Lech GŁADYSIEWICZ
Robert KRÓL
Jędrzej BUKOWSKI

TESTS OF BELT CONVEYOR RESISTANCE TO MOTION

EKSPERYMENTALNE BADANIA OPORÓW RUCHU PRZENOŚNIKA TAŚMOWEGO*

The modern of belt conveyor calculations are based upon the advanced computational methods, mostly multivariate simulations. Dimensioning of a conveyor drive depends on the identification of belt conveyor resistance to motion which can be identified with the biggest accuracy after adopting the exact methods of calculation the components of the main resistance force. The development of these methods requires verification of theoretical algorithms. Various tests of the belt conveyor resistance to motion, from the laboratory individual idler rotational resistance to motion, through the combined idler rotational and indentation resistances with the use of a special test rig up to the in-situ tests of an idler subjected to typical operational conditions have been presented. The obtained results have been used both for the verification of calculation methods and the comparison of idlers with alternative steel or polyurethane coating.

Keywords: *belt conveyor, idler, rotational resistance, loading, strain gauge.*

Streszczenie: *Podstawą projektowania przenośników taśmowych są zaawansowane metody obliczeniowe oraz wielowariantowe symulacje różnych stanów pracy. Kluczowym zadaniem projektowym jest wymiarowanie napędu głównego w oparciu wyznaczone opory ruchu przenośnika, Najlepsze oszacowanie oporów ruchu przynoszą metody oporów jednostkowych rozwijane różnych środkach badawczych. Doskonalenie metod obliczeniowych wymaga prowadzenia badań w celu weryfikacji opracowanych zależności. W artykule przedstawiono eksperymentalne metody badań wybranych składowych oporów ruchu przenośnika taśmowego, obejmujące pomiary na stanowisku do badań krążników, pomiary toczącego się wózka z dwoma krążnikami na bieżni wyłożonej taśmą przenośnikową oraz pomiary oporów ruchu pojedynczego zestawu krążnikowego na przenośniku kopalnianym. Uzyskane wyniki pomiarów posłużyły nie tylko do weryfikacji metod obliczeniowych, ale również do porównania krążników z płaszczem stalowym z krążnikami z płaszczem poliuretanowym.*

Słowa kluczowe: *przenośnik taśmowy, krążnik, opór obracania, obciążenie, tensometr.*

1. Introduction

A good machine (belt conveyor) design is based on calculations while a theory is based on experiments, which are an exhaustible source of knowledge. A theory and calculations are inseparably bound. Without a verified theory taking all the factors into account one cannot make accurate calculations and so one cannot optimally design a machine (belt conveyor). Currently, belt conveyor calculations are based on advanced computing methods, mostly multivariate simulations. This approach guarantees the best solutions at all the design stages. The identification of the effect of different factors on belt conveyor motion resistance is the basis for any measures taken to modernize existing transport systems. In most cases, solutions reducing energy consumption are sought.

2. Belt conveyor motion resistance components

Primary resistances – all the forces which occur along the belt conveyor's route in the zones of contact between the belt and the support elements (typically idlers, or sliding elements) – predominate in over 80 m long belt conveyors. Considering the energy conversion (dissipation) phenomena which accompany the motion of the belt, the primary resistances are divided into:

- idler rotational resistance W_k,
- belt-on-idler rolling (indentation) resistance W_e,
- belt bending resistance (flexure resistance of a belt) W_b,
- flexure resistance of bulk material W_f,
- sliding resistance of a belt on idlers W_r,

The effect of the conveyor's technical parameters and the properties of the belt and the transported bulk materal on the particular components of the primary resistances has been quite well explored (mainly theoretically and to a smaller degree, experimentally) [7]. Multivariate simulations have become possible thanks to the advanced computing methods. One of the key problems is the effect of the properties of the belt and the idlers on conveyor motion resistances. The problem has been the subject of numerous investigations [1,2,3,5,6,10]. Another major problem is the effect of the force in the belt on the magnitude of motion resistances. Knowledge in this regard is essential for designing and operating long and ascending belt conveyors since the belt and the idlers generate most of the primary resistances and the force in the top strand varies widely [4,9]. This is illustrated in figure 1 which shows all the primary resistance components for the whole range of force variation in the top strand for conveyor route length L=1100 m. When the conveyor is in steady motion, the force in the top strand grows from S=142 kN in the vicinity of the return station to S=638 kN near

the stub-end drive station. Being independent of the force in the belt, idler rotational resistance and belt rolling (indentation) resistance along the conveyor's top strand remain constant. The proportions of the other three primary resistance components (flexure resistance of a belt, flexure resistance of bulk material and sliding resistance of a belt on idlers) significantly depend on the force in the belt. The motion resistance components shown in fig. 1 were calculated per single top-strand idler set.

The division of the primary resistances into the components shown in fig. 1 is based on the phenomena which accompany the motion of the belt (with transported material) on idlers. Knowing the conveyor specifications, the operating conditions, the belt and spoil influence parameters, the components can be quite accurately analytically determined, whereas experimentally they are not always separable. The only component which can be experimentally investigated on special measuring rigs is idler rotational resistance. Various methods of investigating conveyor motion resistances, aimed at identifying the phenomena and refining computing methods in order to reduce the energy consumption of the belt conveyor's main drive, are presented below.

