

RESEARCH OF LOADING CARRYING IDLERS USED IN BELT CONVEYOR – PRACTICAL APPLICATIONS

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Summary

The article presents a method and results of the implemented measurements of loads of a single carrying idler set on a belt conveyor under working conditions. Currently, identification of the quantity and flow stream of material on the conveyor's belt in mining conditions takes place by means of roller weights. These are devices ensuring identification of temporary efficiency, however, they do not allow precise definition of the scope of real forces to which a single idler is subjected to in the set. Such information can be obtained using a strain gauge measurement method prepared in the Mining Institute of the Wrocław University of Technology. At this point it should be remembered that nothing else but load is a key input parameter in any analyses and design calculations of idlers. The obtained measurement results of loads of carrying idlers and the conducted analyses of performed experimental works find practical application in the process of optimizing construction solutions of idlers - both with regard to the strength and operating requirements. They may be used to estimate a level of durability of idlers and are a valuable source of information when determining the actual level of their power consumption. The selected examples of such applications have been included in this paper.

Key words: idler, belt conveyor, measurement of loads.

BADANIA OBCIĄŻEŃ KRAŻNIKÓW NOŚNYCH PRZENOŚNIKÓW TAŚMOWYCH – EFEKTY UTYLITARNE

Streszczenie

W artykule przedstawiono metodę i wyniki realizowanych pomiarów obciążeń pojedynczego zestawu krażników nośnych na przenośniku taśmowym w warunkach eksploatacyjnych. Aktualnie identyfikacja ilości i strumienia przepływu materiału na taśmie przenośnika w warunkach kopalnianych odbywa się za pomocą wag rolkowych. Są to urządzenia zapewniające określenie wydajności chwilowej, jednak nie pozwalają precyzyjnie określić zakresu rzeczywistych sił jakim poddawany jest pojedynczy krażnik w zestawie. Takie informacje uzyskać można stosując opracowaną w Instytucie Górnictwa Politechniki Wrocławskiej tensometryczną metodę pomiarową. Należy przy tym pamiętać, że właśnie obciążenie jest kluczowym parametrem wejściowym we wszelkich analizach i obliczeniach projektowych krażników. Pozyskane wyniki pomiarów obciążeń krażników nośnych, oraz przeprowadzone analizy realizowanych prac eksperymentalnych znajdują praktyczne zastosowanie w procesie optymalizacji rozwiązań konstrukcyjnych krażników, zarówno w zakresie wymagań wytrzymałościowych i eksploatacyjnych. Mogą być wykorzystane do szacowania poziomu trwałości krażników oraz stanowią cenne źródło informacji przy określaniu rzeczywistego poziomu ich energochłonności. Wybrane przykłady takich zastosowań zawarto w niniejszej pracy.

Słowa kluczowe: krażnik, przenośnik taśmowy, pomiar obciążeń.

1. INTRODUCTION

Load of idlers is the main input parameter both in design calculations of idlers, in durability analyses as well as in the process of evaluation of power consumption of idlers installed on the route of a belt conveyor. The knowledge on this topic has been gathered from the previous theoretical studies [1, 2, 3] as well as during tests of belt conveyors in Ger-

man mines [4]. The laboratory of the Mining Institute of the Wrocław University of Technology has prepared a strain gauge measurement method enabling to determine the forces acting on coat of idlers both radial and axial forces. The idea of the method [5] consists in application of specially prepared measurement pins.

Strain gauges for measuring deformations under the effect of the working load on coat of idler are glued in the places of shearing of measurement pins. The laboratory measurement method with the use of measurement pins have been used in a typical top idler set, replacing the pins joint-connecting the set with the structure of the conveyor's route. The measurements on a belt conveyor are implemented by means of six measurement pins (Fig. 1). The forces acting on the measurement pins identified in this way, are converted by means of simple geometric dependencies to the forces acting on the bearings of idlers. The results of measurement of loads described in this work give a complete image of real loads for a given conveyor in a specific point of the route.

