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JUSTIFICATION OF USING CLOSED TYPE BEARINGS IN BELT CONVEYOR ROLLERS IN MINES

The article analyzes the influence exerted by various types of protective seals of bearings in rollers of belt conveyors on the value of the roller rotational resistance. Domestic and foreign methods for determining and calculating the resistance to rotation of rollers are reviewed. Based on analysis, it is concluded that it is necessary to develop an updated method for calculating the roller rotational resistance and improving the design of the conveyor rollers through the use of the closed type bearings.

Keywords: *belt conveyor, roller rotational resistance calculation, belt conveyor roller, bearing assembly, seal, closed type bearing*
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Introduction

Transport has always had a special role in mining. It is of no matter whether it is a principal or accessory transport system. Whether it is a railway, motor, pipeline or conveyor transport, reliability of either mode has a direct effect on economic efficiency of the whole work. Nonetheless, reliability and efficiency of a conveyor transport is of major significance in mining owing to high automation level and productiveness.

The most common structural unit of a belt conveyor is a roller which very often incurs breakdown. Delayed replacement of a fault roller affects the service life of a conveyor belt and the performance of the whole transport system. The principal function of rollers in belt conveyors is supporting the moving belt length-wise a conveyor. The main requirements imposed to the rollers are concerned with certain limitation of their parameters, namely, diameter and weight, duration and reliability of operation and the value of rotational resistance which should be as low as possible as it influences energy input in mineral transportation. The decrease of a roller diameter increases the roller rotational resistance, which brings the risk of stopping of a roller. A substantial portion (up to 40%) of energy consumed by conveyors is spent to overcome the roller rotational resistance.

Reliability and faultless operation of rollers depends on many factors, including two most important aspects, namely, operating conditions and structural features of rollers. These parameters should be taken into account when selecting structural members for the roller sealing arrangement. Statistics shows that a majority of failures of conveyor rollers are associated with the loss of operability by the bearing assembly of a roller. The causes of such loss are heavy wear due to deficient or zero lubrication, overheat during operation, corrosion because of water entry or contamination, and some other factors, all of which one way or another are connected with the efficient operation and service life of sealing arrangements of roller bearing groups [1].

Modern designs of conveyor rollers are adaptable to different sealing arrangements which protect the bearing assembly from dust and other impurities. In this manner, both the bearing and its lubricating system are prevented from the adverse effect, which enhances reliability of the conveyor roller. Furthermore, the sealing arrangement of a bearing assembly ensures proper temperature of a lubricant, prevents the lubricant leak and eliminates entry of foreign bodies and liquids capable to bring a bearing out of operation [2]. The use of latter-day and higher-end constructional decisions allows handling some of the listed problems partly but incompletely.

The performance attributes which have influence on the roller rotational resistance are: the type of a seal; the type of a lubricant; the value of load on a roller; the speed of a roller; the ambient temperature [3]. It is also necessary to take into account that effective viscosity of plastic lubricants increases in long-term operation of rollers, and the roller rotational resistance grows as a consequence, which leads to jamming and wear of the bearing assembly. Presumptively, the main cause of untimely failure of conveyor rollers is the use of inappropriate sealing arrangements in the bearing assemblies of conveyor rollers.

New designs of sealing arrangements for the bearing assemblies of rollers of belt conveyors in modern mines actualizes determination of rotational resistance of the rollers depending on their embodiment [4]. The Fuels and Lubricants Laboratory at the Mining and Transport Machine Engineering Department of the NUST MISIS' College of Mining studied and determined the main parameters of the present-day protecting seals for the bearing assemblies of conveyor rollers, and substantiated application of the closed type bearing in the roller structure.

Main part

Review of the modern methods and techniques of conveyor roller diagnostics reveals a whole series of various approaches to handling this issue. However, some aspects dealing with the assessment of the effect exerted by the design of sealing arrangements of the roller bearing assemblies and by their wear, working temperature and mechanical vibrations on the roller rotational resistance are studied insufficiently. In this context, the experimental and theoretical research and analysis of operational capability of conveyor rollers on a full scale with regard to the listed aspects is a relevant scientific problem.

