EXPERIMENTAL STUDYING THE BELT CONVEYOR ROLLER WEAR DEPENDENCE ON THE INTENSITY OF TECHNOLOGICAL DUST ACCUMULATION IN OPEN PIT MINING

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Resume

The paper presents the research on revealing the causes of belt conveyors downtime at open-pit mining operations. By results of researches it is established that the reasons of the above mentioned problems are technological dust formed at crushing of mineral ore, further loading and unloading, and also at transporting by conveyors. Dense dust-air mixture settling on the rotating mechanisms of conveyors, gets into the bearing units and on the surfaces of friction gears, which accelerates the process of wear of parts several times.

The problem of determining the dependence of the wear of the working surface of roller bearings on the intensity of accumulation of process dust deposited on the parts and units of conveying machines has been set and solved.

The analysis has shown that one of the methods of protection of parts of conveyor equipment as a whole is removal of aggressive medium.

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1 Introduction

At present, not a single industrial enterprise can do without transport continuous machines, since this type of transport is easy to manufacture and efficient in transportation due to the low cost of moving goods. With proper operation of these devices, uninterrupted operation of production is ensured. In this regard, the most common type of conveyors is the belt conveyor, without which no industrial enterprise can do, and which, due to its simplicity of design, is the most popular and cost-effective at the present time [1].

The performance of belt conveyors depends on their reliable and trouble-free operation. The breakdown of belt conveyors is being caused by the breakdown of their elements due to increased wear and tear [2]. Prediction of occurrence of wear of elements with the help of models received by analysis of the data received in production conditions, will allow solving the problem of increasing the time of trouble-free operation of a belt conveyor [3].

One of the important elements which deterioration can strongly affect the operation of the belt conveyor is a roller support. A number of works [4-7] are dealing with the problems of roller conveyor wear. In these works the reasons of wear are analyzed, methods of diagnostics and modeling are presented. The review of the sources shows that the main reasons of roller failure are the bearing unit failure, wear of rollers surface as a result of action of abrasive particles of a settled dust. At the same time, in the absence of modern diagnostic tools at the enterprise an important source of information for studying the reasons for the conveyor elements failure could be the aggregate logs which with the use of corresponding methods of the analysis allow obtaining sufficiently acceptable scientific results.

2 Relevance

For the Republic of Kazakhstan, the most promising trend in open pit mining is the development and

Figure 1 *Cyclic-flow transport of the crushing and screening complex of the «BAST» mining and processing plant [9]*

widespread introduction of conveyor transport. The preliminary analysis in the Republic of Kazakhstan and abroad shows the almost complete absence of effective designs of apron conveyors. In this regard, issues of developing innovative designs of apron conveyors require a comprehensive study and providing scientific foundations in this area [8].

The conveyor pan line with rollers is an important part of the belt conveyor, the technical condition of which depends on reliability of the conveyor as a whole.

Reliability of the pan line is determined by reliability of the roller bearing rollers, since reliability of the supporting metal structures is an order of magnitude higher.

An important indicator for evaluating reliability of a roller is its service life that depends on the type, parameters of roller supports and operating conditions.

Figure 1 shows images of cyclic-flow transport of the crushing and sorting complex of the mining and processing plant of "BAST" taken during the experiments.

The task of determining the service life of the belt conveyor rollers was dealt with by L. G. Shakhmeister, V. G. Dmitriyev, V. F. Monastyrsky [10-11]. Their works show that the main cause of failure of the rollers is the bearing assembly failure, the wear of the roller bearing surface as a result of depositing abrasive particles of settled dust on them. The loads on the rollers in the course of transportation of the rock mass are determined, and based on this, formulas are proposed for calculating their service life. At the same time, the loads on the roller working surface arising from large pieces of freight are not taken into account accurately enough.

In works, there are proposed formulas for calculating the average service life of bearings and rollers of a belt conveyor. However, when describing the load on the roller bearing, the authors did not take into account the dynamic forces arising from the movement of the load along the conveyor line and due to the bending of the belt. It is shown in work [12] that with the belt speeds of more than 2 m/s, these forces are significant.

