

## The influence of belt cover thickness on conveyor belt indentation rolling resistance

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*Date of submission to the Editor: 05/2019*

*Date of acceptance by the Editor: 07/2019*

### INTRODUCTION

The operation of a belt conveyor is accompanied by a number of physical phenomena which entail various forms of energy conversion. Depending on the location and the reason of these conversions, three groups of motion resistances are identified (Gładysiewicz, 2003):

- main resistances, which accompany belt movement along the complete conveyor route,
- secondary, concentrated resistances, which occur on the head pulley, the drive pulley, the tail pulley, the take-up pulley, as well as in the locations where cleaning/scraping devices are installed,
- lift resistances of the bulk material, which occur only on the inclined sections of the conveyor route.

The share of concentrated resistances in the total resistances to motion decreases in proportion to the increasing length of the conveyor. As currently constructed belt conveyors boast increasing lengths, main resistances are becoming increasingly important in the context of the energy consumption of conveyor transportation systems. Due to energy dissipation, main resistances are classified as follows (Gładysiewicz, 2003):

- belt flexure resistances, related to the cyclical process of bending the belt on supporting idlers,
- flexure resistance of bulk material, due to cyclical deformations of the stream of transported material, directly related to the bending of the belt between and on idlers,
- sliding resistance of belt on idlers, due to the relative, transversal movements of the belt on the idler coat. Each of the above components accounts for maximum 10% of main resistances,
- idler rotational resistances may account for up to 20% of main resistances and are related to the phenomenon of energy dissipation in roller bearings and seals,

- belt indentation rolling resistances (sometimes also referred to as the rolling resistance of belt on idlers), due to the rolling of a rigid cylinder (roller) on a viscoelastic surface (belt). Research indicates that belt indentation rolling resistances may account for as much as 50-60% of main resistances (Hager and Hintz, 1993). This component demonstrates a particular potential for the reduction of conveyor resistance to motion and its resulting energy consumption.

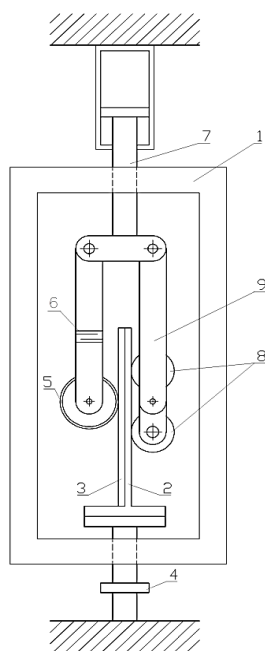
Many analytical and numerical models are known which enable determining the value of belt indentation rolling resistance (Gładysiewicz and Konieczna, 2016; Qiu and Chai, 2011; Wheeler and Munzenberger, 2009; Qiu, 2006; Jonkers, 1980). However, particular importance is placed on experimental tests, in which belt indentation rolling resistance is measured directly. Such tests allow verification of theoretical methods and identification of the characteristic influences of various factors on the rolling resistances. Literature points to a number of laboratory testing methods, the majority of which require complex test rigs with power-driven belt loop tensioned by a drive and return pulleys (Munzenberger and Wheeler, 2016; Wennekamp et al., 2012; Yan et al., 2015). A method is also known in which belt indentation rolling resistance is measured in a situation reverse to actual conditions: instead of being rolled on idlers, the belt is fixed and idlers are allowed to roll over it. The physical phenomena involved in this process are nevertheless the same. The belt rests on an inclined plane and an idler rolls on the belt (Bajda, 2009).

The new method described in this article requires smaller test samples than the previous methods and therefore it is referred to as a small-scale belt indentation rolling resistance testing method. It consists in direct measurement of rolling resistances as an idler is cyclically rolled on a belt sample. The main objective was to develop a simple and inexpensive method for testing belt indentation rolling resistances and analyzing how various factors influence these resistances.

### **SMALL-SCALE METHOD FOR TESTING INDENTATION ROLLING RESISTANCE**

The test rig schematically shown in Fig. 1 is located inside a thermal chamber (1). The belt sample (3) is secured in the clamp (2). The sample is prepared by removing the top cover and pre-tensioning. The idler (5) rolls on the tested belt sample (3). The idler is pressed against the belt using a tensioning system equipped with a force sensor. Rolling resistance is measured with force sensors (6) and (4). To compensate for the transverse forces transmitted to the force sensor and the piston rod of the hydraulic actuator (7), additional rollers (8) were used, which always roll on the metal part of the clamp (2). Both the idler and the additional rollers are guided with hinged arms (9). The idler's reciprocating movement is effected by a hydraulic actuator (7). Prior to measurements, own resistances of the test rig must be determined. Own resistances are determined for the idler rolling on the metal clamp (without the belt sample) and at preset

test parameters. In the next step, the measurements are performed with the belt sample inserted.



