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The Influence of an Operating Conditions on the Friction Coefficient in Transportation Machines Drives

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INTRODUCTION

Belt conveyors are the largest in terms of demand and production and the fastest growing group of continuous transport devices. Belt transport in the raw materials industry has been showing significant progress for several years. New technologies and materials are used in the construction of conveyors. Conveyor components are constantly improved, in particular the belt structure and its connections, rollers with reduced rolling resistance or drive technology. At the same time, computational methods and IT tools are being developed to support the design of belt conveyors. This allows the design of conveyors that are better adapted to transport tasks and ensuring reduced energy consumption and increased durability. All this means that belt conveyors play a dominant role in spoil transport systems in both surface mining and underground mining, becoming an alternative to rail or tire transport (Feng et al. 2019, Żur, 1979). In belt conveyor drive systems, the drive force is transferred from the drum to the conveyor belt due to friction coupling (Persson, 2020). Friction coupling conditions depend on parameters such as belt tension force, drum wrap angle, and friction coefficient between the belt cover and the drive drum surface. While the first two parameters are easy to measure even in industrial conditions, estimating the value of the friction coefficient is much more difficult (Solski, Ziemba 1965).
The basic factor determining the value of the friction coefficient μ is the type of friction steam materials, i.e. the type of material for the belt cover and the drum drive lining. In addition, the presence of any intermediate layers between the belt and the drum, dirt and moisture usually lead to a change in the value of the friction coefficient μ. The combination of impurities and moisture is particularly unfavorable, but the impact of the impurities is not always the same. It depends not only on the type of physical-mechanical and physicochemical properties, but also on the amount of these impurities and the way they are distributed (Burdzik et al., 2012, Furmanik & Oleksiak, 2002,

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Hebda, 2007, Hebda & Wachal, 1980, Hryciow et al., 2018, Kotwica et al., 2016, Siedlar, 1990).

Determining the value of the friction coefficient is difficult in industrial conditions, which is why the Chair of AGH Mining, Processing and Transport Machines developed a unique stand for testing the friction coefficient under high pressure and extremely low slip speeds, also in the presence of impurities.

TEST STAND AND METHODOLOGY OF RESEARCH

Designed and built an innovative laboratory stand for testing the friction coefficient under high pressure and low slip speeds met the following design and construction assumptions (Lawrowski, 2007, Stawowiak & Żołnierz, 2018, Szczerek & Wiśniewski, 2000):

- the friction pair pressure system enables the application of unit pressures corresponding to the pressures obtained in operating conditions, e.g. friction pair drum lining − conveyor belt, drive wheel − rail,
- the propulsion system ensures a sliding speed below 0.001 m/s with the possibility of its adjustment,
- it is possible to test various friction pairs, e.g. steel − rubber, rubber − rubber, steel − steel,
- the measuring system used in the station ensures the registration of friction force and friction pair pressure,
- overall dimensions of the station allow it to be placed in a climatic chamber and to study the phenomenon of friction at temperatures from −30°C to + 50°C.

The main components of the constructed station are: frame, pressure system and drive system. The stand frame is made of C-profiles connected by welding. Two lead screws with trapezoidal thread are installed in the frame of the station. The purpose of these screws is to feed the inner frame with the counter-sample. Figure 1 shows the construction of the test stand.