The analysis of the conveyor belt failures shows that the main reasons for the roller failure are surface wear due to abrasive wear and fatigue failure of bearing elements under the impact of dynamic loads. Consequently, the service life of one roller depends on the degree of wear of the roller shell and the service life of the bearings.

3 Statement of the problem

The purpose of this work is to determine the roller bearing wear dependence on the intensity of technological dust accumulation deposited on the surface of rotating mechanisms and belt conveyor units.

The tasks of the study are to determine empirical dependences of:

1) the roller shell wear in time;
2) dust accumulation in time;
3) the roller bearing wear dependence on the intensity of dust accumulation.

4 Technology of the freight movement at the enterprise

Figure 2 shows the transport and technological diagram of ore at the Maksut mining and processing plant. The ore mining technology begins with the geological and surveying department (position 1) that is engaged in the exploration of mineral deposits, studying ore blocks and their content. This service also gives the development trend.

Drilling and blasting, mining and transportation of ore is provided by the Interrin Research and Production Enterprise (position 2). This organization performs "overburden" of waste rock located above the ore blocks

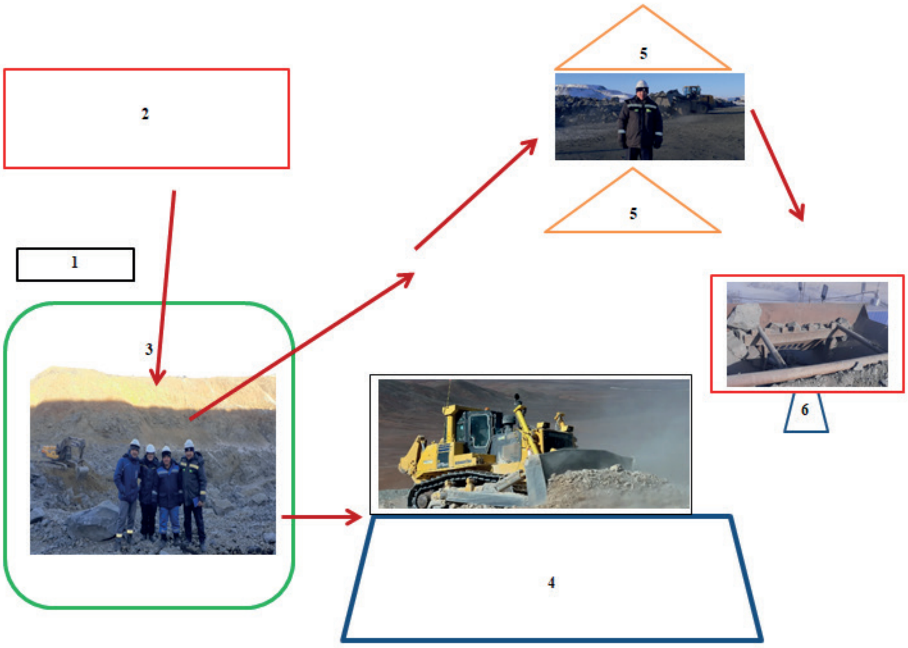

Figure 2 *Transportation-technological scheme ore transportation at Maksut mine [9]*
1 - geological and mine surveying department, 2 - dislocation of the Interrin Research and Production Enterprise, 3 - quarry, 4 - ore warehouse, 5 - rock dump, 6 - receiving hopper of the jaw crusher feeder

Figure 3 *Receiving hopper of the coarse lump crusher of the Maksut mine (position 6 of Figure 2) [9]*