The main trend of the structural improvement of a conveyor roller in **Fig. 1** is the use of the advanced sealing arrangements (**Fig. 2**) of hard-to-overestimate significance [5]. Such seals should provide effective moisture and contamination protection at the minimized roller rotational resistance. Another trend is eliminating protective sealing arrangement from the roller design through the use of a closed type bearing, which prevents contamination and avoids jamming. A closed type bearing is protected by different shape and material seals shown in **Fig. 3**. The seals cover and protect the space between the races, while an open type bearing is structurally unprotected.

Formula (1) for calculating the total resistance to the belt motion on the roller carriage, W_r, is a sum of four members: belt deformation resistance W_{bd}, load deformation force W_{ld}, indentation rolling resistance W_{ind} and roller rotational resistance W_{rot}. The roller rotational resistance in conveying different minerals can reach 25% of W_r [6–8]:

$$W_r = W_{rot} + W_{ind} + W_{ld} + W_{bd}. \quad (1)$$

So, it is relevant to develop an experimental determination procedure of roller rotational resistance as function of type of seals and bearings in use.

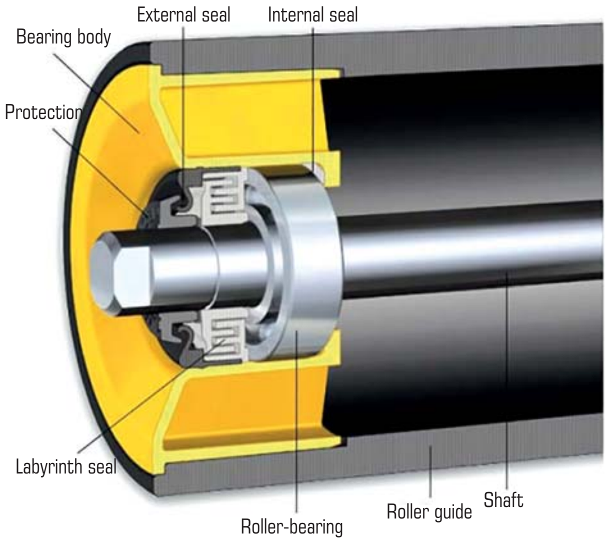

Fig. 1. Conveyor roller as per State Standard GOST 22646–77

Complex design engineering successfully uses the method of modeling which mostly accurately describes the influence of all factors and processes on a test object.

Regression equations connect the test parameters of the physical and mathematical models of an object. Inclusion and modeling of all influences on a test prototype is possible in simple cases only. In modeling units and assemblies of a complex structure, they are divided to separate parts at certain constraints. Such cases use the principles of physical similarity and dimensionless values.

In this connection, the experiment assumes that individual characteristics of a test object (size, material performance, operating regime, etc.) unalter and have no influence on the test results. The influencing parameters are selected from the analysis of dimensions of a problem, then basic parameters are determined and used to construct dimensionless groups.

This study analyzes the influence exerted by different structural and operation factors on a bearing assembly of conveyor rollers. The most important parameters are the characteristics of operating conditions of belt conveyors in mines [9].

The influencing parameters for the operational capabilities of belt conveyor rollers are selected to be: the roller rotation frequency f, the bearing assembly load (with regard to the weight of rolling part of a roller) F_r, the external diameter of a roller-bearing, D, the effective viscosity of a lubricant, μ_{EF}, the acceleration of gravity g and the ambient temperature t.

The independent dimensions of the mass M, time t, length L and temperature T were also determined as the characteristics of the test system. The influencing parameters and their dimension attributes are given in **Table**. The influence of the operating temperature of a roller is analyzed separately.

Influencing parameters in test system

Parameter	Dimension attribute	Unit of measure	Symbol
Rotation frequency of roller	t^{-1}	1/s	f
Radial load on bearing	MLt^2	kg·m/s^2	F_r
External diameter of bearing	L	m	D
Effective viscosity	$ML^{-1}t^{-1}$	kg/m·s	μ_{EF}
Acceleration of gravity	Lt^{-2}	m/s^2	g
Ambient temperature	T	°C	t

