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Research of air movement in the labyrinth seal of rollers of conveyor belt

In the paper, the authors present the solution aimed at increasing reliability of the conveyor units. The analysis of technological and operational defects of conveyor rollers is presented. The changes in manufacturing technology have been proposed, which allowed for avoiding welding and provided the required level of tightness.

Computer simulation of the motion of air in the labyrinth seal of the roller was conducted to determine the numerical parameters of possible airflows. It is proved that the airflow is present in the gap of the labyrinth seal due to the roller rotation. It is shown that the reason for the penetration of abrasive particles through the labyrinth seal after stopping is decompression, which occurred as a result of temperature change and push out of airflows during rotation. It is also suggested that the number of stops during the operation should be taken into account when determining the durability of rollers. Practical recommendations are given for preventing the penetration of abrasive particles during conveyor stops and the need for combined seals. The results can be used for the construction of roller conveyor belts in any industry.

1. Introduction

A conveyor belt is one of the most efficient vehicles. The total length of belt conveyors in an industrial enterprise can reach hundreds of meters, or even several hundred kilometers [1, 2]. Most belt conveyors in the extractive industry operate in extreme conditions of temperature drop, high humidity and dust. The close relationship of conveyors to the technological process at the enterprise determines

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their high responsibility, because they do not have duplicate systems. In the transport system, the failure of even one conveyor causes a breakdown of the entire network or enterprise.

Analyzing the reliability of belt conveyor components at different plants, we found that conveyor rollers and conveyor belt have the least operational life and require the greatest labor and material costs. They held 40 per cent of all cost of repairs and maintenance and 30 per cent of the cost of the entire conveyor. The durability of conveyor rollers in mining enterprises is from 0.5 to 1 year. The estimated service life of the most loaded middle roller bear, on average, is 25,000–35,000 hours, which exceeds the actual lifetime several times. On average, over the entire life of each roller in the conveyor it is replaced 3–5 times, that is, the need for rollers exists and constantly increases [2]. For example, in Ukraine, the estimated demand for rollers is 250,000 pieces a year according to statistical data, and this need grows with the commissioning of new enterprises.

Many large enterprises make belt conveyors and their units; they often offer their design solutions, including constructs of roller bearings [3–5]. All these design solutions are original bearing units with a specially designed labyrinth or combined seal and various versions of the roller hub [6, 7].

One of the first developments of the labyrinth seal is described in work [8]. The authors propose to make a long radial gap through which lubricant flows and displaces dirt. Despite many drawbacks, it was a good idea, which was developed in subsequent works. For example, in [9], the authors developed a labyrinth seal in which the lubricant moves but does not leaks out. A great idea was published in [10]. The authors propose to install a shut-off valve inside the seal so that the air flows out during operation and does not enter during stopping. All these and hundreds of other labyrinth seal designs pursue this goal. To achieve this, we need to understand well what are the causes of air movement in the channels of the labyrinth seal.

Despite a great deal of research, statistical data indicate that there is a significant percentage of jams of belt conveyor rollers that lead to stops and emergencies. The main cause of the ribbon fire on the linear part of the conveyor is the destruction of the roller bearing, increased energy consumption, roller friction on the belt, heating and damage to the conveyor belt [11]. The main reasons (Fig. 1) for the failure of the rollers is jamming of the roller bearings resulting from their clogging with dust particles, and small lubrication during operation [12]. Also, one of the reasons for bearing jamming is the action of dynamic loads, which lead to a tilt of the inner ring against the outer one, and clamping of rolling elements.

Therefore, it is advisable to continue research aimed at finding solutions to improve the reliability of parts of conveyors. After analyzing the design, technological and operational defects of existing conveyor rollers, the authors demonstrated the need to improve the reliability and life of rollers by creating a more perfect and technological design.