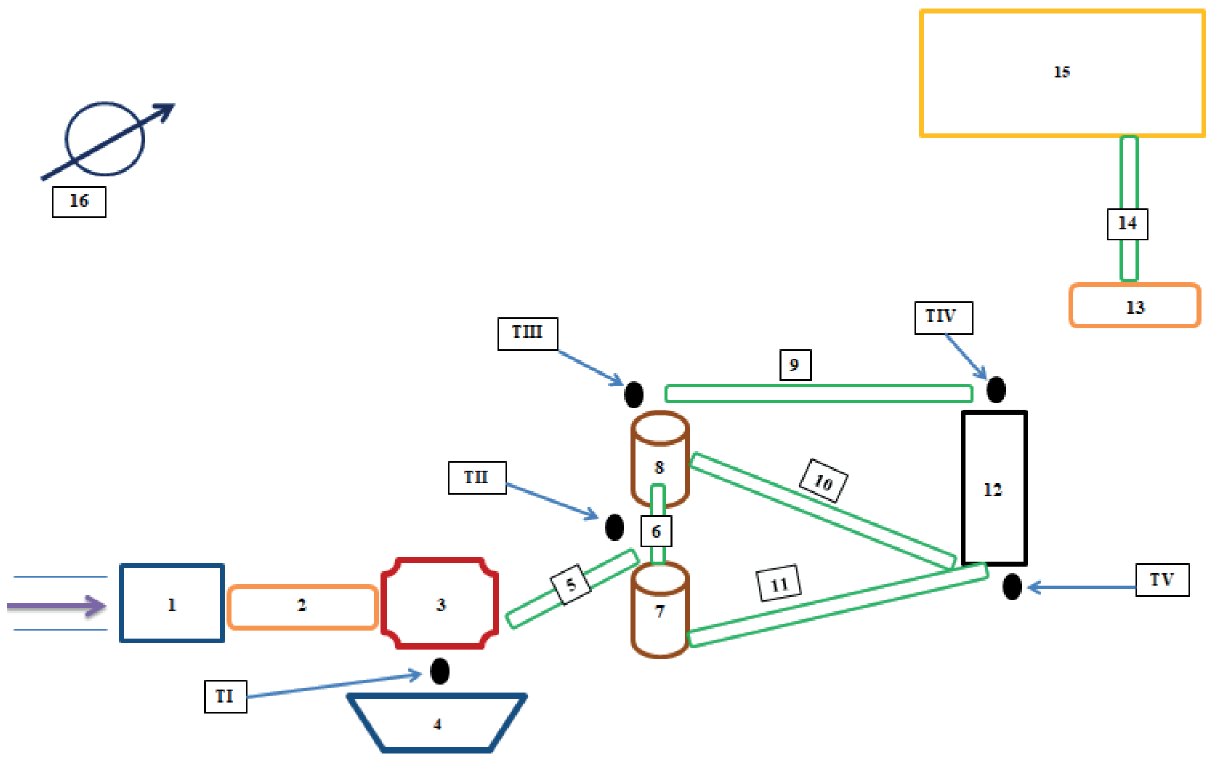

Figure 4 *A diagram of locating the equipment of the crushing and screening complex*
1-feeder hopper, 2-feeder, 3-jaw crusher, 4-crushing room operator, 5-conveyor No.1, 6-conveyor No.2, 7-cone of secondary crushing, 8-cone of secondary crushing, 9-conveyor No.3, 10-conveyor No.4, 11-conveyor No.5, 12-grinder, 13-feeder of conveyor No.6, 14-conveyor No.6, 15-building of concentrator, 16-south-east wind direction; TI- the place of dust sampling and thickness measurement, is located at the height of 5 meters from the zero mark; TII-place of sampling and measurement of dust thickness growth, located at the height of 3 meters from the zero mark; TIII-place of sampling and measurement of dust thickness growth, located at the height of 0 meters from the zero mark; TIV-place of sampling and measurement of dust thickness growth located at the height of 5 meters from the zero mark; TV-place of sampling and measurement of dust thickness growth, located at the height of 0 meters from the zero mark

in the quarry (position 3) and takes it to the rock dump (position 4) intended for storage of waste rock. After the ore blocks are cleared of waste rock, wells are drilled with a certain grid, then there follow blasting and direct ore mining.

Loading is carried out by excavators onto dump trucks with the carrying capacity of 20-50 tons that deliver the ore to the ore warehouse (position 5). It is a ramp for storing marketable ore. The volume of ore storage in the ore warehouse is 2500-3000 tons, which is enough to provide the crushing and screening complex for 10-12 days.