Then, it is necessary to select the basic parameters and values that remain constant during the experiment. After that, the dimensionless groups p_i are constructed for the influencing parameters — Eqs. (2) and (3). In the present study, the selected influencing parameters are the radial force F_r on the roller-bearing and its rotation frequency f:

$$\pi_1 = F_r D^{\alpha} \mu_{EF}^{\beta} g^{\gamma} , \quad (2)$$

$$\pi_2 = f D^{\alpha} \mu_{EF}^{\beta} g^{\gamma} . \quad (3)$$

Dimensionless groups (4) and (5), after insertion of values of all powers, have the form:

$$\pi_1 = F_r D^{-3/2} \mu_{EF}^{-1} g^{-1/2} , \quad (4)$$

$$\pi_2 = f D^{1/2} g^{-1/2} . \quad (5)$$

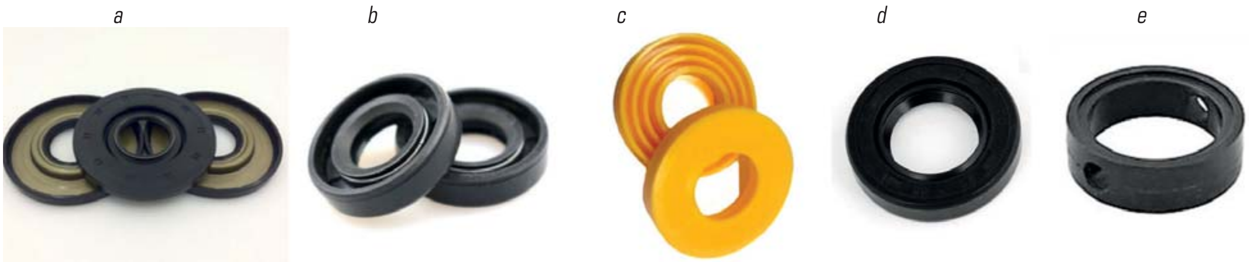

Fig. 2. Types of external seals for rollers:
a – cage-lip seal; *b* – gland seal; *c* – labyrinth seal; *d* – groove seal; *e* – disk seal

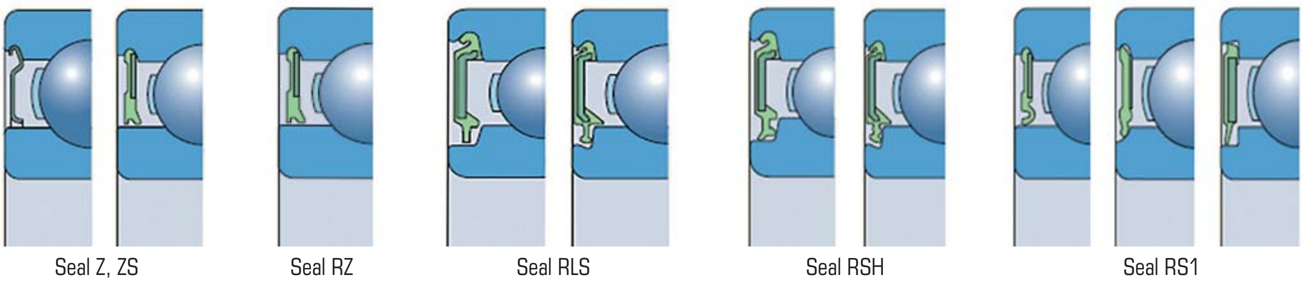

Fig. 3. Types of internal seals of bearings

The factor to be determined is the dimensionless roller rotational resistance w_{rot} which is given by:

$$w_{rot} = f\left(\pi_1, \pi_2, t\right). \quad (6)$$

The relation of the output parameter w_{rot} and the input parameters is written as a polynomial w_{rot} multiplied by a temperature factor:

$$w_{rot} = f\left(\pi_1, \pi_2\right)k\left(t\right) = \left(A_0 + A_1\pi_1 + A_2\pi_2 + ...\right)k\left(t\right) =$$
$$= \left(A_0 + A_1F_rD^{-3/2}\mu_{EF}^{-1}g^{-1/2} + A_2fD^{1/2}g^{-1/2} + ...\right)k\left(t\right), \quad (7)$$

where $k(t)$ is the temperature factor ranged from 0 to 1.

The analysis of the roller rotational resistance used the method of whole factorial and some basic factors represented by the roller rotation frequency f, load of the roller, F_r, and by the temperature of the bearing assembly of the roller, t. The listed factors vary on three scales and group with all factors on each scale [4]. The ranges of the variables are [10]: f — 130–250 $s^{-1}(min^{-1})$; F_r — 2.5–7.5 (150–450) $s^{-1}(min^{-1})$.

By now there are many known test benches and calculation procedures to determine conveyor roller rotational resistance. The most common test bench to determine the rotational force of rollers using the method of weights is depicted in **Fig. 4**.