3. Tests of idler rotational resistance

The rotational resistance of a single roller is defined as a tangential force applied to the roller shell in order to overcome the frictional resistance in the bearings and the seals. This component can be only experimentally determined. In accordance with Polish standard PN-91 M-46606 "*Belt Conveyors. Idlers*", idler rotational resistance is tested on a special measuring rig shown in fig. 2.

One end of the roller axle is fixed in rotary fixture (4) through which the rotations from motor (2) are transmitted via belt transmission (3). Its other end is clampwise supported in nonrotary fixture (5). The roller shell is fixed in a clamping ring whose arm rests on a balance (whereby the roller shell is immobilized). The motion of the axle motion relative to the stationary shell produces a torque which is transmitted by the arm (having a constant length) to the balance or a force gauge. The registered force is converted, using the condition torque equilibrium relative to the roller axle, into a rotational resistance value. The
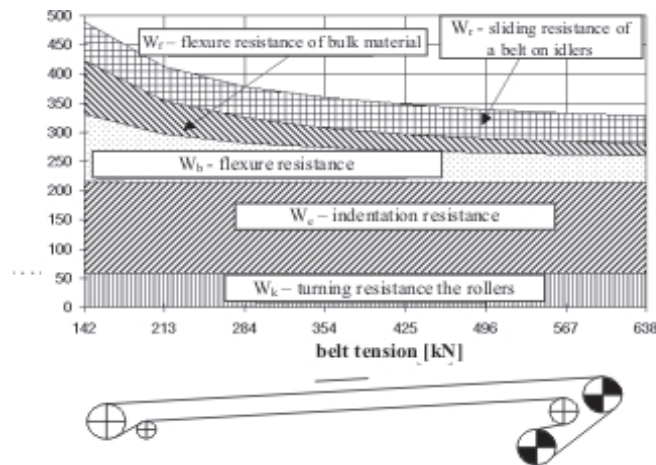

Fig. 1. Proportions of primary resistance components along top strand of overburden conveyor with specifications: route length L=1100 m; load-lifting height H=10 m; route inclination angle δ=0.52°; belt width B=2.25 m; belt speed v_t=5.24m/s; top-strand idler set spacing l_g=1.0 m; mining spoil bulk density ρ=1600kg/m³; top strand trough angle λ=45°; ambient temperature T_C=0°C; main stub-end station drive 4×1000kW, belt St 3150, idlers in good technical condition
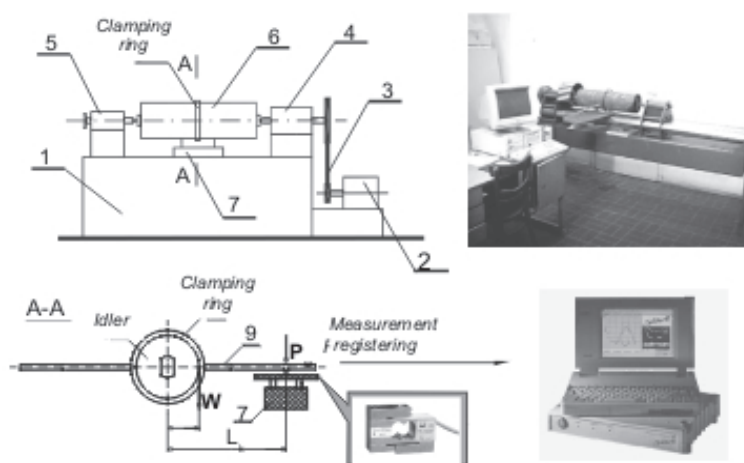

Fig. 2. Rig for measuring rotational resistance of idler rollers: 1 – frame bearer, 2 – electric motor, 3 – belt transmission, 4 – rotary fixture support, 5 – nonrotary clamping fixture support, 6 – tested idler, 7 – force gauge, 8 – clamping ring, 9 – arm

motor which drives the axle is equipped with a system of infinitely variable speed control through supply current frequency adjustment. The balance is coupled with a measuring laptop registering idler rotational resistance over time. Idler rotational resistance W_k is calculated from the formula:

$$W_k = P_w \cdot \frac{L_k}{r_p} [N] \qquad (1)$$

where: P_w - balance readings, in N; L_k - the distance of clamp ring arm pressure on the balance pan from the roller axle, in m; r_p - the outer radius of the roller shell, in m.

According to standard PN-91 M-46606, prior to the proper measurements new idler rollers should be rotated with a rotational speed of 600 rpm for 4 hours. Then after stabilization (about 2000 seconds) one can start measuring the rotational speed. Figure 3 shows typical rotational resistance traces for an roller with a steel shell and an roller with a polyurethane shell.

From the point of view of comparisons and analyses of the influence of conveyor structural parameters on motion resistances the dependence between idler rotational speed and angular velocity is a key one. Results of the measurement of rotational resistance during starting at rotational speed growing from 0 to 500 rpm for 2 types of roller shell are compared in fig. 4.

Since the above method of determining idler rotational resistance is simple, its error is small. Its drawback is that the idler is not under load when its rotational resistance is measured. A new test rig enabling the measuring of idler rotational resistance under load has been developed in the Institute of Mining at Wrocław University of Technology in collaboration with the German idler manufacturer Artur Kuepper GmbH & Co AG. A schematic of the new test rig for measuring idler rotational resistance is shown in fig. 5. The axle of the tested idler is fixed in two supports (3). The idler shell is loaded with two wheels (6 and 7) one of which is connected via a drive shaft and a belt transmission (2) with an electric motor (1). This wheel drives the idler. The other wheel is put into motion directly by the rotating idler and it performs the role of the loading wheel. Through set screws (5) and a link mechanism the two wheels can exert pressure on the idler shell, generating radial force F_r of up to 20kN.