At the ore stockpile there is a receiving hopper (Figure 6), which is the beginning of the mineral ore crushing process. In front of the hopper there is an open area (ramp) for maneuvering a front-end loader, which delivers ore from the ore stockpile and doses ore to the receiving hopper.

Figure 3 shows the receiving hopper of the lump crusher located in the ore stockpile (position 6 of Figure 2), which is the beginning of the mineral ore crushing process. In front of the hopper there is an open area (ramp) for maneuvering the front-end loader, which delivers ore from the ore stockpile and doses ore to the receiving hopper.

The receiving hopper has sorting grates that prevent the ingress of oversized pieces with the length of more than 500 mm.

Figure 4 shows a diagram of the equipment of the crushing and screening complex.

Under the receiving hopper there is a feeder. It is a plate conveyor that doses ore into the jaw crusher by changing the speed of the load-carrying belt. Then, from the jaw crusher, the crushed ore with the fraction of 40-80 mm enters conveyor belt No. 1 and is fed through it to the loading cone of medium crushing at the level of 4500 mm. From this equipment, the crushed ore enters the grate with the cells of 30 mm, from where it enters conveyor No. 5 located below. Larger ore that has not passed through the grates enters along an inclined plate to conveyor No. 2.

On conveyor No. 5, the crushed ore enters the vibrating screen that has a sieve on the upper tier with the cells of 40 mm and 20 mm on the lower tier of screening.

From unloading conveyor No. 2, ore with the fraction of more than 30 mm is fed to the fine crushing cone at the level of 4500 mm. The slots of this cone are 15 mm

***Table 1** Downtime of conveyors Nos. 1 to 6 due to failures and repairs*

No.	Date	Unit and defect characteristics	Amount of work done to eliminate the defects	Real service life of the unit, part	Rquipment downtime, hour
1	13/03/2019	Cut on the belt	Patching - 1.5 m	3 months	5
2	23/03/2019	Wear of supporting and bearing rollers	Replacing rollers 3 pcs.	3 months	1.5
...	...	...	...	...	...
325	18/08/2021	Wear of the vertical roller	Replacing the vertical roller 2 pcs.	1 month	1

***Figure 5** Measuring technological dust in the CSC section*

but despite this, larger ore passes through these slots and therefore, it is transported on conveyor No. 3 to the vibrating screen for further screening.

The ore passed through the lower sieve of the screen enters the feeder of conveyor No. 6, through which it enters the factory for further grinding and dressing.

In the process of crushing, the ore splits at the boundaries of the mineralization of the ore body that mixing with air, rises up forming a thick captivity, eventually settling on the rotating mechanisms and equipment of the crushing and screening complex.

5 Research part

Based on the results of studying the operation of cyclic-flow transport at the Maksut mining and processing plant of the BAST JSC in the East Kazakhstan region (hereinafter referred to as GOK) carried out from September 2020 to September 2021, significant downtime of the crushing and screening complex (hereinafter CSC) was revealed due to premature wear of components and parts of conveyor equipment, which naturally led to non-fulfillment of the enterprise plan and losses. To determine the reasons for downtime of the CSC equipment, studies were carried out on the aggregate logs of six conveyors, a feeder with a jaw crusher, cones of fine and medium crushing, as well as oil stations providing a lubrication system for the mechanisms of all the CSC equipment. The results for the last 3 years are shown in Table 1.

The analysis of the aggregate logs showed that significant downtime of the CSC equipment was caused by the failure of the roller bearings of the conveyors and their replacement. The main reason for the roller bearings failure is the working surface wear due to the abrasive action of technological dust. The main measure for dust protection of equipment is irrigation of crushed material during transportation. Sticking to the conveyor belt, it enhances the abrasive effect on the roller support shell, and getting into the bearing units in the form of a liquid suspension, destroys the roller bearings. One of the measures to protect mechanisms against the aggressive impact of dust was dust cleaning, which was carried out every four days with the complete stop of the equipment.