At the Gorbachev Kuzbass State Technical University, it is proposed to use a procedure and facility which simulate real-life operational conditions of conveyor roller as per DIN 22112-3 Germany but with some modifications [11, 12].

The rotation resistance is determined using a special bench tester and a mixed measurement and calculation method. A cylinder is set on the bench tester so that its axis is fixated tightly in a special frame and a shell ring rotates at the same velocity as a belt of a conveyor has in motion. A tensometer measures the force of retention of the roller axis by the special frame and sends the measurements to a special device model Microsim-06.

The roller rotation force is calculated from the formula below [13]:

$$W = FL_i, \quad (8)$$

where F is the roller retention force measured by device 5 (Fig. 4), N; L_i is the distance from the roller axis to the lever arm which interacts with the force measurement device, m.

The testing conditions are described below:

— the load on the shell ring of the roller is symmetrical and correlates with the roller diameter;

— the roller is rolled for a few minutes before testing;

— the force F is calculated as an average of values recorded in rotation of the roller in two directions (forward and backward [14, 15].

Such bench tester is designed at the Rostov State Transport University to:

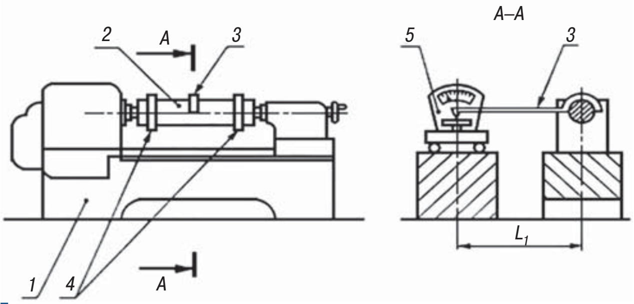

Fig. 4. Layout of test bench to determine conveyor roller rotational resistance according to State Standard GOST R 51042-97:
1 – foundation slab with shaft and tailstock for clamp holding and activation of rotation of roller; *2* – test roller; *3* – lever arm; *4* – loading ring; *5* – device to determine roller axis retention force

— calculate the limit static load applicable to a roller beyond a guarantee period;

— determine effect of dynamic loads on operational capabilities of a bearing and its seal components;

—study effect of thermal factor on sealing of a bearing assembly;

— adjust calculation methods and mathematical models to determine reliability of a roller and its service life at such reliability [11, 16, 17].

For the experimental study of the bearing assemblies of conveyor rollers, the Fuels and Lubricants Laboratory at the Mining and Transport Machine Engineering Department of the NUST MISIS' College of Mining designed and manufactured a new bench tester for the determination of the roller rotational resistance (**Fig. 5**) [18].

The bench tester in Fig. 5 consists of: supports *1*, pipe sockets *2*, connection sleeves *3*, foundation slab *4*, simulator of load applied to conveyor roller *5*, conveyor roller *6*, electric motor *7*, frequency converter *8* and electronic thermal couple to measure temperature of a lubricant *9*.

The lab-scale test involved a conveyor roller with a diameter of 127 mm and with a labyrinth seal and a roller of the same diameter and with the closed type bearings. The first-type roller was equipped with radial spherical bearings 6304-SKF with the nitrile butadiene rubber seals, and the second-type roller used the closed type bearings 6304-2RSH SKF and the three-channel labyrinth seals composed of two frost-resistant polymer rings. The test samples were filled with plastic lithium grease NLGI 2 LGMT 2 SKF [9, 19]. The plastic lithium greases take 50–60% of the whole global market. The standard lubricant for the bearings SKF is NLGI 2 LGMT 2 SKF. The lubricant was used in the labyrinth seal of the conveyor roller and in the tests in a wide range of temperatures.

