Studies of The Durability of Belt Conveyor Idlers with Working Loads Taken into Account

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Abstract. The results of laboratory and operational studies conducted in the Machinery Systems Division of Wroclaw University of Technology in recent years have become the basis for selecting proper belt conveyor roller designs optimized for specific strength and operational criteria. The usefulness of the results for assessing the energy intensity of idlers, estimating their durability and determining modernization policies has been confirmed. Methods of estimating the durability of carrying idlers on the basis of the identified output stream distributions are presented. Results of studies carried out using an analytical method and a laboratory method are reported. It has been shown that the operational durability of a roller is determined by its design, the roller set parameters (the spacing and the angle of bevel) and the operating conditions having a bearing on the irregularity of the transported output stream.

1. Introduction
Belt conveyors, due to their reliability, maintenance and operation cost and high mass capacities, are one of the most commonly used methods of transportation of bulk material in modern industry. Large number of applications of belt conveyors in almost every branch of industry drives the demand for new, improved and energy efficient solutions of belt conveyors’ components. Users of conveyor belts are looking for energy-efficient solutions, including: low-rotational resistance and durability of idler [1], energy-saving belt, high efficiency drive systems [2]. All these factors have an impact on the cost of transporting the spoil [3] through the conveyor belts and on the durability of the transport equipment [4,5,6]. Since the durability of the belt conveyor’s roller sets has a direct bearing on its operating costs it is one of the main criteria used in belt conveyor optimization. For many years the Machinery Systems Division of Wroclaw University of Technology has been conducted research on determining the effective lifetime of idlers in variable operating conditions. An approximate estimate of the durability of idlers for a single mine or an entire mining company can be obtained on the basis of an analysis of the roller management. Mines usually have data on the number of installed roller sets, the number of renovated or purchased idlers and even on the number of replacements. The ratio of the number of installed roller sets to the number of their replacements per annum can serve as a very rough estimate of the durability of the roller sets. However, since the estimate is very sensitive to changes in the length of the belt conveyor routes its error can be considerable. When the routes are extended or new belt conveyor flights are put in operation in the course of the year, a larger number of installed roller sets appears, whereby the durability indices markedly decrease. On the other hand, when the routes are shortened or some of the belt conveyors are put out of operation, the indices markedly increase, since instead of installing new or renovated idlers the maintenance service install the roller sets taken down from the decommissioned belt conveyors. Such operations are usually not
recorded and it may happen that in a particular year the mine uses almost no new or renovated idlers. Then the annual reliability index may reach a very high value of 70 years or more. Obviously, in such a case the index is a dubious measure of durability. Another drawback of this index is the inaccuracy due to the cyclicity of roller set replacement in new or altered belt conveyors in which all the idlers are new. Since idlers age, an accumulation of replacements after a few years can be expected. First the idlers defective from the beginning will be replaced and much later (when the end of the expected life approaches) the gradual wear of the idlers will lead to their mass replacements. Thus the use of this index for estimating the durability of idlers would lead to the overrating of their durability in the first years of belt conveyor operation and to the underrating of their durability in periods of replacement pile-ups. Over time the cyclicity of this process would blur and the number of replacement in a year would stabilize at a constant level and the annual index of durability could quite precisely estimate the actual durability of the idlers. Thus the usefulness of this index depends on how many belt conveyors in a given mine are equipped with new or freshly renovated idlers of the same type.

The durability of roller sets can also be estimated through simulation calculations performed using the QNK-TT computer program based on advanced unit resistance method computing algorithms [7]. The program calculates the loads on the particular idlers, as a function of output, and taking into account the data on output stream variation calculates the approximate durability of the idlers. Both empirical and theoretical distributions can be implemented in the QNK-TT program. The roller reliability estimation accuracy depends on the accuracy of the adopted instantaneous output distribution for the particular transport tasks. In practice, Geesmann’s computing algorithms [8] are most often used since they take into account the variable operating conditions typical of opencast mines. This method consists in calculating the radial reactions on the particular bearings of the investigated idlers and their shares in the particular classes of the randomly variable belt conveyor instantaneous output. The calculation coefficients take into account the influence of the operating conditions (temperature variation, humidity, dustiness).