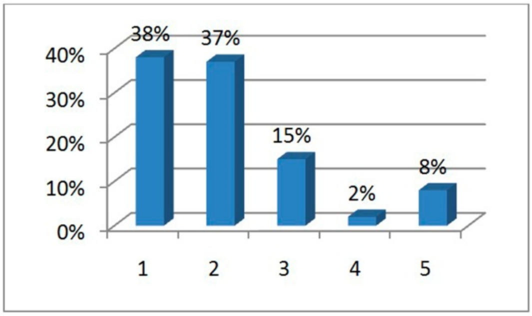

Fig. 1. Statistical distribution of bearing failures: 1 – clogging, 2 – lack of or insufficient lubrication, 3 – relaxation of interference fit, 4 – wear of the body during overloads, 5 – other

2. Results and discussion

The first problem is tightness of connection between roller housing and bearing housing. Previously, we used interference fit and welding, which led to problems with tightness: the surfaces needed additional machining to improve interference fit, which greatly increased the cost of manufacturing, and the use of sealing materials was impossible due to the use of welding. The overall construction of the bearing roller is presented in Fig. 2. In the proposed design, the connection technology of the roller housing and bearing housing was refined. The mounting seat of the roller housing was sealed (sealant A-1046) before the connection, and then the bearing housing was pressed and locked by rolling (Fig. 2a) or by bending (Fig. 2b). In this way, we don't need to weld and provide the required level of tightness in

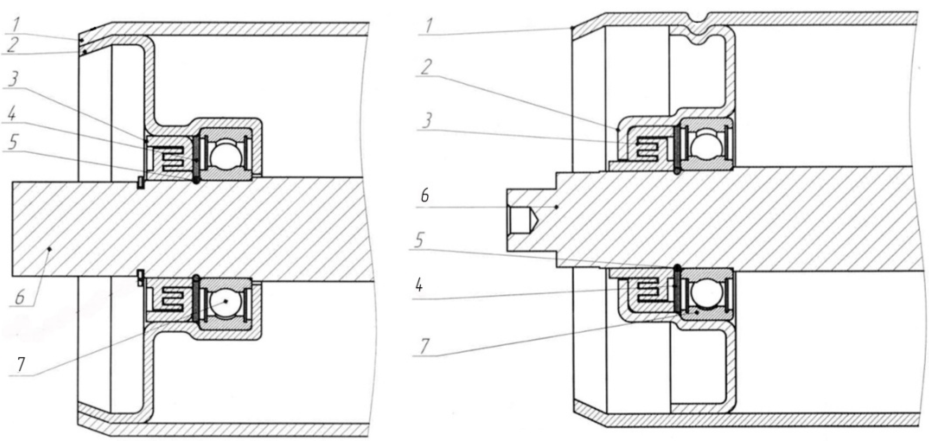

Fig. 2. General construction of bearing roller: a) locked by rolling; b) locked by bending: 1 – roller housing, 2 – bearing housing, 3 – labyrinth seal, 4 – contact seal, 5 – ring, 6 – shaft, 7 – bearing

the connection. Because of this, we are confident that air flows are only possible through the labyrinth seal.

Also problematic for tightness is the labyrinth seal. Methods for calculating labyrinth seals, which are based on determination of gas leaks due to the difference in pressure before and behind the seals, are known [12–15]. This difference in pressure is small in the bearing unit of the conveyor roller, so the problem has been solved in a different way – with the help of the calculation software SOLIDWORKS Flow Simulation, which uses the finite elements method. In order to determine the possible airflow in the gaps of the labyrinth seals of the bearing unit, a computer simulation of the process was carried out. To reduce the calculation time, 1/4 of the typical seal was used for rotation (Fig. 3). The model is constructed taking into account the peculiarities of this calculation module. The design model is an assembly of two parts: the roller housing that rotates with the second half of the seal (Fig. 3 – part a) and the fixed roller axial shaft with half a horizontal labyrinth seal (Fig. 3 – part b). The overall dimensions of the seal longitudinal section are approximately 24×24 mm. The radial size (cross section) of the seal depends on the bearing model size, so it is not given. The seal gap width is 0.3 mm.