Two measuring bolts (2) registering radial force F_r acting perpendicularly to the roller axle are placed in holes in the supports (3) (fig. 6). Radial force F_r decomposes into reactions T_1, T_2 in the places where the largest shearing stresses occur in the measuring bolts. Force F_o which can act along the bolt axis is compensated by the measuring system whereby it does not disturb the measurement. If the roller shell remains stationary, bolt reactions T and T_2 are equal.
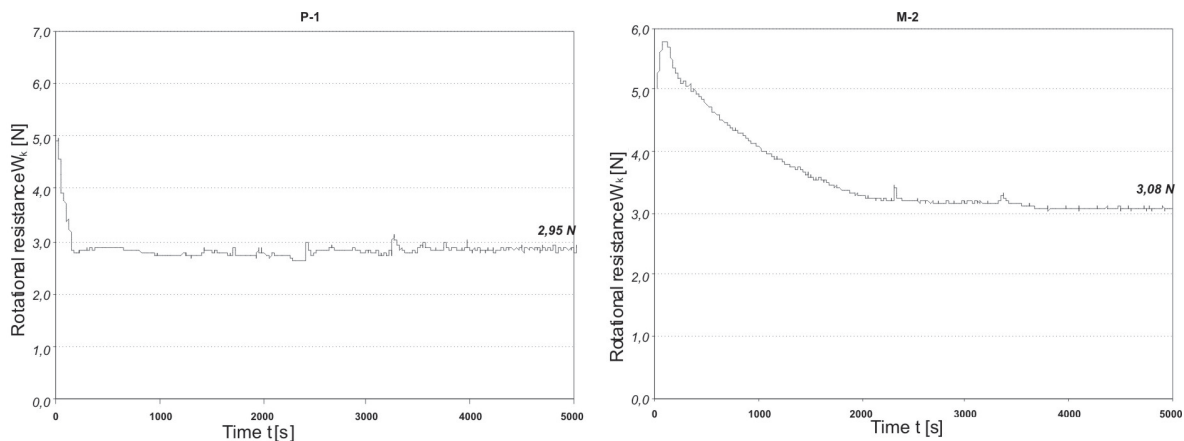

Fig. 3. *Traces of rotational resistance for idler rollers with polyurethane shell (P-1) and with steel shell (M-2)*
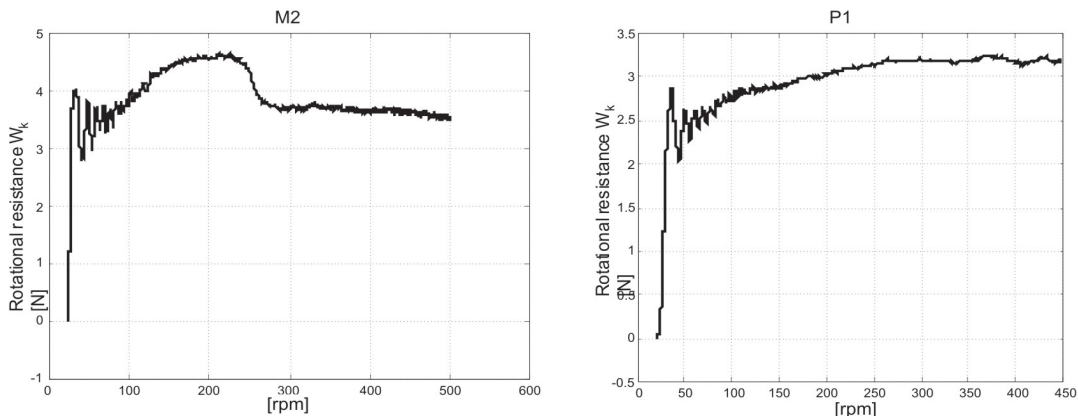

Fig. 4. *Comparison of recorded rotational resistance traces for idler rollers with metal shell M-2 and with polyurethane shell P-1 in rotational speed range of 0-500 rpm*
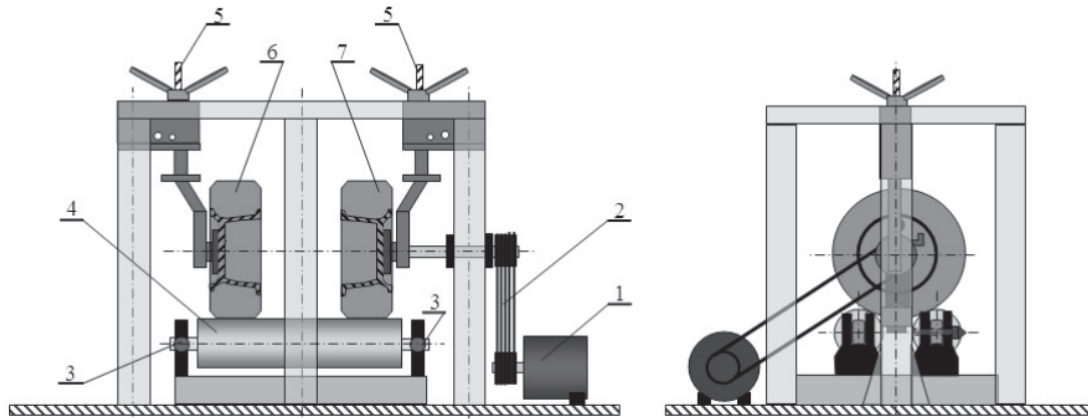
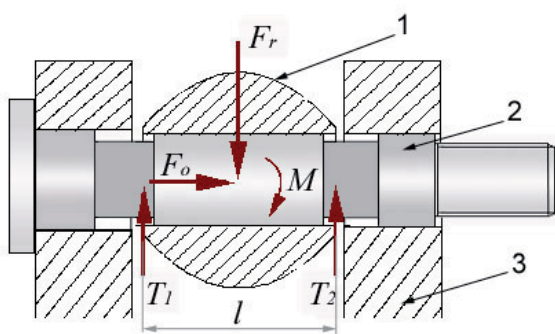*Fig. 5. Test rig for measuring idler rotational resistance*