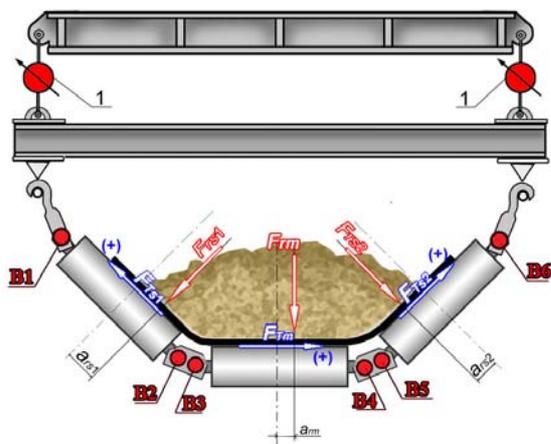


Fig. 1. Designation of measuring forces and measuring bolts

2. MEASUREMENT METHOD OF IDLER LOADS

Typical upper idler set consists of three idlers, combined with each other by means of connectors and pins. In a measuring set, typical pins were replaced with measuring pins marked B1 – B6 (Fig. 1). The idea of the method consists in measuring forces in mutually perpendicular planes [6], the pins are placed in joints so as to ensure that it is possible to carry out measurement of radial and axial forces on the tip of the idler (Fig. 2).

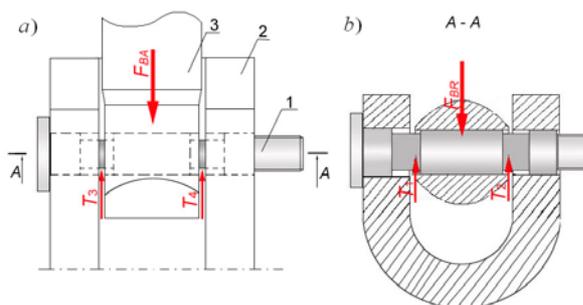


Fig. 2. Force system on single measuring bolt

Knowing the geometry of the idler, the values of radial forces acting on a measuring pin may be recalculated to radial forces acting on bearings. Definition of the value of axial forces gives information about the friction forces occurring in a contact of belt – coat of idler. A single measuring pin with glued strain gauges is shown in figure 3.



Fig. 3. Measuring bolt with installed strain gauge

3. MEASUREMENTS ON A CONVEYOR

Measurements of idler loads have been performed on a overburden conveyor working in an open pit mine. On the route of the conveyor there is mounted a special measurement unit (Fig. 4), the structure of this unit enables assembly of sensors of strength and registration of idler loads. In addition, the unit allows changing construction parameters of the conveyor (change in spacing of idler sets, change in basin angle). The above modification of the structure of the route in a measuring station allows determining impact of these factors on the value of idler loads as well as optimising in terms of power consumption of the set.



Fig. 4. Measuring unit assembled on construction of conveyor

The tests were conducted on a conveyor with the following parameters:

- length of the conveyor - $L = 1205$ m, horizontal
- width of belt - $B = 2250$ mm
- speed of belt - $v_t = 5,98$ m/s
- belt type St 3150,

- belt unit mass $m_f=46.67 \text{ kg/m}^2$

The transported material was overburden with overlaying density $\rho = 800 \text{ kg/m}^3$ and angle of natural dump on belt $\alpha = 17^\circ$. Mass capacity of the examined the conveyor amounted to 25 000 t/h. Support of upper string of conveyor was formed by joint idler sets with angle basin $\lambda = 45^\circ$. Top idler sets consisted of idlers with the diameter $D_{kg} = 0.194 \text{ m}$ and length of idler coat $l_{kr} = 0.8 \text{ m}$. At the same time, the measurements of loads of pins was accompanied by recording temporary vertical loads of the entire idler set. The resultant vertical force recorded by means of these sensors originates from the transported output and the belt weight. Thanks to recording the vertical force we could analyse measurement results in the function of temporary mass capacity of the conveyor.

4. MEASUREMENT RESULTS

Stream of output resulting reactions one idler is irregular and has random variability, thus the reactions one idlers are also characterized by great random changeability. A sample recorded course of variability of loads of six bearings of the measuring idler set is presented in Fig. 5. A measurement unit is equipped with two sensors of vertical load. Thanks to recording vertical forces it is possible to analyze measurement results in the function of temporary mass capacity of the conveyor (Fig. 6).