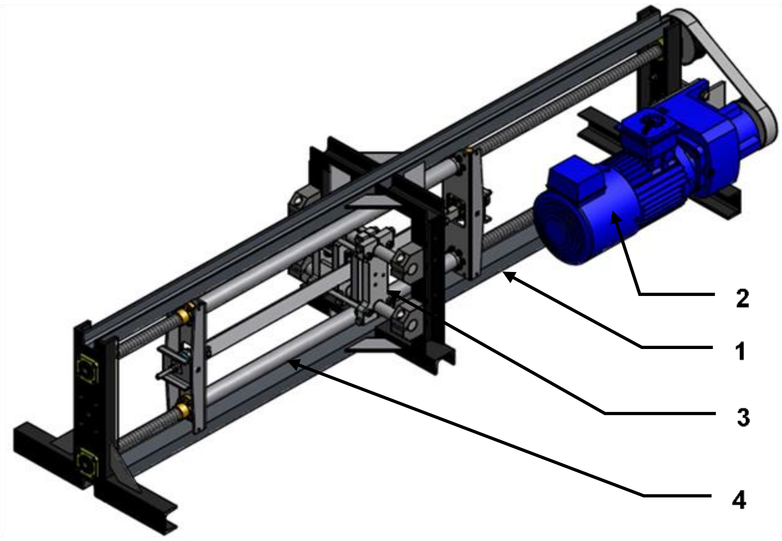

Fig. 1 General view of the laboratory stand:
1 - frame, 2 - drive system, 3 - pressure system, 4 - inner frame

The central part of the station is equipped with a sample clamping system (Fig. 2) made of aluminum flat bars, the shape of which enables collision-free cooperation. In order to achieve a smooth movement and pressure, guide shafts (1) with sliding sleeves (2) mounted on these shafts were used. Thanks to the use of sliding sleeves and the selection of the correct fit of the shaft in the hole, the movement of the pressure plates (3) relative to the guide shafts takes place without unnecessary resistance. The required pressure of the sample against the counter-sample (10) is obtained by using a set screw with a fine thread (5) together with a threaded steel sleeve (6). The use of this sleeve avoided the need for a thread in an aluminum plate. The phenomenon of beveling during mutual sliding of the pressure plates should also be taken into account. To avoid this, a symmetrical loading system connector (11) fitted parallel to the axis of the guide rollers was used. The tested sample (9) is mounted in a holder located on the pressure plate (7) with Allen screws.

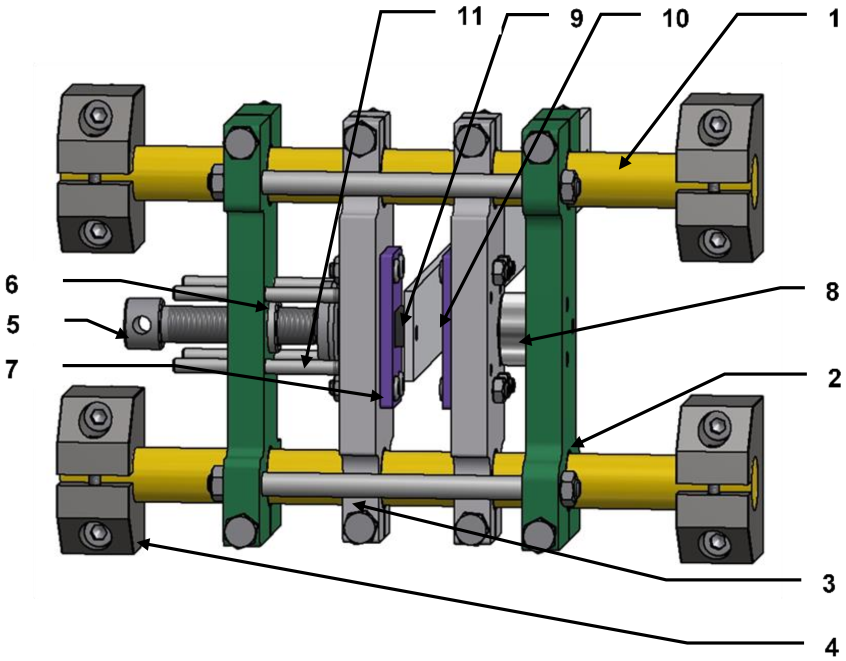

Fig. 2 Pressure system:
1 - guide shaft, 2 - slide sleeve, 3 - pressure plates, 4 - guide shafts holders, 5 - pressure screw, 6 - threaded bushing, 7 - sample holder, 8 - pressure force gauge, 9 - sample, 10 - counter-sample, 11 - loading system connector

The drive system (Fig. 3) uses a belt transmission with a toothed belt. Belt pulleys (1) driven by a toothed belt (2) were mounted on the gearmotor shaft (3) and on trapezoidal bolt journals (4) by means of self-centering clamping bushes whose mechanical parameters meet the conditions assumed in the project assumptions.

