TRANSPORT PROBLEMS 2022 Volume 17 Issue 2
PROBLEMY TRANSPORTU DOI: 10.20858/tp.2022.17.2.05

Keywords: belt conveyor; roller; motion resistances

Tadeusz OPASIAK[1]*, Jerzy MARGIELEWICZ[2], Damian GĄSKA[3], Tomasz HANISZEWSKI[4]

ROLLERS FOR BELT CONVEYORS IN TERMS OF ROTATION RESISTANCE AND ENERGY EFFICIENCY

Summary. The paper shows the results of researching the rollers used in belt conveyors working in a hard coal mine. Rollers should be characterized by low rotation resistance, which results in low power consumption of the propulsion unit. The tests conducted aimed to assess the technical condition of the new C-type rollers after several years of operation in a hard coal mine. The research was carried out from the new approach to the standard issues of roll testing and verification in a hard coal mine. Laboratory tests were combined with testing the entire belt conveyor in terms of power demand. The research was carried out for 3 years and it was monitored how the dynamic resistance of the working rollers changed and how this translates into the power demand consumed by the belt conveyor in a hard coal mine. The aim of the research was a new approach to the research of rollers used in conveyors operating in a mine.

1. INTRODUCTION

In the mining industry belt conveyors for transporting mineral resources are commonly used due to their high efficiency and continuous operation [30]. Due to the resistance generated by the individual elements of the belt conveyor, it causes that they generate a high level of demand for power supply and this is a high cost of their use [16]. Therefore, the current technical solutions focus mainly on new solutions, for which energy consumption is a very serious issue leading to the improvement of individual elements of the belt conveyor in terms of operation [25]. The main areas where improvement related to resistance to movement can be achieved is the selection of individual elements on its route by appropriate selection of, among others, such elements as rollers, which are its main equipment [12].
The work of the main elements of the belt conveyor, such as rollers, is its main resistance, which is not determined theoretically but can be determined in a laboratory [10, 14]. There are standards [31, 32] that propose methods to measure rotation resistance. That is why different research centers use different approaches to roller testing [15, 20]. Therefore, special attention is paid to experimental tests in which the resistance to roller rotation is measured directly, with a particular impact of the tested rollers on the operation of the entire belt conveyor [25]. But because of the high cost of such research in real conditions, it is not practiced. Research on real objects allows for better verification of the identified roller rotation resistance values on a laboratory stand. Therefore, the work uses the method of combining tests of roller rotation resistance in conjunction with a real object, which was a mine belt conveyor operating in difficult conditions. On the other hand, laboratory tests of rollers were carried out in strict

[1] Silesian University of Technology; Krasińskiego 8, 40-019 Katowice, Poland; email: Tadeusz.Opasiak@polsl.pl; orcid.org/0000-0002-0777-2316
[2] Silesian University of Technology; Krasińskiego 8, 40-019 Katowice, Poland; email: Jerzy.Margielewicz@polsl.pl; orcid.org/0000-0003-2249-4059
[3] Silesian University of Technology; Krasińskiego 8, 40-019 Katowice, Poland; email: Damian.Gąska@polsl.pl; orcid.org/0000-0001-6775-7559
[4] Silesian University of Technology; Krasińskiego 8, 40-019 Katowice, Poland; email: Tomasz.Haniszewski@polsl.pl; orcid.org/0000-0002-4241-6974
*Corresponding author. E-mail: tadeusz.opasiak@polsl.pl

accordance with the applicable standards [31, 32], which only define the test methodology and permissible values of measured parameters. Based on standards, new rollers are usually tested, but no one tests rollers after a longer period of operation to identify at what level the roller rotation resistance coefficient is maintained, which was done in this work. It should also be noted that the main and basic condition to obtain a good effect in terms of reducing the energy consumption of the working conveyor is the use of rollers with an appropriate structure ensuring not only adequate strength but also characterized by a guaranteed low rotation resistance of all rollers along the entire length of the working conveyor [27]. Such an approach to these parameters has not yet been included in any standard. Rotation resistance and roller durability are a quality feature that is particularly difficult to estimate by the manufacturer, and the life of the roller under operating conditions is often much shorter than that declared by the manufacturer. By making a change in the verification of rollers to work in a belt conveyor, a new and better approach in the selection process is implemented, which generates a change in the currently functioning criterion-based mainly on laboratory research regarding the impact of the rolling resistance of the rollers on the better performance of the entire belt conveyor in terms of resistance [29].

The mining industry generates demand for very large amounts of energy, especially for the executive departments of the mining sector. These executive sectors consume about 11% of the world's energy demand [17]. Currently, it is required that the industry, including the mining industry, pay special attention to the level of consumed energy, among others, to its growing prices, which translates into the overall costs of mining or production plants. Reducing energy consumption can be achieved in a mining plant. Result of lowering the energy consumption of the continuous transport equipment used, including belt conveyors, due to their significant impact on energy efficiency [13]. Although conveyor belts are a very efficient means of transport, they are also considered the main consumers of electricity in mines, it is clear that if there is an improvement in overall energy efficiency through lower energy consumption, this is of great economic importance [1]. In several publications, the authors of research studies have shown that the improvement of transport systems visibly reduces the total operating costs by up to 30% [3, 15]. Currently, improving energy efficiency is a very appropriate measure, mainly due to the reduction of energy costs, especially in the transport of mining materials. There is a wide range of belt conveyor practice tests that analyze problems from various aspects. In particular, energy efficiency is analyzed as the main and most important factor, already in the design stage [7, 24, 28]. The investigated problems to be solved focus on two levels, related to devices and operational. The amount of resistance to rotation of the roller [19], as well as its durability [4], the resistance of the belt rolling on rolls and the overall required efficiency of the drive systems [5] are the basic elements and assemblies that are taken into account in new constructions as well as in modernization existing structures in continuous use [2]. The influence of standard roller design on rolling resistance and bearing durability for rollers has been little investigated. The tests were carried out on standard load-bearing rollers but on an energy-saving conveyor belt [11]. On the other hand, in the lignite mine, the influence of the change of the working roller load on the efficiency of the tested belt conveyor was investigated [8]. In particular, the research activities were directed to the construction of the conveyor belt in which altered rubber mixtures were used, which changed the entire structure of the internal construction of the belt in terms of the operation of the new belt, it showed that the newly constructed belt also has an impact on the energy demand [9]. In [8, 9] it has been shown that the use of an energy-saving belt instead of a standard belt may result in a reduction in energy demand.