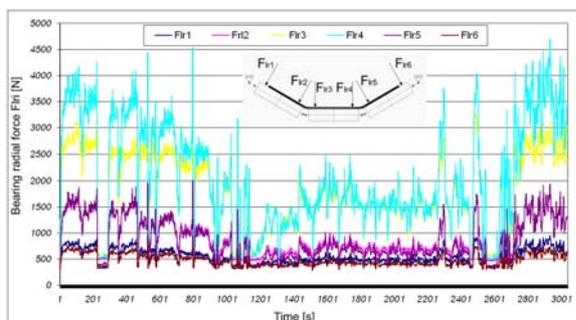


Fig. 5. Variation of radial forces for different bearing

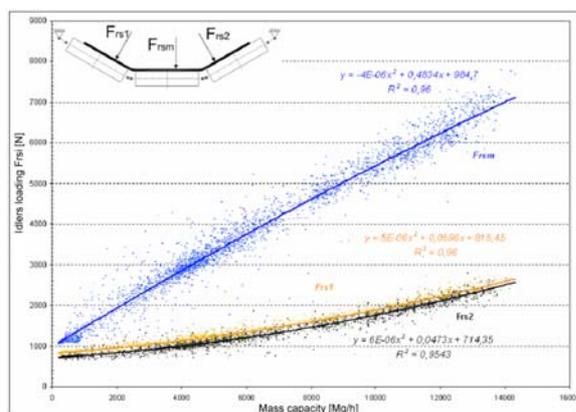


Fig. 6. Loading of particular idlers for mass capacity

Additionally, a structure of pins enables measurement of axial forces, the difference of these forces measured on both ends of the idler is a friction force [7]. This force is caused by a side converging of the belt or advancement of side idlers in a jointed idler set. A sample course of friction forces is presented in Figure 7. In the middle roller a positive return was adopted in accordance with marking in the figure, on the other hand on side runners, the positive return was accepted outside of the idler set.

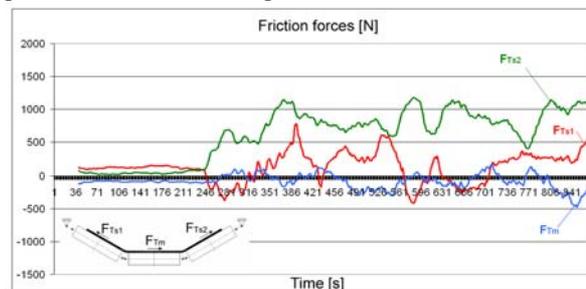


Fig. 7. Variation of friction forces on particular idler

5. POSSIBILITY OF APPLICATION OF THE MEASUREMENT METHOD WITH ANY CONVEYOR

The recorded changes of forces over time confirm random variability of the output stream. This variability is a characteristic feature not only for a particular conveyor type, but it also depends on its horizontal location within the transport system of the mine, on the type of machines and equipment cooperating with it, it will also be different for gathering conveyors. For this reason, an important thing is measurement of real loads at any point of the conveyor's route and not only measurement on the measuring unit installed in a given point of the conveyor's route. For this purpose, a special measurement frame (Fig. 8) was designed and made to measure loads of carrying idlers. The structure has been provided in a way enabling easy and fast assembly at any point of the route on a given type of belt conveyors. Apart from the built-in vertical force sensors, the design envisaged sensors in the horizontal plane for defining resistance of traffic of a single upper idler set as well as layout of sensors for measurement of belt side converging. For the purpose of easier and faster recording of variability of forces there are currently conducted works in order to create a mobile system to acquire and process measurement data.

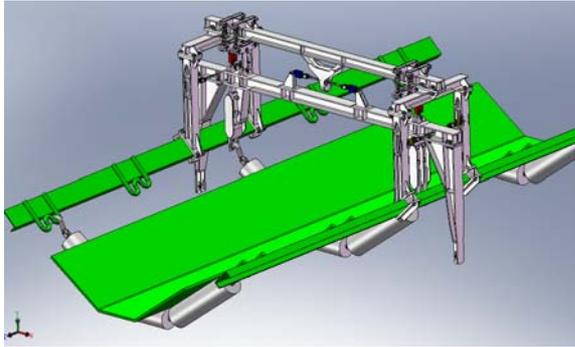


Fig. 8. Frame steel construction used for measuring forces on idlers and for measuring resistance to motion

6. UTILITARIAN EFFECTS RESULTING FROM MEASUREMENTS OF IDLER LOADS

6.1. Optimization of construction solutions of idlers

The idlers offered by different manufacturers do not always meet the operational requirements because they might have been designed without consideration of many important factors. Often a cause of expensive replacements is premature wear of constituent elements (e.g. coat or bearings), at the same time, keeping usable features of other elements. This may indicate lack of sufficient knowledge of the problem at the stage of designing and incorrect selection of idlers for specific operating conditions.