For the construction of the station, a 3.0 kW geared motor with an output speed of n = 160 min − 1 was used as the drive element. To regulate the slip speed, the drive system is equipped with a frequency converter. The minimum frequency of the current supplying the gearmotor was set to 2 Hz, thanks to which the counter-sample shifting speed of 6.4 * 10-4 m/s was achieved.

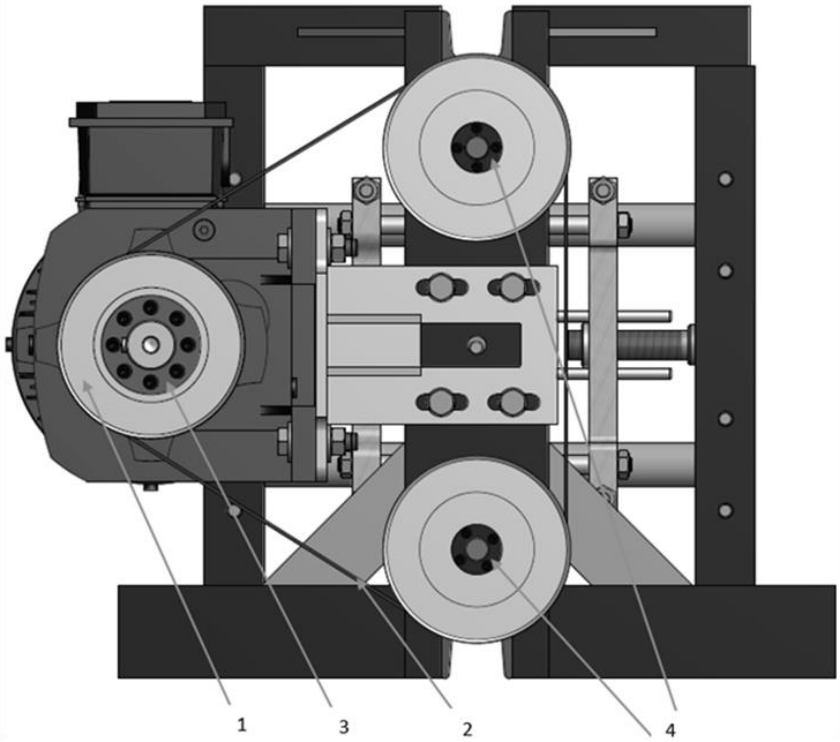

Fig. 3 Drive system of the stand:
1 - belt pulley, 2 - toothed belt, 3 - gearmotor shaft, 4 - trapezoidal bolt journals

Two samples with a contact area of 400 mm^2 each were used in the stand. The value of the maximum unit pressures is 6.25 N/mm^2. Three strain gauges were used to build the measuring system used in the station.
In the measuring system used in the station, a system of strain gauges was used to measure the tractive force and the pressure force of the sample against the counter-sample. These sensors have the ability to measure force up to 5 kN. The location of the sensors is shown in Figure 4.

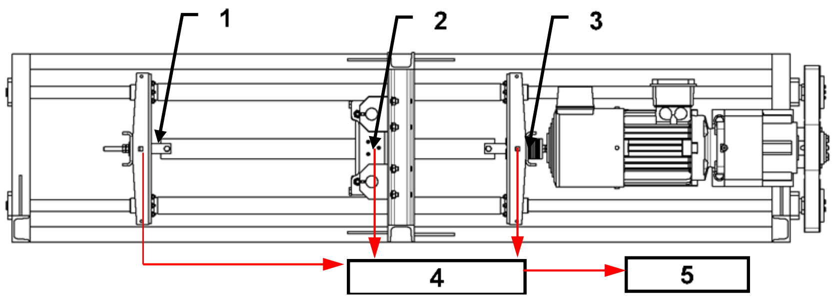

Fig. 4 Scheme of the measuring system
1 - tensile force gauge I, 2 - pressure force , 3 - tensile force gauge II,
4 - measuring card, 5 - computer

Counter-tensile force and sample clamping force sensors are connected to the NI-USB 6009 measuring card. The card's measurement signals are recorded in the computer at a frequency of 1 kHz or higher, depending on the needs.