The rollers supporting the conveyor's belt are the most numerous groups of elements, and their right operation depends on the correct guidance of the belt and its durability, which mainly affects the generation of the total resistance to movement of the operated conveyor. For this reason, the high quality of their construction and operation is very important, which translates into the appropriate durability of the rollers used during their operation. The amount of resistance that rotates the rollers has also been influenced by the type of lubricant in the bearing cavity, as well as the bearing itself. Furthermore, the type of seal in the bearing chamber is also important, preventing grease leakage and the entry of contaminants from the environment [18]. The roller jacket is mainly made of welded steel pipes. The accuracy of the pipes is of great importance here. Too large of tolerance of pipe diameter and its unbalance causes the development of dynamic forces during the operation of the roller, which reduces its durability [8].

The transport means in Polish factories are belt conveyors. According to different sources from the literature, in Poland, the total length of the belt conveyor ways is about 2000 km. Also, other extremely important for other industrial plants where conveyor belts are widely used, such as heat and power plants, steel plants, metallurgy has a significant impact on reducing energy costs. It follows that this huge scale of operation of belt conveyors is important in order to reduce the overall energy costs related to their operation, also dictated by the improvement of their design. The rollers used have a major impact on both these factors and in particular on the technical condition due to the number of these units that occurs in the belt conveyor. [7].

The PN-M-46606 standard provides for the use of three groups of L, N, or C type rollers for belt conveyors operating in various plant environments. For cost reasons, the industry purchases the cheapest and weakest rolls. Later, the industrial sector does not conduct an appropriate analysis related to the regeneration, exchange, and power demand of the conveyor with a given type of rollers. This is mainly motivated by the lack of such purposefulness for a company that mainly cares about mining and does not employ an appropriate person to conduct such an analysis. Only conducted research can justify the desirability of such an analysis in terms of cost-effectiveness. Many factories producing rollers offer a wide range of various types, but as a result of their use in heavy mining conditions, they are not fully proven in terms of strength and durability. The offered standard, commonly used N-type rollers are subject to accelerated wear and their constant replacement [32].

In conveyors commonly used in the domestic mining industry, the average distance of a set of rollers is used on the 1.25 m upper working route and 5 m in the lower belt, which means that there are about 3000 rollers in the mining industry per kilometer of the conveyor [4]. This is a significant amount when you take into account the costs of purchase and replacement, regeneration, and movement resistance per 1 m^3 of transported output extracted in the mining plant [7]. The number of rollers used in the mining industry shows huge potential for savings for this type of industry, not only in the case of extending the use and operation time of a single roll but also while reducing its resistance to movement, which translates into total costs. The mining coal industry does not have a written register time to work the operation time of the rollers, therefore, it is not possible to estimate the working time of the roller for its replacement, both for newly placed rolls on the belt conveyor and for regenerated rolls. The roll manufacturers predict that the new N-type rollers should be in service for approximately 4 years without damage. This information is not appropriate when it comes to the work of these rollers in the difficult mining conditions of the mining industry. In hard coal mines, the rollers are replaced with new ones after a month of uninterrupted work. These are data provided by the employees of the coal mine, where standard N-type rollers are regularly replaced after working around a month on a belt conveyor [21].

Based on data from the supply department, it appears that the mining industry completely replaced approximately 635,000 pieces of rollers per year. Approximately 290,000 units a year are replaced by hard coal mines, 180,000 units per year of rolls in the case of lignite mines, about 90,000 rolls per year in ore mines, about 60,000 units per year in mineral mines, and about 15,000 pieces per year in cement plants [6]. These data clearly show the benefits of carrying out tests to verify the necessity of using C-type rolls instead of commonly used N-type rolls (according to the PN-M-46606 standard, C-type rolls are not commonly used in the mining industry as recommended by the standard) [32]. It is common practice in large mining plants to maintain reconditioning and repair facilities, which appears to be common and reduces the costs involved in purchasing new rolls and transporting them to the mining plant. It does not matter how much work and energy is necessary to repair and regenerate the roller used. To this can be added the costs related to the plant logistics related to the removal of used idlers, transport, storage, operational collection, and storage, in which case it becomes questionable whether it is profitable.

Rollers, which in the case of belt conveyors constitute a significant number in their construction, generate about 50-60% of the total resistance caused mainly by the movement of the conveyor belt in the roller sets [21]. It follows that a significant reduction in the demand for power that supplies the drive of the main belt conveyor can be achieved by using rollers with a correspondingly reduced resistance value to rotation. The force resulting from the value of resistance to motion depends mainly and to a decisive extent on the overall structure and quality of the roller workmanship. Lowering the roller rotation resistance can only be achieved by:

- proper seating of support bearings,
- choosing the right lubricant for the bearing,
- the use of an appropriate labyrinth seal, securing the bearing,
- adequately rigid entire structure.

All rollers classified for research were subjected to the following tests: checking the external appearance and condition of the surface, checking external dimensions, checking radial run-out, checking static resistance torque, checking dynamic rotational resistance, and checking the bearing condition. Extensions of research not used so far were extended in time. The standard [32] does not provide for tests of rollers after stretching them in time and monitored after a specified period of operation on a belt conveyor. In research work, there is no monitoring of the behavior of the operating parameters of rollers stretched over time. In our case, over a period of three years, an appropriate batch of fencing was tested, selected for both laboratory and real object tests, during which the changes in the dynamic resistance of the working rollers and their translation into the power demand of the operating belt conveyor Gwarek type in a hard coal mine were examined.

