media but it is equipped with a removable operator terminal containing the LCD display, navigation buttons, configurable keys, "Simply Start" menu etc. This terminal is mounted on the front of the frequency converter and communicates together via the RJ45 port. The monitoring and evaluation

unit of the testing stand comprises the computer and software for the processing of received data [13].

### ANALYTICAL CALCULATION OF SLIP OF BELT TRANSMISSION

For the analytical calculation, the tensioning force of 150 N was used at input speed  $n_{1t} = 1300 \text{ min}^{-1}$ . The results of the variables are given in Table 1.

The calculation of input values:

- theoretical gear ratio  $i_t$ :

$$i_t = \frac{D_p}{d_p} = \frac{160 \text{ mm}}{80 \text{ mm}} = 2 \quad (1)$$

where:

$D_p$  is diameter of larger pulley and  $d_p$  is diameter of smaller pulley.

- theoretical revolutions of driven electro motor  $n_{2t}$ :

$$n_{2t} = \frac{n_{1t}}{i_t} = \frac{1300 \text{ min}^{-1}}{2} = 650 \text{ min}^{-1} \quad (2)$$

Table 1  
Input parameters of calculation

Input known values	Input calculated values	Input measured (real) values
$D_p$ 160 mm	$n_{2t}$ 650 $\text{min}^{-1}$	$n_{1r}$ 1300 $\text{min}^{-1}$
$d_p$ 80 mm	$i_t$ 2	$n_{2r}$ 635 $\text{min}^{-1}$
$n_{1t}$ 1300 $\text{min}^{-1}$		

Calculation of slip:

- sliding revolutions  $\Delta n_2$ :

$$\Delta n_2 = n_{2t} - n_{2r} = 650 \text{ min}^{-1} - 635 \text{ min}^{-1} = 15 \text{ min}^{-1} \quad (3)$$

- measured time of sliding revolution  $T$ :

$$T = \frac{60}{\Delta n_2} = \frac{60}{15 \text{ min}^{-1}} = 4 \text{ s} \quad (4)$$

- the specific belt slip  $\xi$ :

$$\xi = \frac{60}{T \cdot n_{1t}} \cdot i_t = \frac{60}{4 \text{ s} \cdot 1300 \text{ min}^{-1}} \cdot 2 = 0.0231 \quad (5)$$

- the coefficient of belt creeping  $\psi$ :

$$\psi = 1 - \xi = 1 - 0.0231 = 0.9769 \quad (6)$$

- the real gear ratio  $i$ :

$$i = \frac{D_p}{d_p \cdot \psi} = \frac{i_t}{\psi} = \frac{2}{0.9769} = 2.0472 \quad (7)$$

The values of slip and other values for the other parameters of measurement were calculated in a similar manner and the results of the variables and the slip values are given in Table 2 [17].

Table 2  
Result of belt slip calculation

$n_{1t}$ [ $\text{min}^{-1}$ ]	$n_{2t}$ [ $\text{min}^{-1}$ ]	$n_{1r}$ [ $\text{min}^{-1}$ ]	$n_{2r}$ [ $\text{min}^{-1}$ ]	$\Delta n_2$ [ $\text{min}^{-1}$ ]	$T$ [s]	$\xi$	$\psi$	$i$	$M_T$ [%]	$M_r$ [Nm]
1300	650	1300	635	15	4	0.02307	0.9769	2.047	25	1.25
1600	800	1600	782	18	3.3330	0.0225	0.9775	2.046	25	1.25
2000	1000	2000	981	19	3.1579	0.019	0.981	2.038	25	1.25
1300	650	1300	636	14	4.2857	0.02154	0.97846	2.044	50	2.5
1600	800	1600	780	20	3	0.025	0.975	2.051	50	2.5
2000	1000	2000	978	22	2.7273	0.02179	0.9782	2.044	50	2.5
1300	650	1300	635	15	4	0.02308	0.9769	2.047	65	3.25
1600	800	1600	780	20	3	0.025	0.975	2.051	60	3
2000	1000	2000	977	23	2.609	0.02299	0.977	2.047	60	3

### BELT SLIP MEASURING BY MEANS OF THE TESTING STAND

The measurement of the belt slip of belt transmission requires preparation of the device (the measuring stand) before the measurement process itself. This preparation includes activities such as proper positioning of the pulley speed sensors, proper tensioning of the belt using the tensometer sensor and the software preparation by loading the known input values into the used software Motor [10]. The process of the belt slip measurement was to set the predetermined input revolutions of the driving motor by means of the Altivar 71 (FM1) (Fig. 3) 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 [16].