THE RESULTS OF THE TESTS

In the initial tests at the new stand, belt and rubber drum lining were used, which operate in one of the copper ore mines. For the purposes of the study, 20 mm x 20 mm samples prepared from the drum lining and a counter-sample of 700 mm × 50 mm cut lengthwise from the belt were prepared. The counter-sample was mounted in the jaws and tightened with adequate force in the inner frame (Fig. 5).

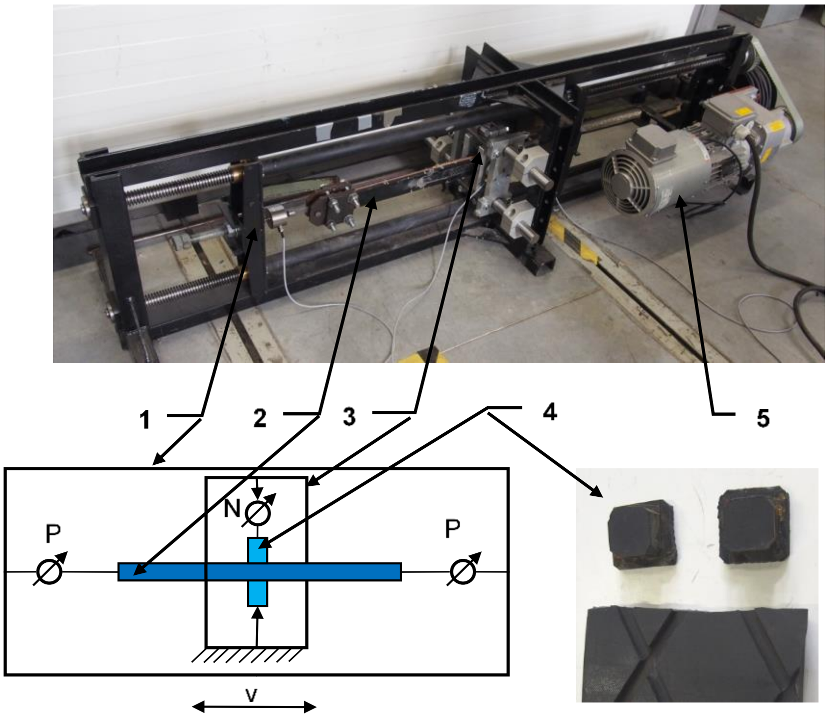

Fig. 5 View and schematic diagram of the stand
1 - mobile frame, 2 - belt counter-sample, 3 - fixed system of sample clamping, 4 - drum lining sample, 5 - drive

During the measurement, tension forces P1 and P2 and pressure force N, measured with strain gauges, are recorded. The absolute value of the difference of forces P1 and P2 is the friction force, therefore the value of the friction coefficient μ is calculated from the following relationship:

$$\mu = \frac{|P_1 - P_2|}{2 \cdot N}$$

where:
$(P_1 – P_2)$ − friction force [N],
N – pressure force [N].
Tests of the friction coefficient were carried out for the determined pressure force N, tension forces P1 and P2 and the sliding speed v. The tests were carried out at different states of friction surfaces (Table 1).