*Fig. 6. Distribution of forces and torque on measuring bolt: **1** axle of tested roller, **2** measuring bolt, **3** support*

When the idler is put in motion, a difference between reactions T_1 and T_2 appears. The difference is the larger, the greater the idler rotational resistance. Knowing the values of reactions T_1 and T_2 and length l of the arm on which the reactions act, one can determine torque M acting on the roller axle. Thus one gets the following relations:

$$M = T_1 \cdot \frac{l}{2} - T_2 \cdot \frac{l}{2} \qquad (3)$$

$$M = (T_1 - T_2) \cdot \frac{l}{2} \qquad (4)$$

where: M – the torque turning the roller axle, in Nm; T_1, T_2 – reactions arising on the bolt as a result of the action of radial force F_r, in N; l – the distance between the places where shearing forces T_1, T occur, in N.

Knowing torque M and roller radius r one can calculate idler rotational resistance W_k from the relation:

$$W_k = \frac{M}{r_p} \qquad (5)$$

where: W_k – idler rotational resistance, in N; r_p – a radius equal to the half of the roller diameter, in m.

The tensometric technique was employed to measure idler rotational resistance W_k. The measuring bolt was so designed that two full strain gauge bridges could be stuck on in the places of the highest shearing stresses (T_1, T_2) (fig.7). The measuring bolts are made of highest quality spring steel whereby they can undergo elastic deformations from 0 to 12kN. Hottinger series Y 120Ω strain gauge rosettes for steel, 6-wire connected into three independent strain gauge bridges, were used in the measurements. Thanks to the 6-wire connection and the use of full bridges the measuring system is insensitive to changes in ambient temperature.

The measuring system enables the simultaneous registration of radial loads and idler rotational resistances. The rig is used for durability tests in which the (rotational resistance versus radial force) characteristic of the tested idlers is determined.
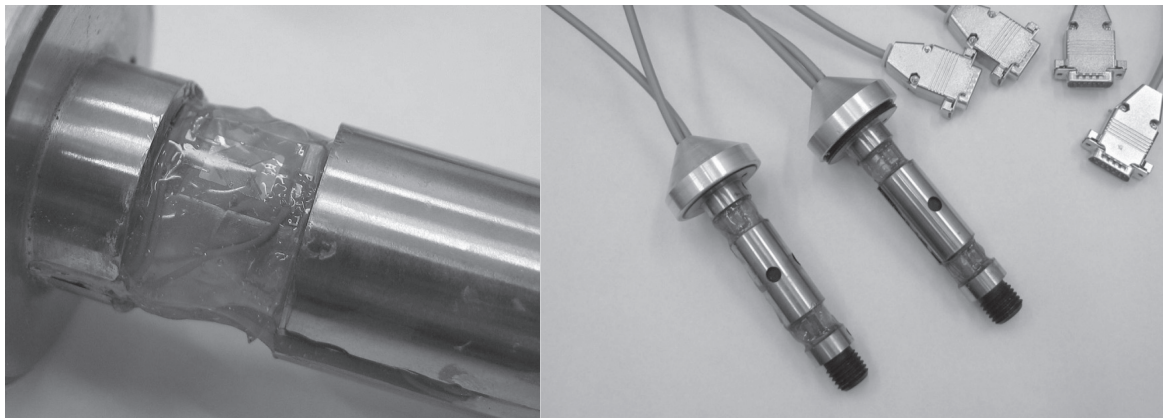