The operational durability of idlers can also be determined on the basis of the results of accelerated laboratory tests carried out on a special measuring stand. The test methodology adopted in [9] consists in applying ever heavier loads while increasing the angular speed in a dusty and humid atmosphere. As a result, wear can be accelerated in comparison with that occurring in the actual operating conditions. Knowing the applied loads and the angular speed of the tested roller one can convert the running time in the laboratory conditions into running time in the real operating conditions. It should be noted that as yet there are no other methods which would make it possible to infer about the durability of idlers on the basis of results obtained in such a relatively short testing time.

2. Analytical method – selected examples
The assessment of conveyer belt roller durability by the analytical method is based on the assumption that the durability of a single roller is determined by the durability of the set’s most loaded bearing. Since the radial load of each of the six bearings in the upper roller set is a random variable a proper model describing the output stream needs to be adopted. Knowing the distribution of the instantaneous output and the distribution of instantaneous roller loads one can determine the durability of the bearing. The parameter which determines the durability of the bearing is equivalent force $F_{zm}$, i.e. the averaged radial load, calculated from relation (1):

$$F_{zm} = \sqrt[3]{\sum_{i=1}^{m} \left( F_{li}^3 \cdot p_i \right)}$$  (1)

where:
- $F_{li}$ – the radial force of the bearing for the $i$-th output (load) class, kN,
- $p_i$ – the probability of the occurrence of the $i$-th output class, determined from output stream variation analyses.
The equivalent force significantly depends on the number of output (load) classes adopted in the calculations. One should remember that in durability analyses the output stream model should cover the entire distribution of loads, including the zero output. In [10] an analysis of the selection of the number of output distribution classes for roller durability estimation was carried out on the basis of the results of measurements performed on an over-burden conveyor with an 1800 mm wide belt. For the recorded measurement series, the probability of the occurrence of nonzero outputs $p_i$ amounted to about 99%. Four hypothetical cases of probability $p_0$ [%] of the belt conveyor not being loaded (due to stoppages connected with mining process organization, the excavator operation regime or the breakdown of the output feeding device) were proposed. Each of the cases was considered for a different number of output histogram classes – from 3 to 15. The diagram of roller set durability for the different cases and for the different number of classes (from 3 to 11 – above class 11 the shape of the curves does not change) [11]. It should be noted that at the level of class 5, the shape of the curves changes and then remains constant. Thus one can assume that the output stream model for roller durability estimation yields correct estimates for a division into more than 5 output classes. But the highest roller durability estimation accuracy is achieved for the division of output distribution into more than 8 classes. For the identified (by measuring the resultant vertical force and recording the instantaneous output) output stream the range of radial loads acting on the bearings of the particular idlers in the set is determined (i.e. for the $i$-th class of the adopted frequency series the proper radial force values are read). Then on the basis of determined equivalent force $F_{zm}$ the durability of a single bearing is calculated from the generally known relation:

$$L_{h, eksp} = \frac{10^6}{60 \cdot n_{eksp}} \left( \frac{C}{\varphi_B \cdot F_{zm}} \right)^3$$  \hspace{1cm} (2)

where:

- $C$ – the catalogue dynamic bearing capacity, kN;
- $n_{eksp}$ – the rotational speed of the bearing in the operating conditions, min$^{-1}$;
- $\varphi_B$ – the operating conditions factor,
- $F_{zm}$ – the equivalent force acting on the bearing, kN.

On the basis of the probability of damage to one of the two bearings in the roller the durability of the latter is calculated from Geesmann relation:

$$L_{h} = \frac{L_{h, eksp,1} \cdot L_{h, eksp,2}}{\sqrt{L_{h, eksp,1}^p + L_{h, eksp,2}^p}}$$  \hspace{1cm} (3)

where:

- $L_{h, eksp,1}$ – the durability of a single bearing in the roller [h],
- $p$ – the coefficient of variation for the conditions prevailing in the mine, $p = 1.111$ (based on Geesmann’s study [5]).