Table 1 Parameters of laboratory tests

Surface condition	**Sliding speed *v* [m/s]**	**Tension force P_1, P_2 [N]**	**Pressure force [N]**
Dry, clean	$\pm 6{,}4 \times 10^{-4}$	2000	200
Wet, clean	$\pm 6{,}4 \times 10^{-4}$	2000	200
Dry dust	$\pm 6{,}4 \times 10^{-4}$	2000	200
Wet dust	$\pm 6{,}4 \times 10^{-4}$	2000	200

Before the basic tests, a pair of rubbing strips around 50 mm in length was achieved to ensure stable friction conditions and repeatability of results. Grooves were made before the measuring section to ensure an even distribution of copper ore dust between the belt sample and the drum lining (Fig. 6).

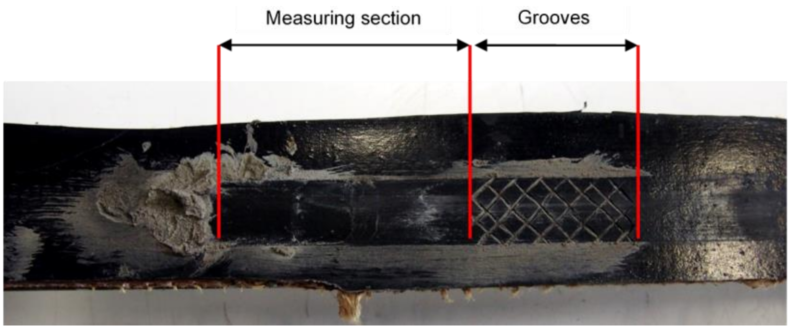

Fig. 6 View of the counter-sample made of belt

The value of pressure force N was estimated on the basis of real pressures in the belt on the first drive drum of the conveyor. In laboratory conditions, the pressure force N was assumed to be about 200 N, which corresponds to unit pressure in real conditions. Four measurement series were carried out, corresponding to the surface condition of the friction pair. Five measurements were taken for each series with left (−v) and right (+ v) slip directions. The graphs in Figures 7 and 8 show examples of friction coefficient value changes.

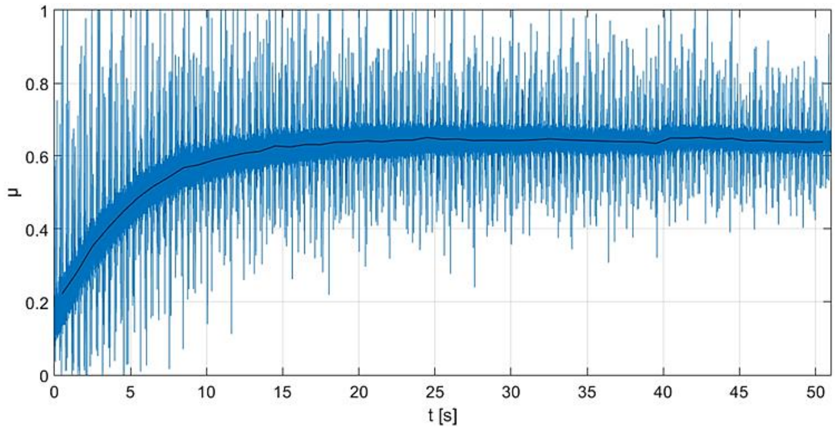

Fig. 7 Chart of friction coefficient value changes for dry and clean friction pair

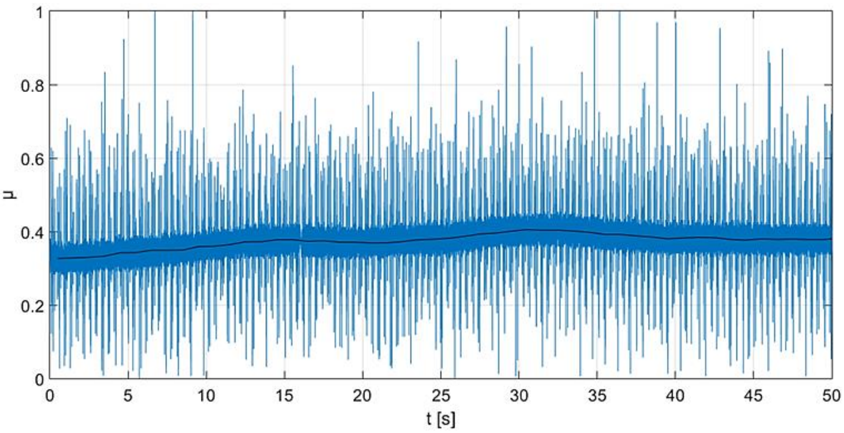

Fig. 8 Chart of friction coefficient value changes for wet and dusty friction pair

Table 2 presents the results of friction coefficient tests between the belt and the drum lining.