Fig. 3 Setting the entry speed and torque on frequency inverters Altivar

The measured parameters scanned by the measuring stand and converted directly by means of an analogue-to-digital converter to the evaluation computer include the actual revolutions of the driving pulley of the electric motor as well as the actual revolutions of the driven pulley of the electric motor serving as the brake of gear [1]. On the basis of the above facts, the necessary quantities are calculated using the software resulting in the determination of the slip of the belt transmission. The scanning of the actual pulleys revolutions is provided by a pair of inductive sensors PLOSKON PAS 126 313 (Fig. 4).

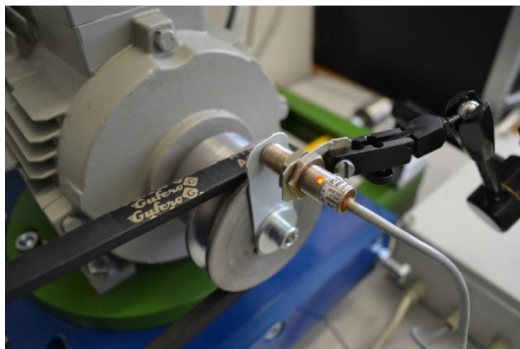


Fig. 4 Detail of the revolution scanning by the PLOSKON sensor

Measurements were made at the tensioning force of 150 N and the other defined input measurement parameters

are the input revolutions ( $1300 \text{ min}^{-1}$ ) of the driving electric motor and the torsional moment that loading the driven electric motor that is defined to value 1.25 Nm, representing 25% of the possible load given by the torque-speed curve of the Siemens 1LA7090-2AA10ZA11 electro-motor.

The initial preparation of the measuring stand included the assembly of the wedge-shaped belt (A 1150 Lw 13x1120 Li A 44) and its tension by a tensioning force. An important part of the preparation was also the correct positioning of sensors of the revolutions of the driving and driven pulley [9].

A further step necessary to carry out the measurement and completion of the resulting slip values and other variables was to start the driving and driven electric motors and to define the required values for the driving electric motor speed and the torque on the driven electric motor [5]. The required parameters were defined by frequency inverters. The required motor drive revolutions  $1300 \text{ min}^{-1}$  was defined by the FM1 frequency converter connected to this electric motor, where the option "Motor speed" was selected in the main menu. Using the frequency converter FM2 connected to a driven electric motor, the torsional moment was set in the menu option "Motor Torque" to 25% which is 1.25 Nm.

The next step was to enter the known input parameters into the software Motor. These parameters include the electric motor speed (electromotor card value of  $1300 \text{ min}^{-1}$ ), the theoretical gear ratio calculated as a ratio the small and large pulley diameters is 0.5. Setting the input values for a given measurement are shown in Fig. 3.

After the initial setting of the required input parameters, the slip measurement process continued by scanning the actual (real) revolutions of the driving and driven electric motors [4]. These data were sent from the sensors to an analog-to-digital converter where they were converted and further sent to the computer where they were evaluated by the Motor software (Table 3) [19]. Fig. 5 shows a result window of a presented measurement showing the results of the gear belt slip measurement and related variables.