An optimal selection of a idler should first of all meet the strength and durability criteria. With insufficient research of operational loads and environment impact on operation of the idler, fulfilment of these criteria most often comes down to redimensioning of constituent elements, which leads not only to overestimated material costs but also to a costly manufacturing technology. A badly designed bearing unit without the impact of loads and discharge of heat on deformation of elements of the idler (bearings) causes decrease in durability even in the case of a large stock of strength. Too overly extended and improperly selected sealing without analysis of possible installation and operating deformations may cause excessive resistance to motion, which, at more intense heat emission, can also lead to decrease in durability. A complex analysis of construction solutions, taking account of the presented issues, requires conducting multivariate analyses based on the knowledge about maximum forces occurring in idlers. The durability analyses of particular elements of the idler conducted at that time provide the possibility of correct selection of both geometric and material construction features. The largest manufacturing potential of alternative strength analyses is delivered by the finite elements method MES [8, 9]. The durability criteria are first of all decisive at dimensioning boss of the idler,

where on the one hand suitable stiffness is required, and on the other hand the design seeks material-saving solutions. A good solution in this aspect is a cast boss, ribbed from the inside, which provides good discharge of heat to the inside of the idler generated by bearing units. Apart from the technology of execution, an important parameter in the process of optimization from the point of view of costs production, is a quantitative criterion concerning mass of the material used for making component elements of the idler.

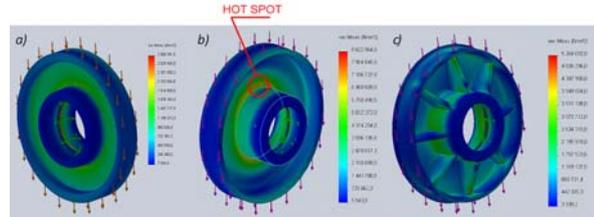


Fig. 9. Result of stress analysis for: a) standard boss (thickness of wall 8mm, mass 1,25kg), b) boss with wall thickness 3mm, mass 0,88kg (modification 1), c) boss with wall thickness 3mm with six ribs, total mass 1,04kg (modification 2)

In view of large disproportions of rigidity of bending coat and axis, an important issue in designing of idler is checking angles of deflection at the place of bearing, because this determines beveling of bearing and work of labyrinth sealing. The previous practice and valid standards indicate acceptable maximum angle of bevel of bearings (difference in angles of deflection between the axis and coat at the place of support of a bearing) amounting to 2 degrees. (Exceeding this number may lead to excessive emission of heat to the inside of the idler and, as a further consequence, growth in resistance to motion, loss of tightness and reduction in durability. The sample results of analyses of deformations of axis and coat of idlers executed in two construction versions, the purpose of which was to determine optimal structure of the coat of polyurethane coat of the load-carrying idler for the needs of open pit lignite mines is presented in Fig. 10.

The obtained results indicate wide opportunities of replacing steel with polyurethane. Application of the solution of a coat in idler $\varnothing 190 \times 670 \text{mm}$ made of polyurethane, required reduction in rigidity of the idler. In the designed idler, the design envisages making axis made of construction pipes $\varnothing 38 \times 3,2 \text{mm}$ (according to PN-84/H-74220). As a result, for the construction elements of the idler selected in such a manner there were obtained similar values in angles of deflection, guaranteeing correct work of the carrying idler $\varnothing 190 \times 670 \text{mm}$.

Replacement of as many steel in idlers with polyurethane allows, first of all, substantially reducing their mass as well as reducing their production costs. On the other hand, pursuit of the largest elimination of steel does not always goes hand in

hand with maintenance of the required strenght and rigidity of the designed elements.