The Gwarek type belt conveyor from which they have dismantled rollers for the test is shown in Figure 1. Excavated material transport conveyor with a maximum capacity of approximately 1200 t/h. The research was carried out in accordance with the guidelines included in the PN-M-46606: 2010 standard. But it was extended by the research on the operational coefficients of long-stretched crawlers, which cannot be found in the literature on the subject. This standard provides only testing stands without testing in extended periods of idler operation on a belt conveyor. So it was decided to change the research method, which included, in addition to testing and verifying new idlers, continuing the research for a longer period of their operation. It was supposed to answer the question of how the operational parameters of the new C-type idlers will change in relation to the parameters after a longer period of operation on the conveyor, and, in particular, how does the rotation resistance change after this period of operation [21].

Fig. 1. Rollers selected for testing disassembled from a belt conveyor in a coal mine

2. TESTING PLACE AND RESEARCH OBJECT

The test was carried out on a Gwarek type belt conveyor operating at the 665 m underground, where N- and C-type rollers for bench tests were assembled and disassembled for bench tests. The distance between the roller set was in the upper belt at 1.5 m. The upper belt has three rollers in the roller set with a trough angle of 30°. The lower twin roller set had a tilt angle of 10° to the horizontal and the distance between the roller sets was 3.0 m. On the other hand, the rollers in the upper and lower bands had the same diameter of ϕ133 mm, and the mass of only the rotating part of the rollers was 6.9 kg. The conveyor drive unit consisted of two induction motors with a power of 90 kW, which developed a rotational speed of 1477 rpm. The gear ratio of the drive unit has two gear ratios $i_1 = 25.6$ and $i_2 = 46.9$, allowing us to obtain the belt speed $v_1 = 3.15$ and $v_2 = 1.6$ [m/s]. The conveyor has a belt width B = 1.2 m. The belt is driven by two drive drums working in a loop system with a diameter of ϕ 1000x1400 [21].

The existing PN-M-46606: 2010 standard classifies the rollers used in belt conveyors according to the industrial environment and the load they work in. If the rollers are to operate in a light environment under a low load that does not require demand, then L-type rollers are used. L-type rollers are used mainly for conveyors with a very low work intensity and at the same time subject to a low load of transported material (Tab. 1). They are intended and recommended mainly for the transport of light mining materials. However, for closed plants that do not have a polluted and humid atmosphere, it is recommended to use N-type rollers, called standard rollers. For work in very difficult conditions, especially in the mining industry and in a polluted environment, when transporting materials with a very high specific weight, it is recommended to use C-type rollers. The specific conditions for the use of rollers are briefly presented in Table 1 [32]. Mining or quarrying plants very often choose the N-type roll for use mainly at the price offered by the manufacturers. The C-type rollers, due to their design and workmanship quality, have a much higher price by about 50% compared to the N-type rollers.

Table 1

The range of use of L-, N-, C-type rolls [32]

Types of rollers	Speed of moving the belt v[m/s]	The specific density of the material transported on the conveyor ρ[t/m^3]	The size of the outer diameter of the clods of the transported material d_{max} [mm]
L	<2.5	<0.85	<100
N	<2.5 (<3.15)	<1.5 (<0.85)	<200
C	>3.15	>0.8	>200

The standard shows that the N-type rollers, so often used, are designed to work on medium-capacity belt conveyors, operating in an environment with little dust (Tab. 1). It recommends that in mines for the transport of coal, rock aggregates and sand, they should be used in the lower belt of the conveyor, which is not loaded. On the other hand, L-type rollers with a structure similar to N-type rollers (Fig. 2a) should not be used in mining conditions only for light work with low efficiency and low load. The bearings of these rollers are exposed and only secured with an outer seal. The general design of these rollers causes that under load, the bearing seat is deformed and destroyed. Figure 2b shows the deformation of the N-type roller under load under operating conditions in a coal mine.

a)

b)

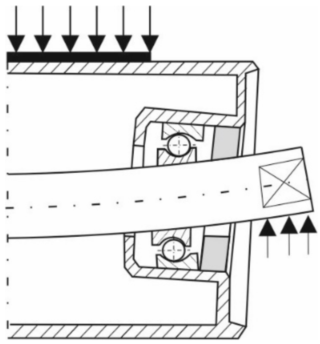

Fig. 2. The appearance of N-type roller hub (a) and diagram of deformation under overload (b) [21]

The tested C-type rollers, which are recommended for operation in heavy mining conditions, are designed for high loads that occur in conditions typical for hard coal mines, where very difficult operating conditions prevail, including very high dustiness. Rollers have a strong structure with hubs made of cast iron pillars into which bearings of higher load capacity are pressed, type 6305 ETN9/C4 with labyrinth sealing U4Exp type. The entire hub is pressed into a thick-walled tube. The whole is a rigid structure (Fig. 3).

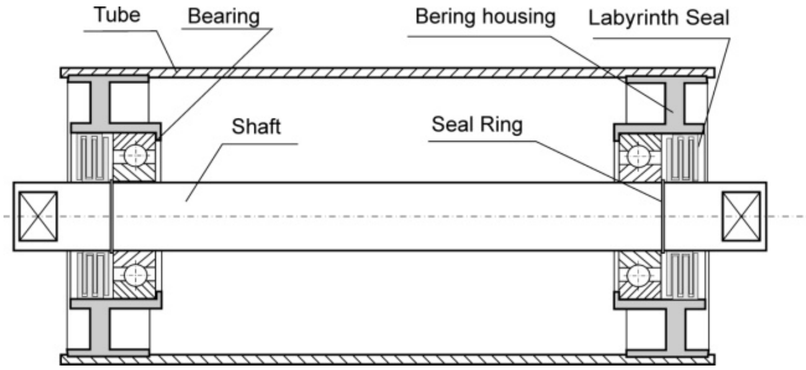

Fig. 3. The construction of the roller C-type [21]