Fig.7. Measuring bolts and measuring point with stuck on strain gauges

For this purpose a series (usually six) idler rotational resistance over time measurements are performed for different idler load levels (ranging from 250 to 12000N). Figure 8a shows a trace of idler rotational resistance W_k over time t under radial load F_r of 1000N. Since the tested idler (Artur Kuepper GmbH & Co AG 219x1160mm with 6312-2Z C4 bearings) had worked in a mine for about 2 years rotational resistance stabilized after 20 minutes since the test start. Then on the basis of the results obtained from the series of measurements under the set load F_r (0.25 ÷ 12kN) rotational resistance W_k as a function of F_r was plotted (fig. 8b). The determined relation shows that radial load F_r has a significant effect on idler rotational resistance W_k.
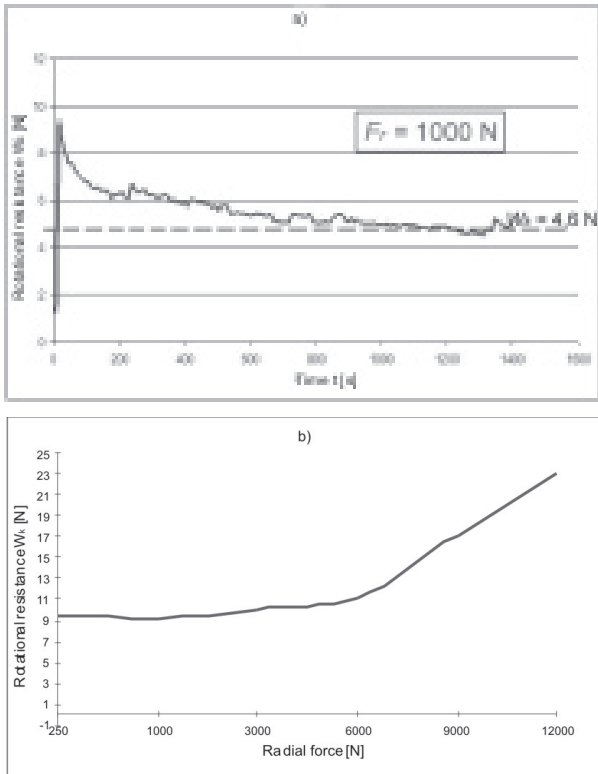

Fig.8. Dynamic rotational resistance for AKT (219 x 580mm) idler versus: time (for radial load F_r = 1kN); b) radial force F_r in range of 0.25-12 kN

The obtained measurement results for the tested five idler rollers with a steel shell and a labyrinth seal are compared in fig. 9. In addition, the arithmetic mean of $W_k(F_r)$, reflecting the character of the changes in rotational resistance, was determined for the above graphs.

The promising results yielded by this measuring method encourage the use of measuring bolts in belt conveyor operating measurements. Preparations for such measurements, with six measuring bolts installed on one set of idlers and registering idler loads and rotational resistances, are underway. These will be the first in situ idler rotational resistance measurements. They will supply data about the actual effect of the operational forces on idler rotational resistances. This, in turn, may shed new light on the energy consumption of the idler set, the optimum idler spacing and the durability of the particular idlers.
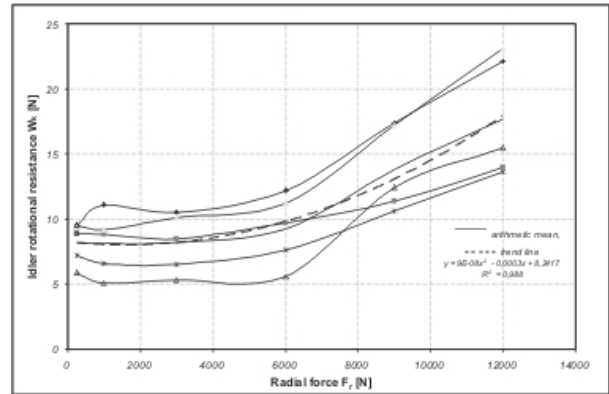

Fig. 9. Idler rotational resistance W_k versus radial force F_r for tested AKT idlers and plotted mean of all relations

4. Belt rolling resistance and idler rotational resistance tests on rig with inclined plane

Figure 1 shows that the largest component of the belt conveyor primary resistances is belt-on-idler rolling (indentation) resistance. This means that first of all this component should be analyzed when seeking optimal conveyor designs. For this purpose a special measuring rig for simulating belt-idler interaction conditions has been developed. Its main units are (fig. 10):
- a carriage with two idlers,
- an inclined section for accelerating the carriage,
- a measuring section on which the distance of idler free rolling on the belt is determined,
- a carriage braking assembly.

The measuring section for investigating carriage motion kinematics is lined with conveyor belt. The weighting carriage consists of two load-bearing idlers and a frame. The idlers are mounted in the frame which can be weighted to increase the force pressing the idlers to the belt. The carriage is accelerated to the required velocity on the inclined plane. Subsequently, on the measuring section the velocity decreases as a result of rolling resistance and idler rotational resistance. Changes in velocity are measured by three tachometric probes (Tacho1, Tacho2 and Tacho3). By analyzing the changes in the kinetic energy of the carriage rolling on the belt one can determine the rolling resistance. For this purpose one must know the rotational resistance of the idlers mounted in the carriage frame. The rotational resistance of the tested idlers is determined (using the methods presented in the previous section) prior to the measurements on the rig described above.

Knowing the times it takes the carriage to travel between the particular probes one can demarcate measuring lengths and determine the changes in kinetic energy along these lengths. For start point **E** and end point **D** of the measuring section one can determine carriage travel velocities according to the schematic shown in fig. 11.