Table 2 Values of friction coefficient between belt and drum lining

Surface condition		Dry clean		Wet clean		Dry dust		Wet dust	
Movement direction		right (+v)	left (-v)	right (+v)	left (-v)	right (+v)	left (-v)	right (+v)	left (-v)
Attempt number	1	0,647	0,727	0,445	0,471	0,411	0,483	0,375	0,449
	2	0,643	0,731	0,437	0,483	0,425	0,492	0,379	0,451
	3	0,646	0,732	0,428	0,505	0,438	0,517	0,387	0,456
	4	0,644	0,742	0,415	0,499	0,451	0,539	0,392	0,462
	5	0,649	0,741	0,394	0,513	0,467	0,533	0,386	0,468
Average value		0,646	0,735	0,424	0,494	0,438	0,513	0,384	0,457
		0,690		0,459		0,475		0,420	

As it results from Table 2, there are some differences in the values of the friction coefficient for the slip direction -v and + v. They result from anisotropy of friction, therefore it is reasonable to use average values (Stefański et al. 2001).

The measurement uncertainty was estimated. Since the value of the tested value of the friction coefficient was determined indirectly on the basis of direct measurements of other physical quantities, the measurement uncertainty should be estimated by the total differential method. The total error of the strain gauges was ≤ 0.2% and the determined measurement uncertainty of the friction coefficient $\Delta\mu = 0.001$.

CONCLUSIONS

The construction of the constructed stand allows tests to be carried out on various friction pair materials, also in the presence of an intermediate layer. A wide range of adjustment of the sample clamping force to the counter-sample and sliding speed allow for the study of friction phenomena occurring in cooperation with various machine components. Test tests carried out on an innovative measuring stand confirmed its high utility in determining the friction coefficient under high pressure and low slip velocity values. High accuracy of measured quantities and repeatability of measurements were obtained. Based on the laboratory tests, the following average values of the friction coefficient were obtained, respectively for the surface condition:

- dry clean: $\mu = 0.690 \pm 0.001$,
- wet clean: $\mu = 0.459 \pm 0.001$,
- dry dusty: $\mu = 0.475 \pm 0.001$,
- wet dusted: $\mu = 0.420 \pm 0.001$.

The value of the coefficient of friction for a given friction pair significantly depends on the state of the surface. The greatest impact on the reduction of the friction coefficient is the presence of moisture with copper ore dust.

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Abstract.
The publication presents the construction of the station for testing the friction coefficient under high pressure and low slip velocity values. These conditions of cooperation of friction pairs occur in the drives of transport machines such as belt conveyors and suspended monorails. The value of the friction coefficient, depending on the operating conditions such as moisture and rock or coal dust pollution, has a significant impact on the correct and efficient operation of such drives. The features of the station allow mapping the operating conditions on a laboratory scale. As part of the research, appropriate friction samples made of rubber or polyurethane were prepared. Referring to the conditions of conveyor operation and conditions of contact of the conveyor belt with the drive drum, the values of unit pressures and values of slip speed occurring in the drum drive of the belt conveyor were determined. A series of laboratory tests were carried out for the friction pair rubber drum lining – conveyor belt cover. The tests were carried out for four different states of friction vapor surfaces, namely for dry and wet samples, as well as for samples in clean or contaminated with stone dust. As a result of the tests, the values of friction coefficients for various surface states were determined, which will be valuable information for designers of friction drive systems of transport devices.

Keywords: belt conveyor, friction coefficient, transportation machines, underground railway