As mentioned above, the tests were carried out on new C-type rollers (Fig. 4a) before assembly on the tested conveyor, and to C-type rollers were disassembled from the conveyor operating in the mine with showing visible signs of wear (Fig. 4b). All verified rollers had the outer surface completely covered with corrosion and other sediments resulting from typical working conditions in a hard coal mine. The appearance of the rollers shows that there was a very aggressive atmosphere there. Contamination of various origins is strongly deposited on the outer surface of the roller (Fig. 4c). There are also visible rust pits on the outer surface of the rollers, which means that the outer surface of the rollers of tested is very uneven and heavily contaminated.

a) b) c)

Fig. 4. Type C roll tested before assembly (a), C type roll disassembled after 12 months of operation (b), and 24 months of operation (c) from conveyor

2.1. Measurement of external dimensions

The measurement of the radial runout was carried out on a laboratory stand to test the dynamic resistance to roller motion (Fig. 5). Measurements were made with a dial gauge with a measurement range of 10 mm and a measurement accuracy of 0.01 mm. On the outer surface of the roller, lines perpendicular to the axis were marked, which were auxiliary lines, and at the same time marked the points of measurement of the radial runout. Measurements of radial runout from the outer surface were made every 10 ° to a complete rotation of the outer surface of the roller. The dial gauge was initially set in position the dial gauge reads zero. Then the roller was rotated, and the values were read from the dial gauge. Measurements were taken for each roller on the left side right side and in the middle of the outer surface.

Fig. 5 shows the average measurement result of the deviation of the radial runout from the nominal dimension ϕ 133 mm for rolls with dimensions ϕ133x465 after the first month of operation (Fig. 5a), after 10 months of operation (Fig. 5b), and 24 months (Fig. 5c) of operation on the conveyor. The measuring points were chosen on the rotating part at a distance of 50 mm from its left edge and the same on the right side, 50 mm from its right edge, and exactly in the middle part of the tested roll. Measurements were made with an accuracy of 0.1 mm.

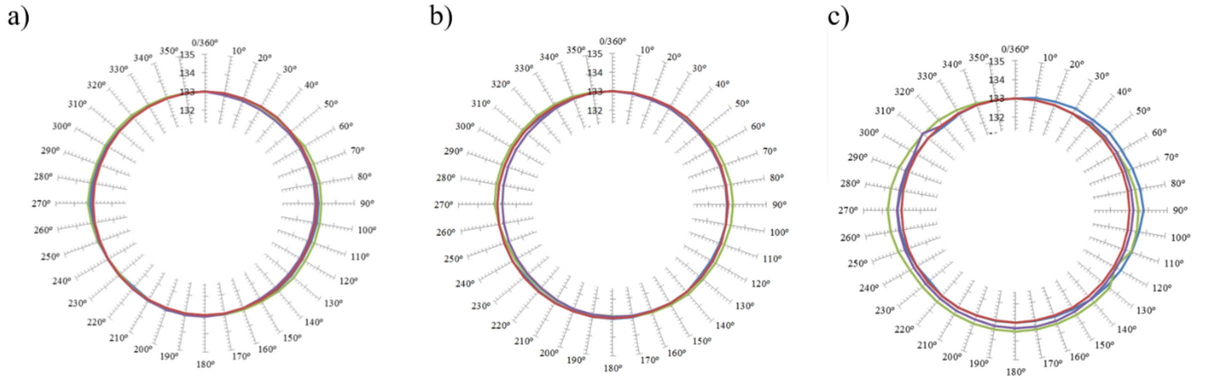

Fig. 5. Diagram increment of deviations for rollers type C ϕ 133x465 after one month of operation (a), after 10 months of operation (b), and 24 months of operation

Based on the measurements of the outer surface outer diameter of the tested rollers, it appears that the mean on the right and the left does not differ from the roller nominal value, while in the middle part of the rollers it is below the nominal value by about 1 mm. The average value is 131.97 mm. Looking at the maximum and minimum values, it can be seen that after such a long period of operation, apart from sticking dirt, abrasion and deformation of the outer surface of the rollers also took place.