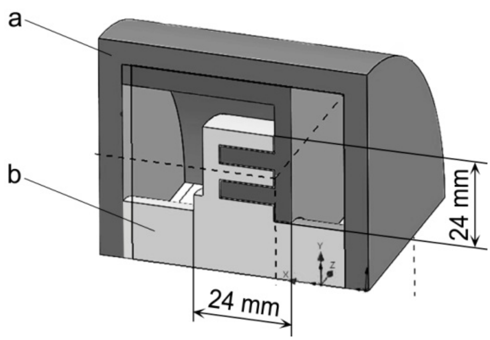

Fig. 3. Seal model: a – rotating part, b – fixed part

The settings of SOLIDWORKS-assembly are as follows. Current environment: air. Static Pressure: 101325.00 Pa. Temperature: 293.20 K. Type of subtask: rotating moving body. Density of the grid: 3 levels with automatic processing of narrow channels. Velocity of rotation: 10 rad/s. Boundary conditions: "Environmental pressure". Gravity is not included, as it is very weak compared to the forces acting during rotation. Turbulence settings were not applied.

As a result, the diagrams of airflow velocity and lines of airflow inside and from the outside the labyrinth were obtained. Fig. 4 shows a diagram of the velocity distribution of airflows. The maximum velocity of air from the outside of the seal is 0.25 m/s, around the seal inlet – 0.05 m/s, in the gap of the labyrinth seal – 0.08 m/s.

The simulation results showed that the airflow is present in the gap of the labyrinth seal due to the rotation of the second part of the seal. Because of rotation

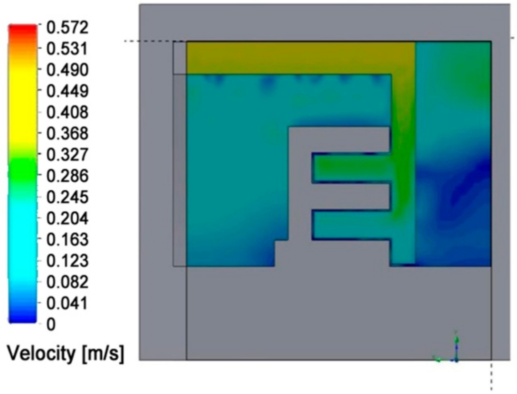

Fig. 4. Airflow velocity around the labyrinth seal

of the seal part, the air is pushed in the radial direction (Figs. 4–6). Such a movement of air occurs inside the roller also, but with a lower intensity. Therefore, the pressure is higher at the internal inlet to the seal gap than at the external inlet and air is pushed out of the seal. However, during the stop of the conveyor, the rollers are cooled, moving seal parts do not push the air in the radial direction and there is a suction of airflow with dust to the inside the rollers. So, we knew that the difference in pressure is due to a change in temperature (change of weather, daily change of temperature and heating-cooling of the roller during operation). We now know that stopping the airflow due to rotation is another reason for the clogging of the bearing during downtime.

The simulation of motion of the particle flux in the labyrinth seal during rotation of the roller was also performed. The particles had a diameter of 0.1 mm; the material was cement (Fig. 7).

The preliminary calculation also provided information that 5 out of 200 particles fall into the seal inlet. Based on the results obtained, the lifetime of the