It is assumed that the durability of a roller set is equal to that of its weakest link, i.e. the middle or side roller, depending on the prevailing operating conditions.

The analytical assessment of roller set durability is illustrated for a special case of idlers, i.e. idlers in an articulated set with a forced bevel of $2.70^\circ$ and a spacing of 1.45 m [12]. For this purpose the recorded radial loads acting on the particular bearings (figure 1a) and the instantaneous output histogram drawn for the overall output stream (average $Q_{mav} = 14.8$ thousand Mg/h) (figure 1b) were used. The results of the calculations are presented in table 1.

**Table 1.** Calculated durability of idlers in bevelled set with spacing of 1.45 for randomly generated instantaneous output.

| Equivalent force $F_i$ [kN] | $F_{i1}$ | $F_{i2}$ | $F_{i3}$ | $F_{i4}$ | $F_{i5}$ | $F_{i6}$ |
|------------------------------|---------|---------|---------|---------|---------|---------|
| Bearing durability $L_{h, eksp}$ [h] | 2 824 374 | 327 405 | 99 090 | 26 468 | 278 454 | 4 359 905 |
| Roller durability $L_{h}$ [h] / [year] | 302 654h / 76 years | 21 957h / 5.5 years | 278 454h / 67 years |
Owing to the extended range of the vertical force a significant reduction in the durability of the middle roller – down to 5.5 years – was obtained. Also the fact that the changed percentage of the effect of the i-th classes of the bearing load frequency series over time was taken into account is not without significance. Therefore an analysis was carried out to check the effect of load variation on the durability of the middle roller for three probable variants of the random flow of the output stream on the conveyor. The same instantaneous output set median of $Q_{\text{max}} = 13$ thousand Mg/h was used in each of the variants. The following variants were analyzed:

- the conveyor transports a regular overburden stream in the whole range of the recorded instantaneous output (variant 100%),
- the conveyor transports overburden coming from two outermost classes of the frequency series (variant 50/50%),
- a bevelled roller set is subjected to the action of four levels of load generated by the transported masses, the percentages of the load levels being identical (variant 25/25/25/25%).

The results of the simulation of the effect of output stream irregularity on the durability of the middle roller are presented in figure 2.

The simulation showed that the durability of the roller depends also on the variation in the distribution of the stream fed onto the conveyor. Maintaining the same conveyor output in each of the analyzed variants, the best result (about 6.8 years) was achieved for the middle roller in the set loaded with a regular stream over the whole range of running time. A significant decrease in durability to the level of 3.8 years was observed when two the extreme ranges of radial forces acting on the bearings of the analyzed roller occurred.

**Figure 1.**
a) Range of radial forces acting on bearings of idlers in bevelled set with spacing of 1.45 m, 
b) histogram of instantaneous output for theoretical model of output stream

**Figure 2.** Effect of output stream irregularity on durability of middle roller of bevelled roller set with spacing of 1.45m
Equally interesting is a comparison of the durability of the middle roller in the bevelled set with the spacing of 1.45 m with the durability obtained for the spacing’s of 1.2 (generally used) and 1.45 m. The results of calculations based on the instantaneous output histogram and the real (measured) values of the radial forces (figure 3) are presented in table 2.

Table 2. Calculated durability of middle roller in particular roller set versions.

|                      | Bevelled set, spacing 1.45m | Spacing 1.45m | Spacing 1.2m |
|----------------------|----------------------------|--------------|--------------|
| Equivalent force $F_z$, kN | $F_{l3}$                    | $F_{l4}$     | $F_{l3}$     | $F_{l4}$     | $F_{l3}$     | $F_{l4}$     |
| Bearing durability $L_{hr, expl}$, h | 2.71                        | 4.21         | 3.13         | 4.50         | 3.03         | 3.70         |
| Roller durability $L_{kr}$, h | 99 090                      | 26 468       | 64 433       | 21 755       | 71 045       | 38 995       |

The roller in the set with the 1.2 m spacing shows the highest durability. The analyzed case of the bevelled roller set represents a system with a negative lead of the side idlers on which friction forces arise, changing the loading of the middle roller [13]. Such a case occurs on a horizontal or downward section of the route. Hence the durability of the middle roller in the bevelled roller set is higher for the same spacing of 1.45 m.