Table 3  
Measured results at a tensioning force of 150 N

$n_{t1} [\text{min}^{-1}]$	$n_{t2} [\text{min}^{-1}]$	$n_{r1} [\text{min}^{-1}]$	$n_{r2} [\text{min}^{-1}]$	$\Delta n_2 [\text{min}^{-1}]$	$\tau [\text{s}]$	$\xi$	$\psi$	$i$	$M_T [\text{Nm}]$	$M_r [\text{Nm}]$
1600	800	1601.7	790.5	10.4	5.8	0.0032	0.9968	0.5016	25	1.25
2000	1000	2001.7	987.8	13.1	4.6	0.0033	0.9967	0.5016	25	1.25
1300	650	1300.5	643.2	7	8.51	0.0027	0.9973	0.5014	50	2.5
1600	800	1601.6	791.7	9.1	6.59	0.0028	0.9972	0.5014	50	2.5
2000	1000	2001.7	989.6	11.3	5.33	0.0028	0.9972	0.5014	50	2.5
1300	650	1300.6	643.6	6.7	8.96	0.0026	0.9974	0.5013	65	3.25
1600	800	1600	792.2	8.8	6.86	0.0027	0.9973	0.5014	60	3
2000	1000	2001.1	989.4	11.2	5.38	0.0028	0.9972	0.5014	60	3

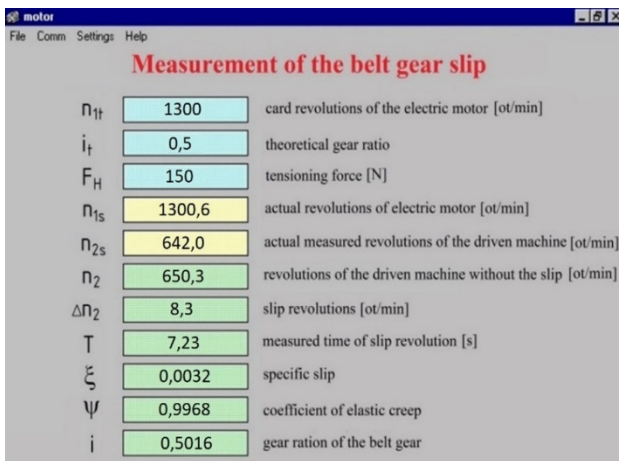


Fig. 5 The results belt transmission gear slip measuring for  $n_{1t} = 1300 \text{ min}^{-1}$ , load 1.25 Nm

### EVALUATION OF CALCULATED AND MEASURED SLIP VALUES

The comparative parameter belonging to the principal indicators of slip is the belt elastic creeping coefficient  $\Psi$ . The comparison of that parameter obtained by the calculation and the measurement process in relation to the revolutions of the driving electric motor was made (Figs. 6-8) [8].

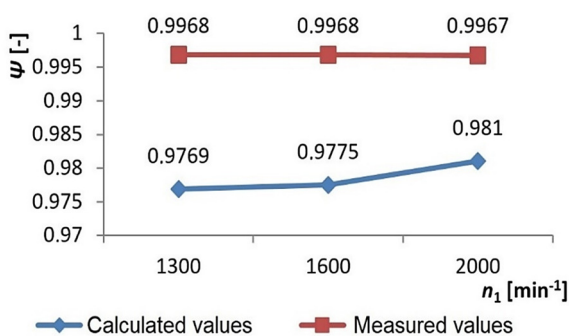


Fig. 6 Comparison of results for 25% of the electric motor load

The graph in Fig. 6 compares the results of the calculated and measured values of the belt elastic creeping coefficient for 25% (1.25 Nm) load of the driven electric motor by the torque in dependence on the revolutions of the driving electric motor at the tensioning force 150 N. The curve formed by the measured values is of a slight decrease in the belt elastic creeping coefficient, indicating a rise in the specific belt slip [2]. Anyway, the curve formed by the calculated values of the belt elastic creeping coefficient increases depending on the gradual increase of the revolutions and the reduction of belt elastic creeping coefficient is indicated.

The graph in Fig. 7 shows the calculated and measured values of the belt elastic creeping coefficient for 50% (2.5 Nm) load of the driven electric motor. The measured results show a slight decrease in the belt elastic creeping coefficient at the maximum revolutions of  $2000 \text{ min}^{-1}$ , thus a slight increase in the specific belt slip [7].