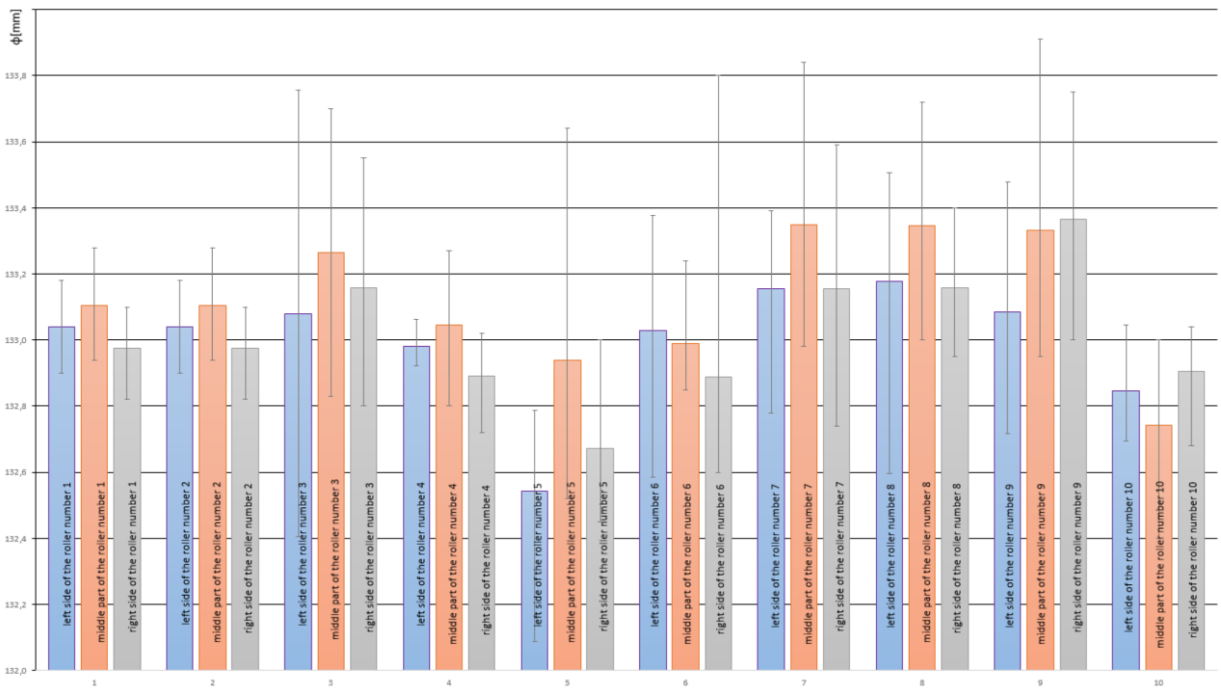

Fig. 6. Diagram changes of deviations for rollers type C ϕ 133x465 after 36 months of operation

Based on the measurements of the outer diameter of the outer surface of the tested rolls, after 36 months of operation on the conveyor, it turned out that the rollers had an external surface damaged to a different range. The overall average turns out to be on the right and the left does not deviate from the nominal value of the roll. This is because some places-had cavities on the surface. The general wear of the exemplary rollers is shown in Figure 6 for the right, middle and left parts of the individual rollers. The average value is 133.12 mm. One can notice very uneven wear on their surface for individual rollers. Looking at the maximum and minimum values, it can be noticed that after such a long period of operation, in addition to sticking to the dirt, there was also abrasion and deformation of the work rollers' outer surface, which can be seen from the markers of deviations from the average value on the entire rotational surface of individual rollers. The largest deviation of the radius values on the left, right, and center did not exceed 0.80 mm after such a long period of work.

2.2. Testing the static resistance torque of the rollers

The study of the static resistance torque of the rollers was performed on a laboratory stand, appropriately adapted to this type of research. The axis of rotation of the test roller (1) was fixed in the centers of the test stand and fixed against rotation. The frame with a two-arm lever (3) is fixed on the roller. The two-arm lever frame (3) was fixed by means of three clamping screws. The permissible static load capacity of the tested rollers should not exceed the values given in the PN-M-46606 standard, which determines the level of resistance at $W_{max} = 0.6$ Nm. It is stated that after the trial period (running-in), the rollers obtained very high operating parameters, which consequently positively influenced their static resistance torque.

The obtained results indicate that the average value of the static resistance torque of the rotating rollers for new rollers is at the level of $W_{sAve} = 0.37$ Nm, which is clearly below the standard which proposes a maximum value of 0.6. However, after 10 months of operation, the static resistance torque of the tested rollers decreased slightly to the average value of $W_s = 0.3$ Nm. With a deviation from the average value $W\sigma = 0.04$ Nm. A clear reduction in the value of the static resistance torque can be seen after 2 years of roller operation, the average value of which is $W_s = 0.21$ Nm. With a deviation from the mean value $W\sigma = 0.05$ Nm. This resistance value remained after another year of work. The static tests showed, in comparison with the values recommended in the standard, that the tested rollers have a very low static resistance torque coefficient. The obtained results are shown in Fig. 7.

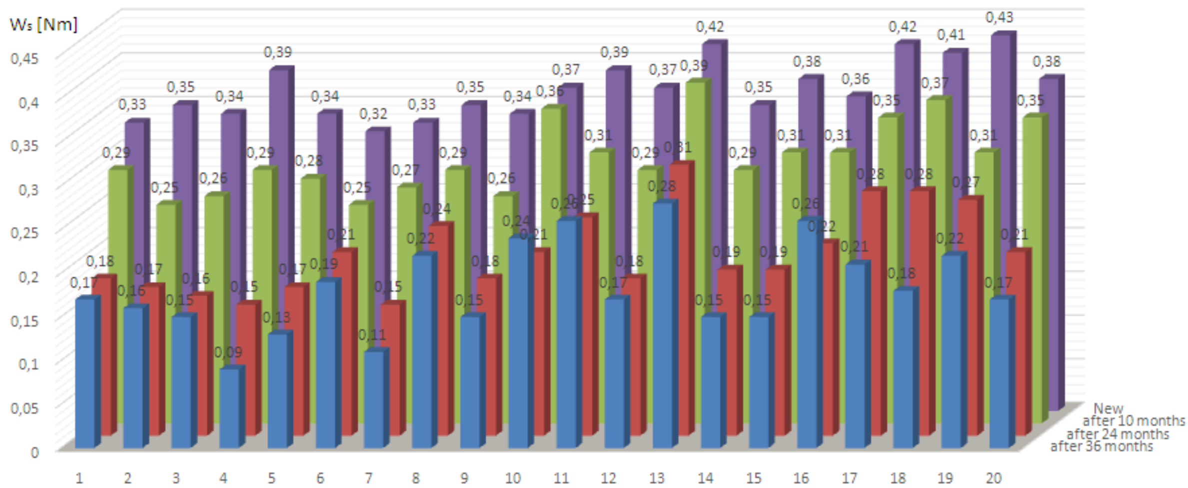

Fig. 7. Average values of static resistance torque for the analyzed rollers after the period of 10 months, 24 months, and 36 months

2.3. Testing the dynamic resistance force to rotation of the rollers

Dynamic resistance force measurements were performed in motion of the rotating roller axis and fixed on the outer surface of the roller (Fig. 8). This method eliminates the possible negative influence of the ovality of the shell on the measurement result and at the same time does not affect the disturbance of the measured force. The value of the resistance torque was made on the stationary external element in relation to the rotating axis of the roller (1). The roller axis is mounted on one side in a rotary holder (2) through which the engine revolutions are transmitted through the belt transmission. On the other hand, the roller axis is supported by a handle (6). The drive unit cooperated with an inverter (4), as a result of this solution it was possible to smoothly change the rotational speed for the tested rollers (1). During the measurements, the speed was constant and amounted to 600 rpm according to the requirements dictated by the PN-M-46606 standard. To the outside of the test roller (1), a clamp ring (3) is attached to the arm base so that the roller the outer surface is fixed. During the rotation axis, relative movement of the axis of the housing causes torque which is transmitted to the arm of the dynamometer (5) of fixed length (Fig. 8). To measure the dynamic resistance force to the rotation of the roller shell, an AXIS FB500 type force gauge (5) was used. To the engine that drives (2) the measurement position, the inverter (4) is connected with which to maintain a constant rotor speed (it was possible to control the speed of the engine) [21].