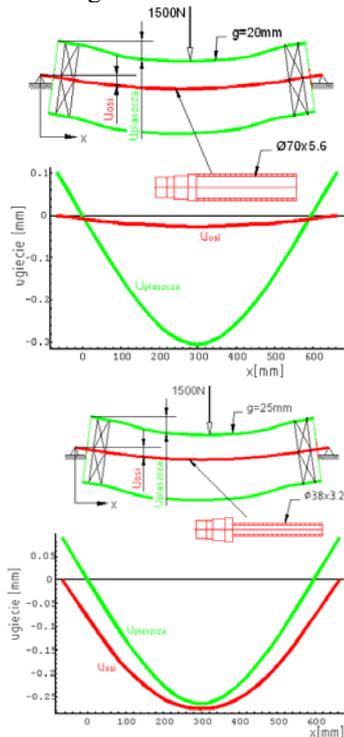


Fig. 10. Comparing result of analysis between bending of axis and coat of idler, for two different construction, loading 1500N

This is especially important in the case of large overburden conveyors B2250, for which the maximum volumes of real working loads of a middle idler reach even 11kN [6]. At that time, the designed idler should be characterized by a layer coat, made of two layers: polyurethane external and steel internal. Such studies were conducted under the project "Research-development works are the source of international innovations in the Gasket company" covered by financial support of POIG 1.4. Based on the new solutions of engineering material created on the basis of polyurethane elastomers, there has been defined optimal polyurethane coating of a idler. It was made by conducting evaluation of strength properties and rigidity depending on the changes in thickness of its steel part. Multi-variant calculations with the MES model were executed in the environment of the SolidWorks application. Reducing stiffness of axis by application of a construction pipe, total thickness of coat 20mm was adopted as optimal version, where the design used steel part with thickness of 2mm. For such a modelled idler the tests obtained the expected concurrent deformation of axis and coat (Fig. 11).

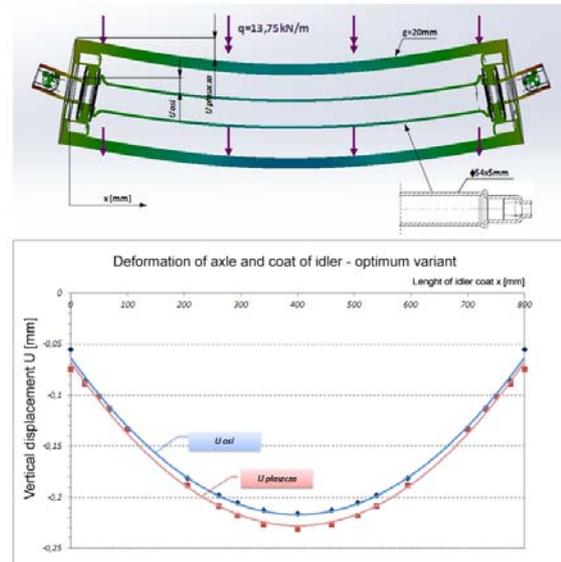


Fig. 11. Bending of axis and coat of idlers model

6.2. Estimation of durability level of idlers

One of the criteria of belt conveyor optimization is durability of idler sets, which directly affects the size of the incurred costs of operation. The Mining Institute of the Wrocław University of Technology has conducted research for many years on determining effective working time of idlers under operating conditions. The implemented operational measurements, apart from setting accidentals of radial forces, enable identification of variability of the output stream and specification of the frequency of the presence of particular classes of idler loads. The sample results of analyses of carrying idlers durability, operated on overburden belt conveyor in mine PGE KWB Bełchatów were presented in the thesis [11]. At the same time, account was taken of the real scope of loads of bearings, as designated using the aforementioned method and relation on durability of the idler developed by Geesmann [4]. The results of analyses proved that in each of the examined cases, the lowest durability shows a middle idler that is subjected to the largest range of loads. In addition, it has been reported that operational durability of the idler is determined both by structural factors related to the adopted technological solution as well as operational conditions, such as: the size in spacing of idler sets, angle of its bevel (tab.1) or variability of distribution of stream of output on a conveyor (Fig. 11)

Table 1. Comparing of durability idlers, middle idler, different work condition

| | <i>Bevelled set, distance 1.45m</i> | | <i>Distance 1.45m</i> | | <i>Distance 1.2m</i> | |
|--|-------------------------------------|-----------|-----------------------|-----------|----------------------|-----------|
| | F_{lr3} | F_{lr4} | F_{lr3} | F_{lr4} | F_{lr3} | F_{lr4} |
| Equivalent force F_z [kN] | 2,71 | 4,21 | 3,13 | 4,50 | 3,03 | 3,70 |
| Bearing durability $L_{h,eksp}$ [h] | 99090 | 26468 | 64433 | 21755 | 71045 | 38995 |
| Idler durability L_{kr} [h] / [year] | 21 957h / 5,5 years | | 17 187h / 4,3 years | | 26 853h / 6,7 years | |