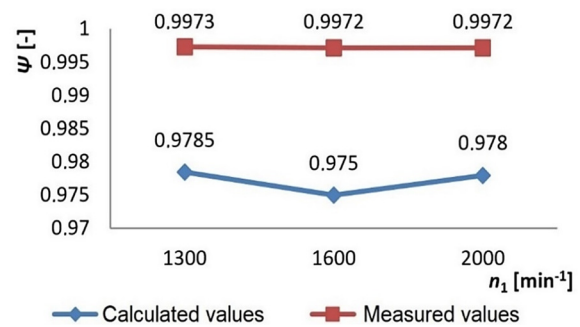


Fig. 7 Comparison of results for 50% of the electric motor load

From the calculated values the apparent decrease of the belt elastic creeping coefficient for  $1600 \text{ min}^{-1}$  and increase at the final revolutions ( $2000 \text{ min}^{-1}$ ).

The graph in Fig. 8 compares the calculated and measured values of the belt elastic creeping coefficient for 60% (3 Nm) load of the driven electric motor. At the measured results obtained by measuring stand, the belt elastic creeping coefficient decreases depending on the revolutions of the driving electric motor, but this drop is negligible [20]. The behaviour of the calculated values shows a certain decrease in the belt elastic creeping coefficient at  $1600 \text{ min}^{-1}$  followed by its increase at  $2000 \text{ min}^{-1}$ .

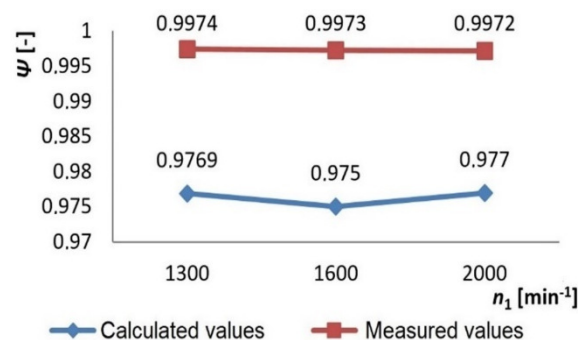


Fig. 8 Comparison of results for 60% of the electric motor load

### DISCUSSION

In belt drives, power is transmitted by friction by means of a closed yielding belt from the drive pulley to the driven pulley. Friction is achieved by tensioning the belt. It is under tension when the belt is under tension due to the tensioning force. The prestressing is adjusted either by changing the axial distance, by reducing the length of the belt or by means of a tensioning pulley. Technical life of belts varies from 1000 to 5000 hours depending on the type and type of belt.

In each belt transmission, an effective pre-tensioning shall be provided which ensures sufficient contact force and with it the frictional force to transmit the required power. Also due to this slip angle size, the frictional force must be equal to the transmitted circumferential force. Experimental results show that the efficiency of belt drives ranges from 0.96 to 0.98 for automatic tensioner drives.



Because the properties of the belt materials and their length are very sensitive to temperature rises, the efficiency drops to 0.90 during operation and slipping may occur if the bias is not properly tuned. Also, with excessive bias, efficiency can drop significantly to 0.80.

## CONCLUSION

The aim of the presented paper was to point to the process of detecting the belt transmission slip as well as the quantities that are closely related to the slip itself. The determination of the belt transmission slip is divided into two separate approaches [11]. The first one describes the detection of the belt slip based on an analytical calculation where known mathematical relations are used. The second approach presents a method of determination of the belt slip using a special measuring stand and software designed for this purpose [6].

The comparison of the belt slip values identified by two approaches at the same input parameters (tensioning force 150 N and input revolutions 1300 min<sup>-1</sup>, 1600 min<sup>-1</sup>, 2000 min<sup>-1</sup>) is obtained. From the individual belt slip values determined by the calculation and measurement, the graphs presenting the course of the belt elastic creeping coefficient at different loading values of the driven electric motor are created, depending on the revolutions of the driving electric motor of the belt transmission.

Based on the calculated values, it can be stated that at input theoretical revolutions 1600 min<sup>-1</sup> and the load of the driven electric motor torque 50% (2.5 Nm) and 60% (3 Nm), the coefficient of belt creeping is reduced due to the higher ratio between the measured time of sliding revolution and real input revolutions.

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