The motor speed was adjusted by the method of vector control. This method is only used if the testing load can be varied at the same frequency and when it is required to obtain a wider frequency control range at the

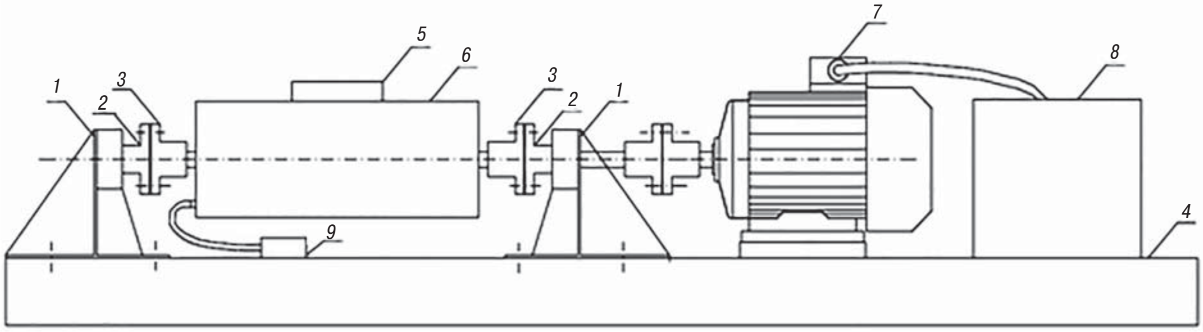

Fig. 5. New bench tester

nominal moments. The frequency control enables real-time recording of change in the moment of rotation on the motor shaft.

The experimental relationships of the roller rotational resistance, roller loading and the roller rotation frequency for the roller with the bearing assembly with the protective labyrinth seal and for the roller with the bearings 6304-2RSH SKF with internal seal are shown in **Fig 6**.

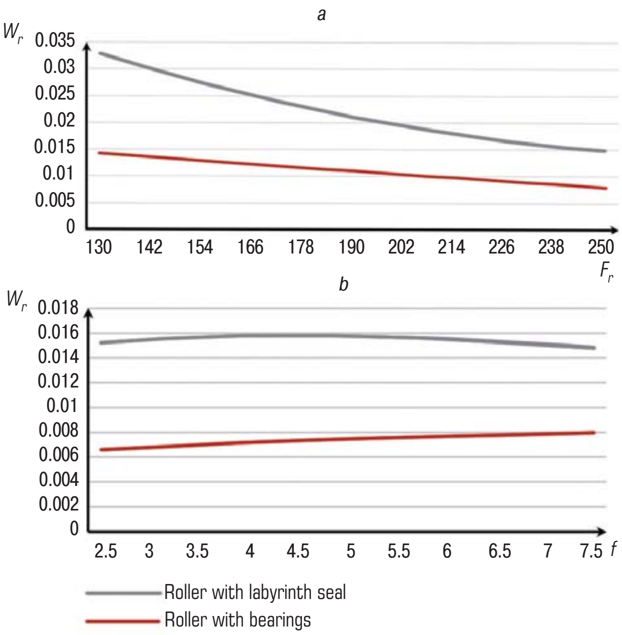

Fig. 6. Rotational resistance versus loading at maximal rotation frequency (*a*) and versus rotation frequency at maximal loading (*b*) for roller with protective labyrinth seal and for roller with bearings 6304-2RSH SKF

From the comparisons of the calculations, the use of the closed type bearing in conveyor rollers allows reduction of the roller rotational resistance by a factor of 1.6–2.2 as against the conventional roller design.

Conclusions

The described theoretical and experimental studies of the dependence of the roller rotational resistance on the main structural parameters of bearing seals at different belt velocities and roller loading allow the following conclusions and recommendations:

1. Rotational resistance of a belt conveyor roller is governed by the structural design of bearings, by their loading and by the roller speed. The influencing factors are: the external diameter of a roller bearing D, the load applied to the bearing assembly (with regard to the roller weight) F_r, the roller rotation frequency f.

2. For determining the rotational resistance of a belt conveyor roller, the moment of the resistance in the bearing assemblies should be measured in real time and with regard to the roller loading and speed. Therefore, the method and special bench tester have been developed for the experimental determination of the roller rotational resistance.

3. The obtained relationships between the roller rotational resistance, design of seal of the roller bearing assemblies, roller loading and the belt velocity make it possible to draw a conclusion that the roller with the labyrinth seal of the bearing assembly has a higher rotational resistance than the roller with the closed type bearings without additional seals.

4. It is most efficient to use the conveyor rollers with the closed type bearings with the two-side contact nitrile butadiene rubber seals (uncombined with other materials) and with lithium lubricant.

5. The use of the closed type bearings in conveyor rollers enables the roller rotational resistance 1.6–2.2 times less as against the conventional-design open-type bearings with external sealing.

6. The obtained relationships of the roller rotational resistance allow proving experimentally parameters of the main assemblies of the belt conveyor rollers with the closed type bearings.

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