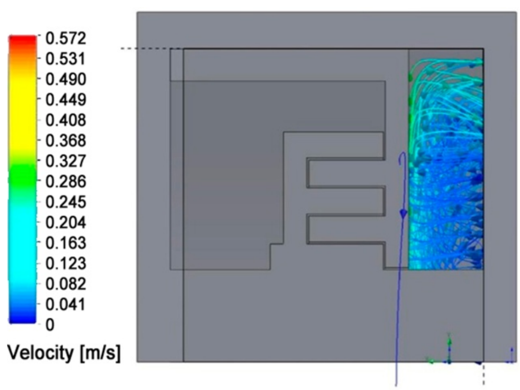

Fig. 5. Lines of airflow from the outside of the labyrinth seal

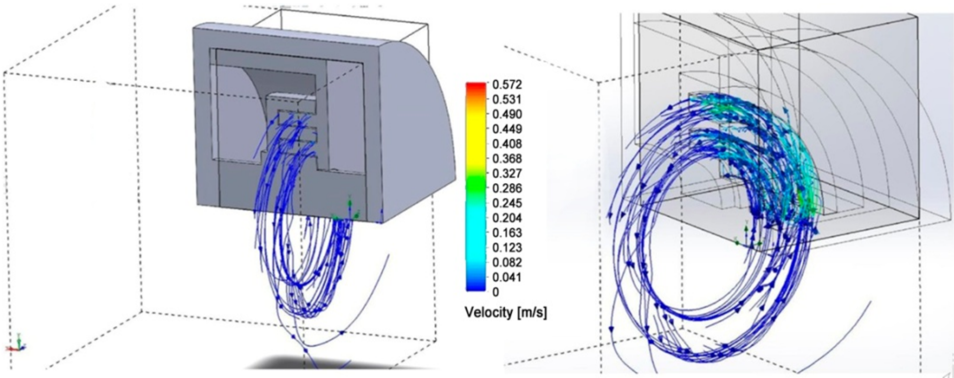

Fig. 6. Lines of airflow in the gap of the labyrinth seal

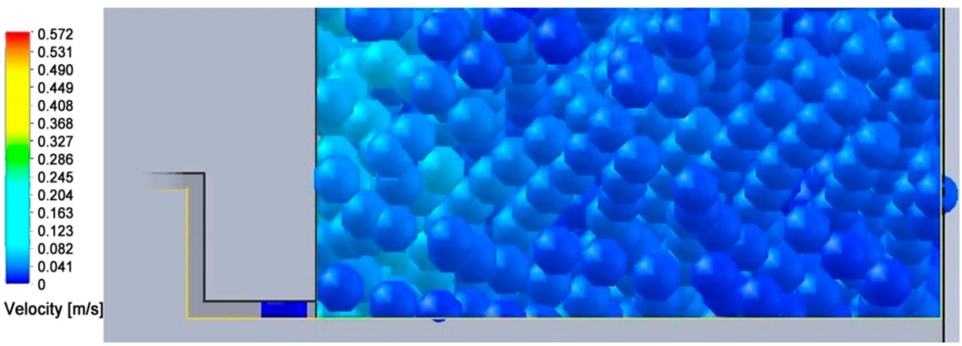

Fig. 7. Simulation of particles falling into the labyrinth seal

labyrinth seal was predicted. The approximate volume of gap in the labyrinth seal was 132 mm^3. We assumed that the seal would fail when the entire gap was filled with dust (132287 particles). Thus, the amount of such particles should be 5291502 or 37.7 g in the atmosphere near the roller, and 9432 m^3 of air should pass through the roller (with a maximum permissible dust concentration of 4 mg/m^3). We took into account that the air was approaching the roller at a speed of 0.2 m/s (according to the simulation results). It was found that the seals would be fully filled through 47360 hours = 5.4 years of continuous operation. The estimated life expectancy is approximately the same as the actual data, which indicates correctness of the hypothesis and effectiveness of the conclusions.

3. Conclusions and recommendations

As it has been shown, clogging of the multistage labyrinth seal does not occur during operation, but during its stopping. The reason of this phenomenon is decompression, which occurs as a result of temperature change and push out of airflows during rotation. Therefore, the number of stops during the operation affects durability of the rollers strongly. To prevent the penetration of abrasive particles during stops, it is necessary to equip the roller with additional seals that improve tightness after the stop, but do not hinder free rotation of the roller. For example, it is suggested to use a contact seal from the felt impregnated with lubricants.

The obtained results are implemented to practice in a production department. An additional long-term experimental industrial research is continued.

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