Initial velocity v_1 and end velocity v_2 for carriage travel between points **D** and **E** on inclined measuring length l_{DE} are calculated from the equations:

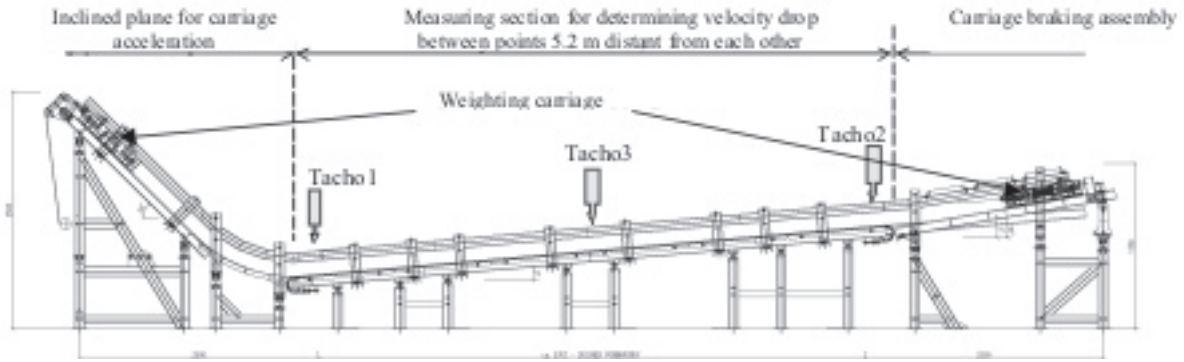$$v_1 = \frac{l_{AB}}{\Delta t_{AB}} \tag{6}$$

Fig. 10. Schematic of inclined-plane rig for testing belt-on-idler rolling resistance
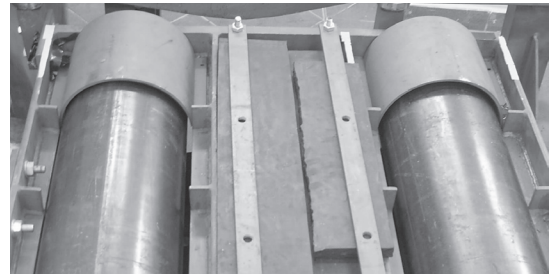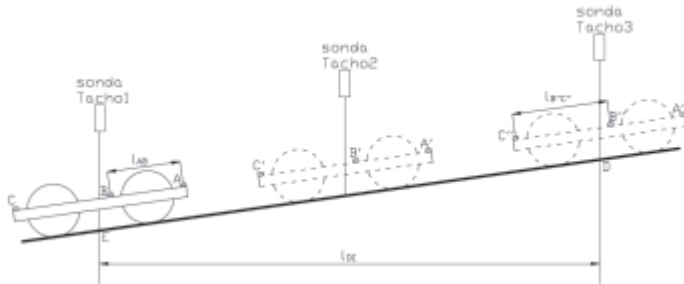

Fig. 11. Spacing of measuring points and view of measuring carriage

$$v_2 = \frac{l_{BC}}{\Delta t_{BC}} \qquad (7)$$

where: l_{BC} – the distance between points B and C on the carriage, in m; Δt_{BC} – the measured time of travel between points B and C, in s; l_{AB} – the distance between points A and B on the carriage, in m; Δt_{AB} – the measured time of travel between points A and B, in s.

The drop in carriage kinetic energy during travel between points **D** and **E** amounts to:

$$\Delta E_k = \frac{1}{2} \cdot \left(m + \frac{I_r}{r^2} \right) \cdot \left(v_1^2 - v_2^2 \right) \qquad (8)$$

where: m – the weight of the carriage, in kg; I_r – the moment of inertia of a single idler roller, in kg·m²; r – the roller radius, in m; v_1 – the initial velocity, in m/s; v_2 – the end velocity, in m/s.

The kinetic energy changes as a result of the work of the external forces along distance l_{DE}. The sum of the external forces acting opposite to the direction of carriage travel amounts to:

$$\sum F = W_e + W_k + m \cdot g \cdot \sin \beta \qquad (9)$$

The work of the external forces along the travel distance is described by the relation:

$$\Delta L = \left(W_e + W_k + m \cdot g \cdot \sin \beta \right) \cdot l_{DE} \qquad (10)$$

where: W_e – indentation resistance (for two idlers in the carriage), in N; W_k – the total dynamic rotational resistance of the two rollers, in N; m – the weight of the carriage, in kg; g – gravitational acceleration, in m/s²; β – the inclination angle of the inclined plane, in °; l_{DE} – the measuring length, in m.

Since the work of the external forces and the drop in kinetic energy balance out: $\Delta E_k = \Delta L$, then taking into account equations (9) and (10) one gets this formula for the idler-on-belt rolling resistance (for the carriage with two rollers)

$$W_e = \frac{1}{2 \cdot l_{DE}} \cdot \left(m + \frac{I_r}{r^2} \right) \cdot \left(v_1^2 - v_2^2 \right) - W_k - m \cdot g \cdot \sin \beta \quad (11)$$

The results of tests carried out on the above rig can be used to compare the effect of belts of different type or various idler designs on rolling resistance. The unit linear belt rolling resistance determined in the way described above is compared for two types of idlers in fig. 12. The diagram clearly shows that idlers with a polyurethane shell generate greater rolling resistance, which is due to their lower stiffness and larger deformation under the radial force.