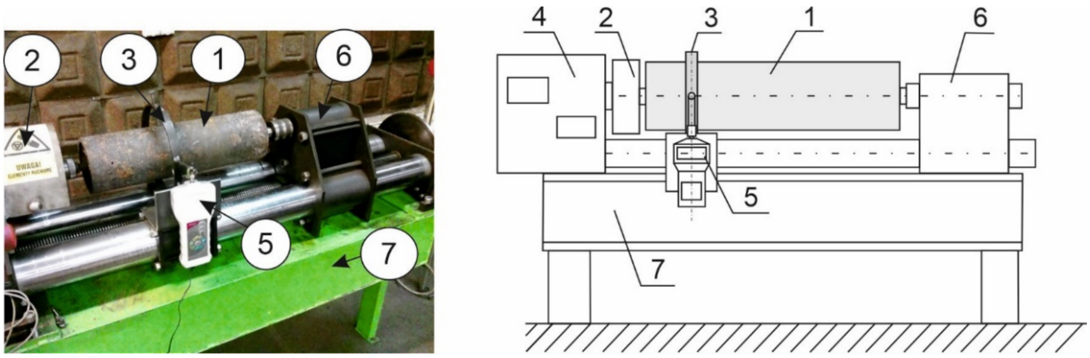

Fig. 8. Stand for roller testing: 1 - tested roller, 2 - drive system, 3 - clamp ring, 4 - inverter, 5 - dynamometer, 6 - pressure support,7 - support of the stand

Each measurement of the new C-type rollers was preceded by a 20-minute running-in on a laboratory stand, and further tests were carried out on disassembled rollers after a working period of 2 months, then after 10 months of continuous operation and after 3 years of continuous operation. For comparison, dynamic resistance forces were also made for N-type rollers, which were used as standard on the tested conveyor.

The dynamic test shows (Fig.9) that the rotational resistance for 133x465 rollers after 3 years of operation, the average value was W_{dAve} = 1.7 N, with the deviation Wσ = 0.33 N. In the case of new rollers, the average value of the dynamic resistance force was W_{kAve} = 3.1 N, with the deviation Wσ = 0.18 N.

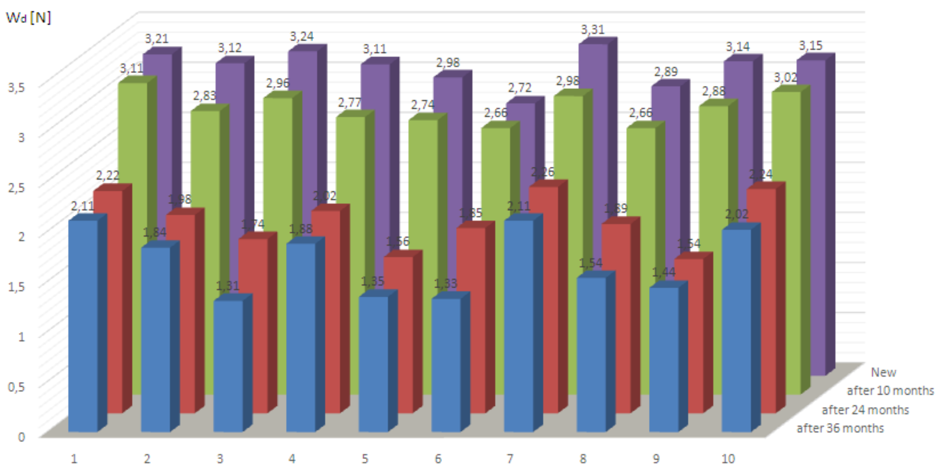

Fig. 9. Time average values of the dynamic resistance force of the tested rollers

On the basis of the presented graph, it can be seen that the value of dynamic resistances force apparently dropped after a year of work. It follows that over time, the resistance to rotation of these rollers decreases. It is the result of their very good sealing. Rollers are seized as a result of dirt entering the bearing. In general, the tested rollers had dynamic resistance force far beyond the range provided by the PN-M-46606 standard, which for this group of rolls is W_{max} = 4.50 N.

The standard provides for only one rotational speed for dynamic resistance force tests. On the other hand, the resistance tests were extended by a different value of rotation speed. The tests were carried out in the range of 100 to 600 rpm. The results obtained are presented in Fig. 10. The research shows that at lower rotation speed the rollers are characterized by lower dynamic resistance force and their value increases with the increasing rotational speed of the tested roll. The conclusion for the conveyor is that at different speeds of the conveyor belt, the general resistance of the conveyor has a different value. This analysis will be the subject of further research.