3. Analytical method – selected examples

Another effective way of determining the effective lifetime of idlers is accelerated aging conducted on an accelerated durability test stand (figure 4) in a laboratory. The results of many studies [14] demonstrate the usefulness of this method for comparing different roller designs and when making (quantity and quality) decisions on the production of idlers. The measuring method adopted in this study is based on the following assumptions:

- during operation an individual roller is acted upon by a randomly variable radial load, which has a decisive effect on the durability of the roller;
- the measure of roller loading is an equivalent force (calculated as for bearings);
- the measure of operational roller wear are the changes in its rotational resistance;
- the roller works under a load greater than the equivalent force (determined on the basis of the varying output stream on the conveyor) in a dusty and humid atmosphere;
- roller durability conversion is performed on the basis of the equivalent radial force and the rpm related to the laboratory conditions (the test acceleration coefficient).

![Figure 3](image)

**Figure 3.** Parameters taken into account when calculating durability of middle roller: a) range of radial forces acting on bearings of middle idlers in particular roller set versions, b) histogram of instantaneous output for theoretical model of output stream.
The knowledge of the identified real operational parameters of the roller (the radial load and the rotational speed) is exploited in the experiment. The starting point for the analyses is the adoption of assumptions valid for ball bearings:

\[ N \cdot P^3 = \text{const.} \]  
(4)

where:

- \( N \) – the rotational speed of the bearing, min\(^{-1}\);
- \( P \) – the dynamic bearing load, N.

Knowing linear belt speed \( v_t \) and roller diameter \( D_k \) it is possible to determine rpm in the operating conditions:

\[ n_{e_k p} = \frac{60 \cdot v_t}{\pi \cdot D_k} \quad \text{[min}^{-1}] \]  
(5)

Applying increased rotational speed \( n_l \) in the laboratory conditions one obtains the acceleration coefficient.

\[ k_s = \frac{n_l}{n_{e_k p}} \]  
(6)

Similarly, as in the case of load, one determines acceleration coefficient \( k_p \), which is the product to the third power, of force \( P_t \) (generated by the loading unit on the test stand) and equivalent reaction \( F_{zm} \) (the equivalent force determined on the basis of a random output run):

\[ k_p = \left( \frac{P_t}{F_{zm}} \right)^3 \]  
(7)

The total coefficient defining the shortening of testing time in laboratory conditions amounts to:

\[ k = k_s \cdot k_p \]  
(8)

Therefore, it is assumed that one hour of roller work on the measuring stand corresponds to \( k \) hours of its work in the real operating conditions. The operational parameters assumed in durability tests for a type series of carrying idlers are presented in table 3. One can notice that the acceleration coefficient has a significant influence on the size of working load \( P_l \). In durability assessment it is assumed that the measure of long lasting roller load are changes in its rotational resistance. The changes are due to the friction and wear of the elements of the bearings and the seals and are characteristic of the
particular design solutions. Therefore, during durability tests the rotational resistance of the idlers is measured at regular time intervals by driving the axle while the casing remains immobilized [15].

Table 3. Working parameters used in accelerated durability tests, taking into account roller type.

| Application area | opencast mines | underground mines |
|------------------|----------------|-------------------|
| Equivalent radial load $F_{zm}$, [kN] | 7.27 | 3.9 | 1.7 | 0.4 |
| Laboratory load $P_l$, [kN] | 21.5 | 8.0 | 5.2 | 2.4 |
| Operational rpm $n_{eks}$, [min$^{-1}$] | 654 | 600 | 625 | 360 |
| Laboratory rpm $n_l$, [min$^{-1}$] | 1200 | 1200 | 1200 | 720 |
| Acceleration coefficient $k$ | 52 | 25.6 | 55.3 | 432 |

The methodology was used to comparatively assess, among other things, the quality of roller seals with ferromagnetic fluid, made of respectively plastic T2 (roller $K_{T2}$) and metal M2 (roller $K_{M2}$) (figure 5). The sealing concept is described in more detail in [16]. The test results were one of the criteria for the selection of a manufacturer for the mass production of idlers Ø194mm in diameter.