5. Tests on measuring segment of belt conveyor

Tests were carried out on specially prepared segment of a belt conveyor route in PGE KWB Bełchatów PLC to measure the total motion resistance per idler set. The total motion resistance of a single idler set is made up of the following components: the rotational resistance of three rollers, indentation resistance, flexure resistance of a belt and of a bulk material, sliding resistance of a belt on idlers (resulting from the random sideways running of the belt and the automatic deflection of the side idlers). The measuring idler set is suspended on both sides on three articulated elements (arranged in three mutually perpendicular directions). Force gauges **F1** and **F2** measuring the vertical load and the set's vertical load being the measure of the instantaneous conveyor output are installed on both sides of the idler set in the points of suspension. The total motion resistance
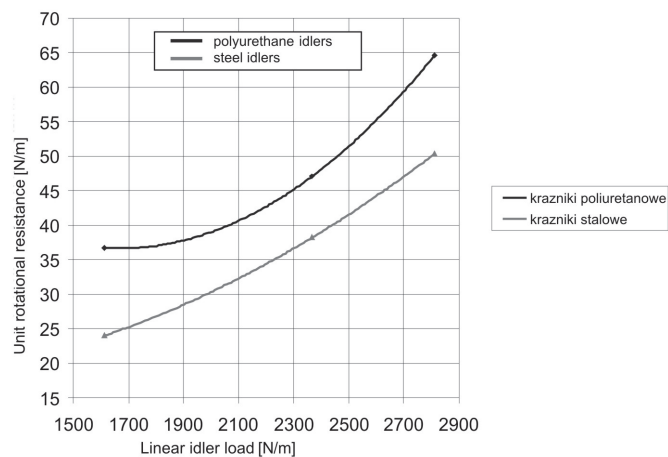
Fig. 12. Comparison of unit rolling resistance as function of linear idler load for idlers with metal shell and idlers with steel shell

per set is measured by pairs of force gauges **F3** and **F4** and **F5** and **F6** mounted on the horizontal elements on both sides of the set. Prior to starting the conveyor, initial forces F_{30}, F_{40}, F_{50} and F_{60} are set in the horizontal force gauges. As the belt moves, the initial horizontal forces registered by the gauges change. Forces F_3 and F_5 increase as follows:

$$F_3 = F_{30} + \Delta F_3 \qquad (12)$$

$$F_5 = F_{50} + \Delta F_5 \qquad (13)$$

Forces F_4 and F_6 decrease relative to their initial values:

$$F_4 = F_{40} - \Delta F_4 \qquad (14)$$

$$F_6 = F_{60} - \Delta F_6 \qquad (15)$$

In order to calculate the total motion resistance per idler set (*W*) one should add up all the force increments registered by the horizontal gauges during the operation of the conveyor:

$$W = \Delta F_3 + \Delta F_4 + \Delta F_5 + \Delta F_6 \qquad (16)$$

It is important to properly position the idler set relative to the belt's axis and to the neighbouring idler sets. In order to eliminate any other idler loads (and so additional local motion resistance increments) it is important that the measuring idler set and the two neighbouring sets (the preceding one and the following one) are positioned in space in such a way that the axles of the idlers in the three consecutive sets lie exactly on one plane. The position of the idler sets is adjusted by means of rigging screws.

The measuring segment installed on the route of the tested overburden conveyor is shown in fig. 14.

During tests the trace of the resultant vertical force (the sum of readings from the two side force gauges **F1** and **F2)** and the trace of the resultant horizontal force (the total signal from the four force gauges **F3**, **F4**, **F5** and **F6**) are registered. The resultant vertical force is a measure of the conveyor's instantaneous output while the resultant horizontal force is the measured motion resistance per idler set.

The registered traces of instantaneous forces can be transformed into diagrams illustrating the dependence between the total idler set motion resistance and the load generated by the transported mining spoil and the belt. Figure 16 shows an exemplary overall diagram for the traces shown in fig. 15.

6. Conclusions

1. The accuracy of the computing methods is essential for analyses aimed at determining the effect of conveyor specifications on resistance to motion. In order to verify
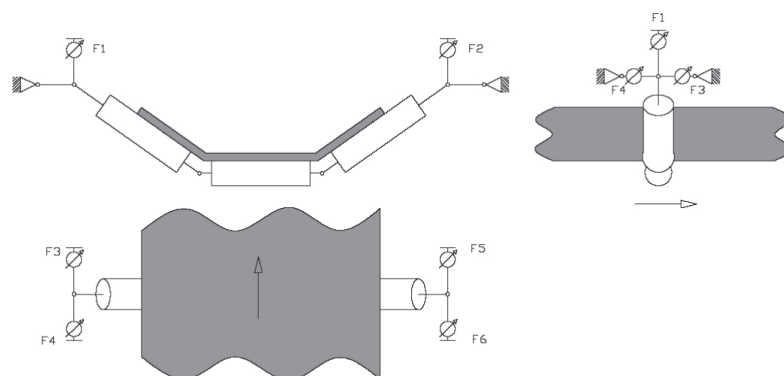

Fig. 13. Schematic of measuring idler set suspension and arrangement of force gauges

Fig. 14. Measuring segment for investigating motion resistance of single idler set

the methods it is necessary to carry out conveyor motion resistance measurements. Except for idler rotational resistance, the particular components of the primary conveyor resistances cannot be distinguished during measurements.

2. Measurements performed directly on the conveyor, during which the sum of all the components of the primary resistances is measured, supply the most data on its resistances to motion.