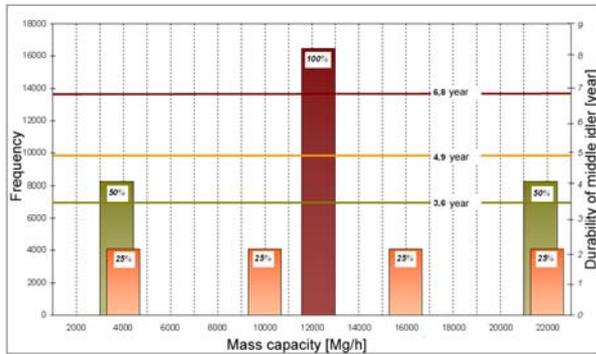


Fig. 11. Depend of different irregular mass capacity on durability if idlers

6.3. Estimation of idlers power consumption

The value of rolling resistance of idler is influenced by its material and geometric construction characteristics, but also operational factors including the load. Using the strain gauges measuring method presented in the article, it is possible to identify the level of demand for power to overcome rolling resistance of idler and unit costs of energy consumption corresponding to a three-idler set. In the first place, in the laboratory conditions there is determined rolling resistance of idler in the function of radial load (Fig. 12).

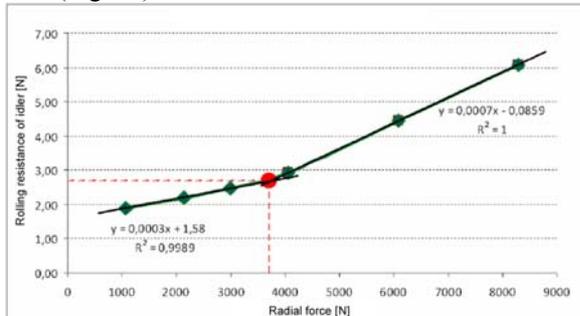


Fig. 12. Rotational rolling resistance for different radial force

Then there are defined shares of particular idlers in transmitting the whole output, performing division of total load of a set per particular steel idlers depending on the degree of the conveyor filling (Fig. 6). Executing the aforementioned calculations there are determined dependencies of rolling resistance of idler set in the function of mass capacity. Figure 13 presents total rolling resistance of a three-idler set in the function of mass capacity for two types of idlers differing in the adopted construction solution, for which, for the purposes of the article, there were assigned following names Z-1 and Z-2.

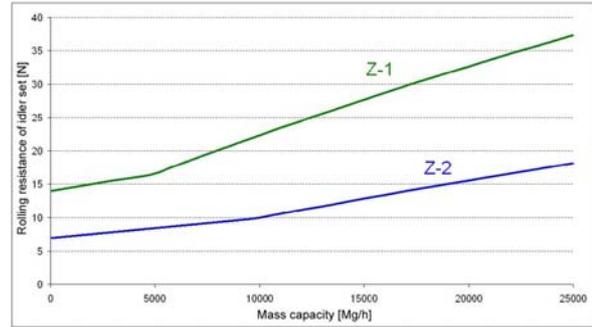


Fig. 13. Rolling resistance of idler set for different mass capacity, for Z-1 and Z-2 set of idlers

Idlers in set Z-2 are characterized by smaller rolling resistance of idler in the whole scope of loads, both for small and large mass efficiencies. An important feature is location of the point of bending of a chart of characteristics of rolling resistance of idler depending on load. The advantages arising from application of idlers from set Z-2 can be estimated, comparing the designated averaged unit rolling resistance of idler for both sets $W_{average}$, on the basis of the adopted distribution of efficiencies of a belt conveyor. Then it will be possible to calculate power coming from rolling resistance of idler set for the route of the conveyor with the length of 1km and to calculate specific consumption of energy with the following formula:

$$\frac{W_{sr} \cdot v_t}{Q_m} \left[\frac{W \cdot s}{kg \cdot m} \right] \quad (6.3.1)$$

whereby:

v_t – speed of belt,

Q_m – average mass capacity,

W_{sr} – average specific resistance to motion [N/m].