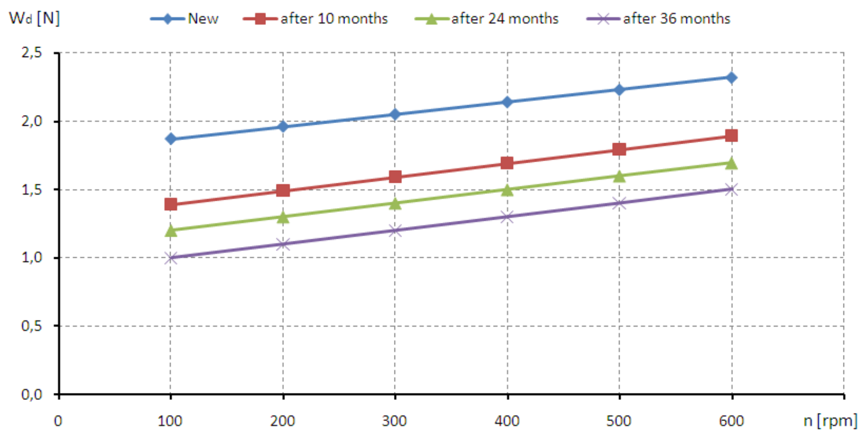

Fig. 10. Influence of rotational speed on dynamic resistance force of rollers rotation

3. CONCLUSIONS

The research showed a confrontation of resistance torque of the rollers to the amount of energy efficiency of the working conveyor under load. These studies are subject to further in-depth research analysis. The tests of measuring the power demand of a belt conveyor with mounted C-type rollers were carried out on the conveyor under real conditions with variable load in continuous motion, with full backfilling with excavated material along the entire length of the conveyor. The recorded values of the measurement results are presented in Fig. 11. Power consumption tests were carried out for 30 months [22]. Then, after three years, the tests were repeated, which showed that the structure of the rollers after three years of operation has not lost its functional properties and can be further exploited in the mine.

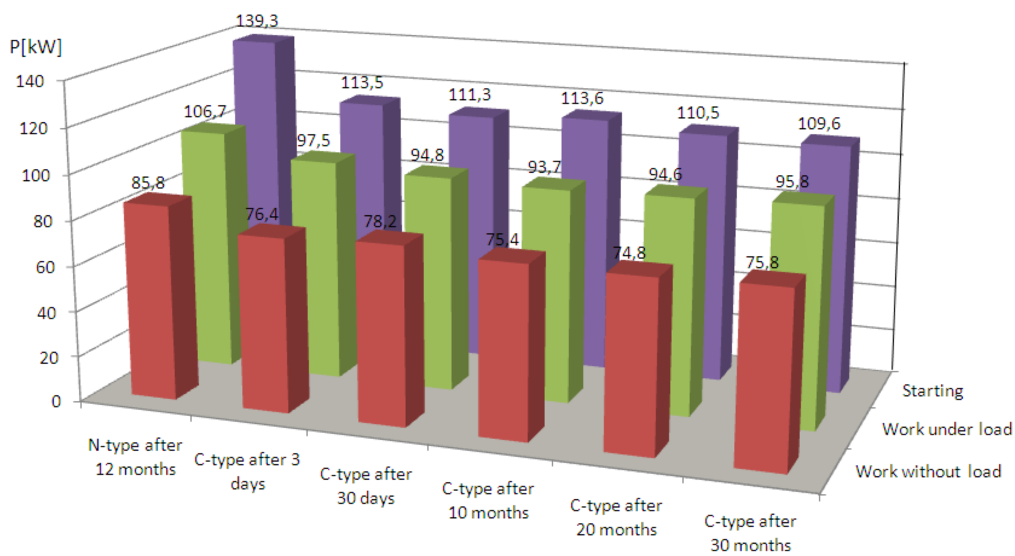

Fig. 11. Average values of the power consumed by the tested belt conveyor

After this period, none of the installed C-type rollers was damaged. None of the values measured by the PN-M-46606 standard was also exceeded. The static and dynamic torque is much lower than the values provided by the standard for this group of rollers.

To sum up the whole research results, the following conclusions were drawn regarding the rollers used in a coal mine:

- the rollers did not change the external dimensions to an extent that prevent their further use,
- the static torque is well below the value recommended by the standard,
- the dynamic resistance force of the tested rollers is below the value recommended by the standard.

The suitably low values of static and dynamic resistance proved to be correspondingly lower energy consumption by the drive system of the tested belt conveyor. Due to the change of rollers from type N to type C, the drive unit consumed 30% less energy. Radial runout showed very high accuracy in the execution of the new design, which did not change after 2 months of operation on the Gwarek type conveyor. The use of an SKF 6305 ETN9/C4 bearing with a glass fiber reinforced polyamide cage results in very low static resistance torque to roller rotation (0.17 ÷ 0.32 Nm). The use of the C4 class seal of the roller bearing and the U4Exp 62/65 labyrinth seal with the 2LU4 cover of the roller structure, results in extremely low dynamic resistance force to motion (values 1.44÷2.11N) also after a period of thirty-six months of operation in difficult operating conditions (dust and humidity) in the coal mine.

References

1. Akparibo, A.R. & Normanyo, E. Application of resistance energy model to optimising electric power consumption of a belt conveyor system. *International Journal of Electrical and Computer Engineering.* 2020. Vol. 10. No. 3. P. 2861-2873.
2. Anath, K.N. & Rakesh, V. & Visweswarao. P.K. Design and Selecting Proper Conveyor Belt. *International Journal of Advanced Engineering Technology*. 2013. Vol. 4. No. 2. P. 43-49.
3. Bajda, M. & Król, R. Experimental Tests of Selected Constituents of Movement Resistance of the Belt Conveyors Used in the Underground Mining. *Procedia Earth Planet Sci*. 2015. No. 15. P. 702-711.
4. Furmanik, K. Analysis of load application on idler roller bearing of belt conveyor in different dynamic models. *Journal of Friction and Wear*. 2009. No. 30. P.142-147.
5. Furmanik, K. Possibilities of dimensional analysis implementation in the investigations of belt inclination resistance on conveyor drums. *Mining Sciences*. 2014. Vol. 21. No. 2. P. 25-32.
6. Gładysiewicz, L, & Król, R. & Kisielewski, W. & Kaszuba, D. Experimental determination of belt conveyors artificial friction coefficient. *Acta Montanistica Slovaca*. 2017. Vol. 22. No. 2. P. 206-214.
7. Gładysiewicz, L. & Kawalec, W. & Król, R. Selection of carry idlers spacing of belt conveyor taking into account random stream of transported bulk material. *Maintenance and Reliability* 2016. No. 18(1). P. 32-37.
8. Gładysiewicz, L. & Król, R. & Bukowski, J. Tests of belt conveyor resistance to motion. *Maintenance and Reliability.* 2011. No. 3(51). P. 17-25.
9. Hager, M. & Geesmann, F. Investigation of the resistance to motion of belt conveyors with a large mass flow. *Surface Mining Braunkohle and Other Minerals*. 2002. Vol. 54. No. 3. P. 208-224.
10. Hötte, S. & Daacke, S.V. & Schulz, L. & Overmeyer, L. & Wennekamp, T. The Way to DIN 22123-Indentation Rolling Resistance of Conveyor. *Belts bulk solids handling.* Germany. 2012. Vol. 32. No. 6. P. 48-52.
11. Król, R. Studies of The Durability of Belt Conveyor Idlers with Working Loads Taken into Account. World Multidisciplinary Earth Sciences Symposium (WMESS 2017). *IOP Conf. Series: Earth and Environmental Science*. 2017. P. 95-106.
12. Kumar, D. & Mandloi, R. K. Analysis and prospects of modification in belt conveyors. *International Journal of Engineering Research and Applications* (IJERA). 2013. Vol. 3. No. 1. P. 581-587.