**Fig. 1 Schematic representation of the test rig for measuring belt indentation rolling resistances**  
Source: (Woźniak et. al., 2016)

The difference between motion resistances recorded with the sample and those recorded without the sample correspond to belt indentation rolling resistance (Woźniak et. al., 2016).

The idler travels on the belt sample upwards and downwards with constant speed. The drawing force is recorded with force sensors located in the idler arms. The calculation of idler motion resistance requires considering the courses of forces during constant motion upwards and downwards. In a steady motion, the force system is balanced, and therefore the force recorded in the idler arm during its motion upwards  $P_G$  is balanced with gravity force  $G$  and motion resistances  $F_O$ . In the case of the idler's steady motion downwards, only the vector of force for motion resistances will change its sense. A motion resistance equation can be derived as follows (Woźniak, 2017):

$$F_O = \frac{P_G - P_D}{2} \quad (1)$$

where:

$P_G$  – force in the idler arms during the upward motion, in N

$P_D$  – force in the idler arms during the downward motion, in N

$G$  – force of gravity, in N

$F_O$  – motion resistances, in N

This method of determining motion resistances by identifying the difference of forces recorded during the upward and downward motion compensates for the force components not related to the motion resistances. Resistances to motion of an idler passing on the belt include idler rotational resistance  $F_R$  and idler indentation rolling resistance  $F_E$ . In the case when the idler travels only on the

clamp (without the belt sample installed), the indentation rolling resistance of a steel idler on a steel surface is a negligibly small value and allows an assumption that motion resistances are equal to idler rotational resistances  $F_{OS} = F_R$ . Fig. 2 show the measured motion resistances of idler on steel clamp  $F_{OS}$  versus idler load.

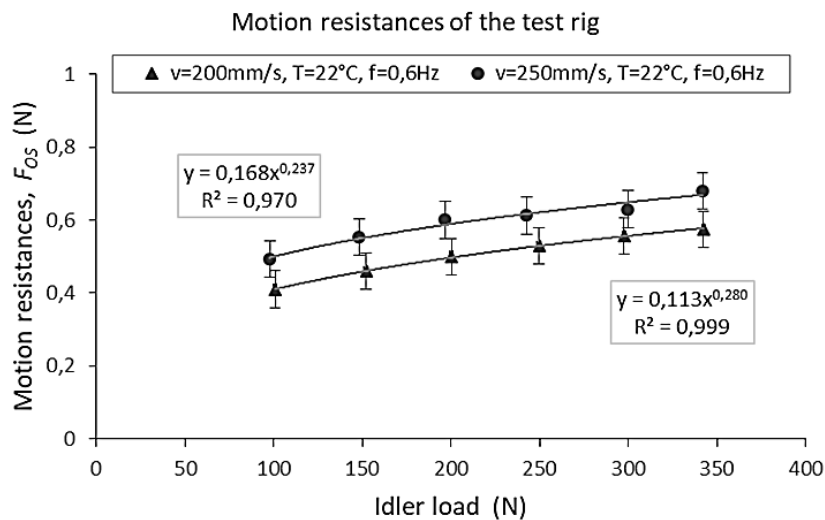


Fig. 2 Measured motion resistances of idler on steel clamp versus idler load

Belt indentation rolling resistance  $F_E$  will be:

$$F_E = F_O - F_{OS} \quad (2)$$

$$F'_E = \frac{F_E}{b_R} \quad (3)$$

where

$F_E$  – idler rolling resistance on belt, in N,

$F'_E$  – idler unit rolling resistance on belt, in N/m,

$F_{OS}$  – motion resistance in a test without a belt, in N,

$b_R$  – the length of the contact line between the belt and the idler coat (the width of the sample), in m.

### TEST RESULTS OF BELT INDENTATION ROLLING RESISTANCE

The tests were performed on belts of various core design and cover rubber properties. The steel-cord belts and the textile belts had bottom covers approx. 7 mm in thickness and the following symbols:

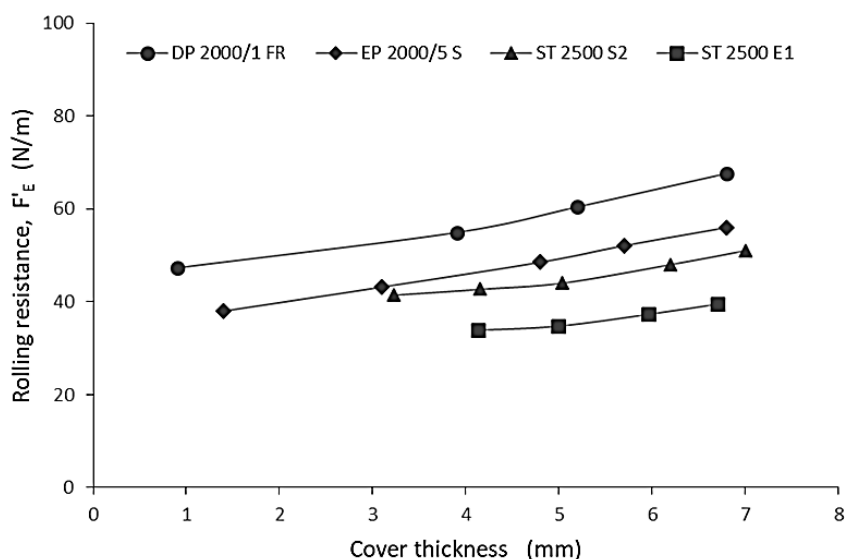
- ST 2500 E1 – belt with reduced motion resistances (the so-called energy-efficient belt),
- ST 2500 S2 – belt with standard motion resistances,
- EP 2000/5 S – standard multiply belt for use on the surface,
- DP 2000/1 FR – flame-resistant aramid single-ply belt.

The belt samples were prepared by removing the top covers in order to eliminate their influence on the process of indenting the idler in the belt. The belt designs are shown in Fig. 3.



**Fig. 3 Conveyor belt samples:**  
a – steel-cord belts, b – textile belts - aramid single-ply belt and multiply belt

Idler load on the conveyor is due to the mass of the transported material and the mass of the belt and thus it depends on the bulk density of the material, the percentage of the conveyor's nominal cross-sectional area occupied by material, idler set spacing and belt mass. During the tests, the pressure of the idler to the sample was  $F_N = 300$  N which, when calculated per unit length of the contact zone between the idler and the test sample, resulted in a unit load 5 kN/m. This value corresponds to the actual range of loads acting on belt conveyors operated in mines (Gładysiewicz et. al., 2019). The tests were performed at ambient temperature  $T = 22 \pm 1^\circ\text{C}$ . The idler traveled on the belt with speed  $v = 200$  mm/s and frequency  $f = 0.6$  Hz. The idler diameter was  $D_R = 108$  mm. Each test consisted of 100 idler-on-belt travel cycles. The tests were performed on the same belt samples, each time with reduced cover thickness. Fig. 4 show the resulting belt indentation rolling resistances for steel-cord belts and for textile belts, depending on cover thickness.



**Fig. 4 Measured indentation rolling resistances versus bottom cover thickness**

As expected, the lowest belt indentation rolling resistances were recorded for the so-called energy-efficient steel-cord belt, while the highest belt indentation rolling resistances were recorded for the belt with aramid core and flame-resistant covers. As can be noticed, cover thickness significantly influences belt indentation rolling resistances. Increased bottom cover thickness entails increased belt indentation rolling resistance. The character of these changes is somewhat different for steel-cord belts and for textile belts. In the case of steel-cord belts, the reduction of cover thickness below 5 mm causes belt indentation rolling resistances to be lower than for the cover thickness above 5 mm. This effect seems to be due to gradual influence of steel cords on the process of rolling the idler on the belt sample and is not observed in the case of textile belts. The core in textile belts consists of layers of fabric and rubber, and therefore, like the belt cover, it also shows viscoelastic properties. A question occurs whether, when and to what extent will the top cover also influence the process of pressing the idler in the belt. The answer to this question requires further research, however.

## CONCLUSION

Belt indentation rolling resistances depend on a number of factors. Designers and users of belt conveyors appreciate information on the characteristics of these factors. The small-scale method for testing indentation rolling resistance allows analysis of the influence of various factors on indentation rolling resistances. With small dimensions of the belt samples, belt cover thickness can be gradually reduced in order to analyze its influence on belt indentation rolling resistances.

Tests performed for four various types of belts demonstrated that cover thickness has a significant influence on belt indentation rolling resistances. Increased thickness of the bottom cover entails increased belt indentation rolling resistance and thus increased forces acting on the belt, as well as power consumption by the conveyor drive mechanism.

In the case of bottom covers having smaller thicknesses, indentation rolling resistances will depend on the type of belt core and its possible interaction with the top cover. This phenomenon requires further research.

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**Abstract.**

One of the methods for lowering of energy consumption in the drive mechanisms of long horizontal belt conveyors is to reduce belt indentation rolling resistances. These resistances depend on a number of factors: bottom cover properties, bottom cover thickness, belt design, idler diameter, load, speed and frequency at which the belt passes on the idler (indentation frequency), as well as on temperature. Determining how these factors influence indentation rolling resistances of various conveyor belt types is of great importance. The article describes a small-scale method for testing indentation rolling resistance. The method allows analysis of the influence of various factors on indentation rolling resistances. The article presents the results of tests on how belt indentation rolling resistance is influenced by thickness of the belt bottom cover. The tests were performed on belts with various core types.

**Keywords:** belt conveyors, conveyor belt, indentation rolling resistance