3. The present research aimed at reducing belt conveyor transport energy consumption focused on the two largest motion resistance components, i.e. idler rotational resistance and indentation resistance. The two components can be investigated on a special measuring rig with an inclined plane (fig. 10). Research aimed at determining the effect of the belt's parameters and differ-
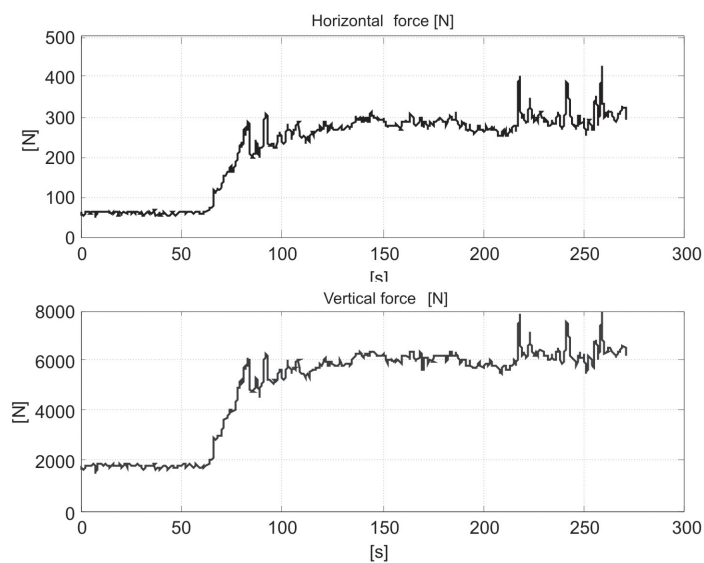

Fig. 15. Typical trace of instantaneous vertical force (mining spoil and belt load) and horizontal force (idler set motion resistance)
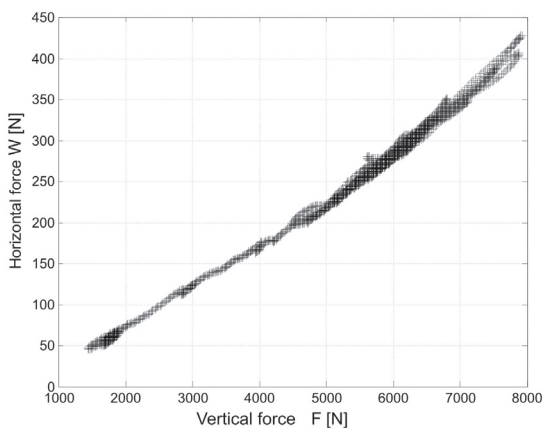

Fig. 16. Set of measuring points illustrating dependence between instantaneous horizontal force and vertical force

ent idler designs on the conveyor motion resistances is conducted on this rig.

4. Investigations of idler rotational resistance aimed at evaluating different idler designs can be conducted using the simple measuring rig shown in fig. 2 in section 3. In the case of idlers for conveyors operating in opencast lignite mines or for other high-capacity conveyors one needs to know the effect of the loads acting on the idlers on the latter's rotational resistance. For this purpose tests are conducted using a special rig with two loading wheels (fig. 5).

5. The tensometric measuring technique employing the specially designed measuring bolts has been verified in laboratory conditions and it can be successfully used for industrial measurements. Currently preparations for such measurements are underway in a brown coal mine and the technique will be used to register the forces and the rotational resistance for three roller idlers.

7. References

1. Bukowski J, Gładysiewicz L. Metoda badań oporów obracania krążników pod obciążeniem: Transport Przemysłowy i Maszyny Robocze 2010; 1: 1899-5489.
2. Furmanik K., Zarzycki J.: Badania laboratoryjne wybranych własności taśm przenośnikowych . Transport Przemysłowy i Maszyny Robocze 2009; 3: 1899-5489.
3. Geesmann F. Experimentelle and theoretischeUntersuchungen der Bewegungswiderstände von Gurtförderanlagen (Experimental and theoretical investigations of the motion resistances of belt conveyor systems). Thesis, Hanover University 2001.
4. Gładysiewicz L, Hardygóra M, Kawalec W. :Determining belt resistance. Bulk Handling Today. 2009; 5.
5. Gładysiewicz L, Król R. Badania wpływu warunków eksploatacyjnych na opory obracania krążników. Transport Przemysłowy 2003; 2: 1640-5455.
6. Gładysiewicz L, Król R. Kompleksowa ocena jakości krążników poliuretanowych stosowanych w górnictwie odkrywkowym. Prace Naukowe Instytutu Górnictwa Politechniki Wrocławskiej. Studia i Materiały 2009; 36.
7. Gładysiewicz L. Przenośniki taśmowe. Teoria i obliczenia. Oficyna Wydawnicza Politechniki Wrocławskiej. Wrocław 2003.
8. Hardygóra M, Bajda M, Gładysiewicz L. Wpływ parametrów mieszanek gumowych na energochłonność transportu przenośnikowego. Transport Przemysłowy 2007; 3: 1640-5455.
9. Kawalec W, Król R, Kubiak D. Długie przenośniki taśmowe dla kopalń rud miedzi. Nowoczesne metody eksploatacji węgla i skał zwięzłych. Kraków: Akademia Górniczo-Hutnicza im. Stanisława Staszica, 2009 (monografia).
10. Kasza P, Kulinowski P, Zarzycki J. Mobilne stanowisko do badania oporów obracania krążników. Transport Przemysłowy i Maszyny Robocze 2010; 3: 1899-5489.

Prof. Lech GŁADYSIEWICZ
Dr inż. Robert KRÓL
Mgr inż. Jędrzej BUKOWSKI
Institute of Mining
Wrocław University of Technology
Pl. Teatralny 2; 50-051 Wrocław
e-mail: lech.gladysiewicz@pwr.wroc.pl
e-mail: robert.krol@pwr.wroc.pl
e-mail: jedrzej.bukowski@pwr.wroc.pl