13. Lodewijks, G. The next generation of low loss conveyor belts. *Bulk Solids Handling*. 2012. Vol. 32. No 1. P. 52-56.
14. Lu, Y. Investigation on indentation rolling resistance of belt conveyor based on Hertz contact theory compared with one-dimensional Winkler foundation. *Advances in Mechanical Engineering*. 2018. Vol. 10. No. 7. P. 1-9.
15. Marasova, D. & Andrejiová, M. & Grinčová, A. Continuous conveyor system evaluation based on the quality of conveyor belts. *International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management*, SGEM. 2018. Vol. 18. No. 1.3. P. 197-205.
16. Masaki, M.S. & Zhang, L. & Xia, X. A design approach for multiple drive belt conveyors minimizing life cycle costs. *Journal of Cleaner Production*. 2018. Vol. 201. P. 526-541.
17. Mclellan, B.C. & Corder, G.D. & Giurco, D.P. & Ishihara, K.N. Renewable energy in the minerals industry: a review of global potential. *Journal of Cleaner Production*. 2012. Vol. 32. P. 32-44.
18. Munzenberger, P. & Wheeler, C. Laboratory measurement of the indentation rolling resistance of conveyor belts. *Measurement*. 2016. Vol. 94. P. 909-918.
19. Munzenberger, P.J. & O'Shea, J.I. & Wheeler, C.A. A comparison of rubber stress relaxation models for conveyor belt indentation rolling resistance calculations. *International Journal of Mechanics and Materials in Design*. 2019. Vol. 15(1). P. 213-224.
20. O'Shea, J. & Wheeler, C. Dielectric relaxation studies of conveyor belt compounds to determine indentation rolling resistance. *International Journal of Mechanics and Materials in Design*. 2017. Vol. 13(4). P. 553-567.
21. Opasiak, T. & Peruń, G. Influence of construction the rollers C type on resistance of rotating driven system of the belt conveyor. *Diagnostyka*. 2016. Vol. 17. No. 1. P. 81-86.
22. Peruń, G. & Łazarz, B. & Opasiak, T. Opportunities to improve the efficiency of the "Gwarek 1200" belt conveyor. *Transport Problems*. 2020. Volume 15. Issue 4. Part 2. P. 215-227.
23. Roffey, P. Corrosion-Initiated Rotating Bending Fatigue Failure of a Fertilizer Conveyor Belt Head Roller. *Journal of Failure Analysis and Prevention*. 2015. Vol. 15. P. 190-199.
24. Rusiński, E. & Czmochowski, J. & Moczko, P. & Pietrusiak, D. *Surface Mining Machines*. Problems of Maintenance and Modernization. Springer. 2017. 179 p. ISBN: 978-3-319-47790-9.
25. Schützhold, J. & Benath, K. & Müller, V. & Hofmann, W. Design criteria for energy efficient belt conveyor drives. In: *Proceedings of the 2014 International Symposium "Power Electronics, Electrical Drives, Automation and Motion"*. SPEEDAM 2014. Ischia, Italy, 18-20 June 2014. IEEE Computer Society: Washington, DC, USA. P. 1256-1263.
26. Shihata, L. & Ebeid, S. Improved energy efficiency in troughed belt conveyors: Selected factors and effects. *International Journal of Engineering and Technical Research*. 2015. Vol. 3. No. 6. P. 174-180.
27. Wheeler, C. & Munzenberger, P. & Ausling, D. & Beh, B. How to design energy efficient belt conveyors. *Bulk Solids Handling*. 2015. Vol. 35. No. 6. P. 40-50.
28. Zhang, L. & Xia, X. Modeling and energy efficiency optimization of belt conveyors. *Applied Energy*. 2011. Vol. 88. No 9. P. 3061-3071.
29. Zhang, S. & Xia, X. Optimal control of operation efficiency of belt conveyor systems. *Applied Energy*. 2010. Vol. 87. No. 6. P. 1929-1937.
30. Živanić, D. & Ilanković, N. & Zuber, N. & Dokić, R. & Zdravković, N. & Zelić, A. The analysis of influential parameters on calibration and feeding accuracy of belt feeders. *Maintenance and Reliability*. 2021. Vol. 23(3). P. 413-421.
31. DIN22123 *Conveyor Belts - Indentation Rolling Resistances of Conveyor Belts Related to Belt Width - Requirements, Testing*.
32. PN-M-46606:2010. Przenośniki taśmowe - Krążniki. [In Polish: Belt conveyor - Rollers]. Warsaw: Polish Committee of Standardization. 40 p.

Received 02.12.2020; accepted in revised form 18.05.2022