The value of rolling resistance if idler W_{sr} is calculated as an algebraic sum of average resistances determined for particular classes of the efficiency histogram W_{sr}^i multiplied by probability p_i :

$$W_{sr} = \sum_i p_i \cdot W_{sr}^i \quad (6.3.2)$$

whereby:

i – class number,

n_i – number of observations in i-class,

N – number of observations

Results of the calculations for the analyzed example have been presented in Table.2. From the analysis of the received results it seems that idlers installed in set Z-2 have smaller rolling resistance in the whole range of efficiency conveyor and any possible replacement. Exchanging idlers from set Z-1 with idlers installed in set Z-2 will bring average savings of approx. 69 kW per 1 km of the conveyor route.

Table 2. Comparing of specific rotational resistance of idler set and power requirements

| | Specific average rolling resistance of idler set | Power demand to overcome rolling resistances of idler sets per 1km of the route | Specific power consumption |
|--------------------------|--|---|----------------------------|
| | [N/m] | [kW/km] | W·s/(kg·m) |
| Idlers in set Z-1 | 22,68 | 136 | 0,029 |
| Idlers in set Z-2 | 11,20 | 67 | 0,015 |

7. CONCLUSIONS

The presented strain gauge measuring method, in which measurement pins were used, turned out to be useful to determine real loads influencing the idlers. This method gives the possibility to record loads in the whole scope of efficiency of the conveyor, which is a valuable source of information for both designers and users of the idlers. Tests presented in the article, for loads of carrying idlers and the conducted analyses are used in the process of optimizing construction solutions of the idlers at the stage of their design. In addition, precisely defined scope of working loads of the idlers is applied, when estimating the level of durability and power consumption of the idlers installed on a conveyor belt.

REFERENCES

- [1] Gladysiewicz L.: *Przenośniki taśmowe. Teoria i obliczenia*, Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław 2003.
- [2] Gladysiewicz L., Kawalec W.: *Optymalizacja rozstawu krzątników górnych*, Transport Przemysłowy i Maszyny Robocze, nr 3/2010.
- [3] Krause F., Hettler W.: *Die Belastung red Tregrollen von Gurtbandförderem mit dreiteiligen Tragrollenstationen infolge Fördergut unter Beachtung des Fördervorganges und der*

Schüttguteigenschaften, Wiss. Zeitschrift der TU Magdeburg 18 (1974), H.6/7.

- [4] Geesmann F.O.: *Experimentale und Theoretische Untersuchungen der Bewegungswiderstände von Gurtfördenanlage*. Dissertation, Universität Hannover, 2001.
- [5] Bukowski J., Gladysiewicz L.: *Metoda badań oporów obracania krzątników pod obciążeniem*. Transport Przemysłowy i Maszyny Robocze, nr 1/2010.
- [6] Bukowski J., Gladysiewicz L., Kisielewski W., Krol R.: *Eksperymentalne badania obciążeń krzątników nośnych*. Transport Przemysłowy i Maszyny Robocze, nr 3/2011.
- [7] Krol R., Kisielewski W.: *Identyfikacja sił tarcia w kontakcie krzątników z taśmą w ciągnie górnym przenośnika taśmowego*. Interdyscyplinarne zagadnienia w górnictwie i geologii Tom III. Wrocław 2012.
- [8] Gladysiewicz L., Król R., Zombróń M.: *Optymalizacja krzątnika na etapie projektowania*. Transport Przemysłowy i Maszyny Robocze, 3/2010.str.37-42; ISSN 1899-5489
- [9] Król R., Zombróń M.: *Ocena poprawności doboru cech konstrukcyjnych wybranych krzątników nośnych z wykorzystaniem MES*. Prace Naukowe Instytutu Górnictwa Politechniki Wrocławskiej. Górnictwo i Geologia XVIII, Wrocław 2012. ISSN 0370-0798
- [10] Gladysiewicz L., Krol R, Gladysiewicz A.: *Wyznaczenie optymalnej struktury płaszcza poliuretanowego krzątnika nośnego dla potrzeb kopalń odkrywkowych węgla brunatnego*, Raporty Inst. Gór. PWr. 2006, Ser. SPR ; nr 30
- [11] Król R.: *Ocena trwałości krzątników dla rzeczywistych obciążeń przenośnika taśmowego*, Przegląd Górniczy. 2011, nr 11, s. 82-90.



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