Figure 5. View of tested seals: a) made of plastic T2, b) made of metal M2.

Already the measurement of the rotational resistance of the idlers with the new type of seals prior to durability testing had shown significant differences. The range of values, the character of the changes in rotational resistance during 4 hour long running-in and the temperature rise had weighed in favour of the solution used in roller $K_{M2}$ with metal seal M2 (figure 6). The results of the durability tests merely confirmed this (figure 7).

Figure 6. Variation in rotational resistance during running-in of idlers
In the first two years of roller $K_{T2}$ operation a running-in period was observed. It is a period in which heavy wear and grinding in of bearing and seal rolling elements takes place. After the running-in period short stabilization occurs, followed by a period of wear (gradual increase in rotational resistance). Before 4 years of operation passed the roller rotational resistance had reached 12.5 N, exceeding the highly unsatisfactory level of 11.80 N. The final tendency in the changes indicated that the roller would stop performing its function in the course of its further use. Roller $K_{M2}$ with metal seals M2 is characterized by a rapid increase in rotational resistance from 0.7 N to about 4.0 N. Subsequently, a decrease to the level of about 3 N (before the 2-year long operation period ends) is observed. Then roller $K_{M2}$ shows full stabilization. After more than five years its rotational resistance amounts to 3.4 N, being 4-fold lower than that of roller $K_{T2}$ with plastic seal T2.

In another study the durability of the idlers used in an underground mine was tested [4]. Six $\phi133\times465$mm carrying idlers in different design versions were selected for testing. Symbols K-1 and K-2 represent a strengthened design with bearing 6305, symbols K-3 and K-4 denote the standard version with bearing 6305, whereas idlers K-5 and K-6 incorporated bearing 6204, which further changed the geometry of the bearing node. The results of the tests are presented graphically in fig. 8. Taking into account the acceleration coefficient, amounting to 432, it was assumed that one year of operation in mine conditions corresponds to 7 h of roller work on the test stand (tab. 3). It was found that the tested roller designs significantly differed in the changes in rotational resistance over time. The character of the changes within a single design (one pair of idlers) was similar.

All the idlers are characterized by a running-in phase corresponding to 2.5 years of operation. In the case of idlers K-3+K-6, this phase is accompanied by a noticeable decrease in rotational resistance, which is typical of properly designed idlers. In the case of idlers K-1 and K-2, rotational resistance increases during this phase, which is symptomatic of a faulty design. After the running-in of the idlers short stabilization takes place, followed by wear resulting in a gradual increase in rotational resistance. The final tendency in the changes indicates that in the course of the further use of the idlers the rotational resistance will exceed the standard level. No deterioration in the utilitarian properties of idlers K-5 and K-6 was observed in the whole period of testing, which means that they can be regarded as the best roller designs.
Figure 8. Results of durability tests carried out on idlers used in underground mine: a) strengthened idlers with bearing 6305, b) standard idlers with bearing 6305, c) idlers with bearing 6204.

4. Conclusions

Methods of assessing the durability of belt conveyor carrying idlers on the basis of the identified distributions of the transported output stream are proposed. Studies made using an analytical method based on Geesmann’s algorithms showed that the middle roller in the upper set, subjected to the widest range of load, is characterized by the lowest durability. It has been shown that the operational durability of a roller is determined by its design, the roller set parameters (the spacing and the angle of bevel) and the operating conditions having a bearing on the irregularity of the transported output stream.

A laboratory method of estimating the effective lifetime of idlers on the basis of tests conducted on a stand designed for accelerated durability testing is proposed. A comparison of the equivalent radial loads for a type series of carrying idlers used in mining, determined on the basis of random output runs, has been presented. It has been shown that the highest accuracy of roller durability estimation is achieved for an output stream model described by an instantaneous output histogram divided into more than 8 classes.

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