Figure 4 shows that to study the effect of process dust on the roller bearings of the conveyors, the places

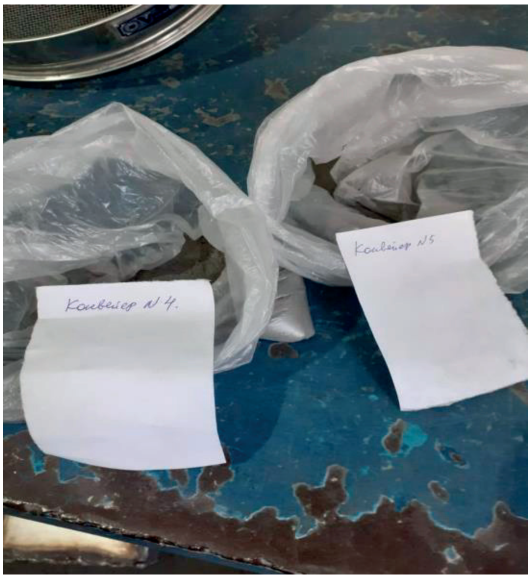

Figure 6 *Samples of technological dust from the CSC*

Figure 7 *Calibrated sieves from the Kraft Company*

Figure 8 *Blue paint marks on the conveyor rollers*

for sampling and measuring the settling dust at the CSC section marked with points T1 to T5 were installed. For the above period, every shift (the shift duration is 11 hours) measurements of dust accumulation were carried out in the most dusty areas of the CSC (Figure 5).

Measurements of settled dust were made using a measuring ruler, the measurement results were noted in the "Register of Research and Experiments" during the inter-shift shutdown of the equipment. In the most dusty areas of the CSC in Figure 4 marked with points T1 to T5, technological dust was sampled and placed in plastic bags indicating the time, date and place of sampling (Figure 6).

Then, in the research and analytical laboratory of the Mining and Processing Plant, there was determined the size of the abrasive dust particles using special calibrated sieves with the mesh range of 0.1 mm to 3 mm.

The dust settled on the conveyor structure was sieved on special calibrated sieves of "KRAFT" company, which are shown in Figure 7.

According to results of sieving it has been defined that 30% of dust consists of particles with grain size 3 mm, 25% - 2 mm, 20% - 1 mm, 25% - smaller than 0.1 mm. These samples were tested for polymetals content: Cu, Fe, Mg, Au, Ag, etc.

6 Experimental part

For the purpose of the experiment, the newly mounted rollers on the conveyor pan line were previously marked with blue paint, as shown in Figure 8.

Figure 9 *Measuring the roller shell wear*

Table 2 *Results of the study of roller wear dependence by day in heavy dusty conditions for seventeen weeks*

Operating time, 24 hours	Operating time of the roller bearings, hours	Dust accumulation thickness, mm	Roller bearing shell wear, mm
1	22	28	0
2	44	42	0.01
3	66	57	0.015
4	88	78	0.02
5	110	85	0.03
6	132	104	0.04
7*	154	118	0.04
8	176	0	0.04
…	…	…	…
119*	2618	121	3.95
120	2640	0	3.98
121	2662	45	4**

*- days when conveyor equipment is shut down and cleaned of process dust

**- values for wear of the shell requiring replacement of the roller bearing

Table 3 *Dependence of roller wear on dust thickness during operation*

Operating time, week (blue marker) - weeks	Number of operating hours of support rollers, (orange marker) - hour	Roller shell wear value, micrometers, (µm) (grey marker) - micrometers, (µm)
1	154	200
2	308	340
3	462	490
...	...	...
15	2156	3320
16	2331	3680
17	2464	3960

On the newly mounted roller bearings with the diameter of 108 mm, measurements of the working surface of the shell wear were carried out every shift using a ShTs-1 caliper, which are shown in Figure 9.

The readings of the instrument were recorded every shift in the Register of Research studies and experiments indicating the date and time of measurements, the wear magnitude of the working surface of the roller bearings, the condition of the rolling bearings on the roller rotation shaft.

Studying and measuring the roller wear, accumulated dust thickness and the abrasiveness of the process dust particles were carried out daily during the planned shutdown of the conveyors within seventeen weeks. The values of the survey results are shown in the Table 2 below.

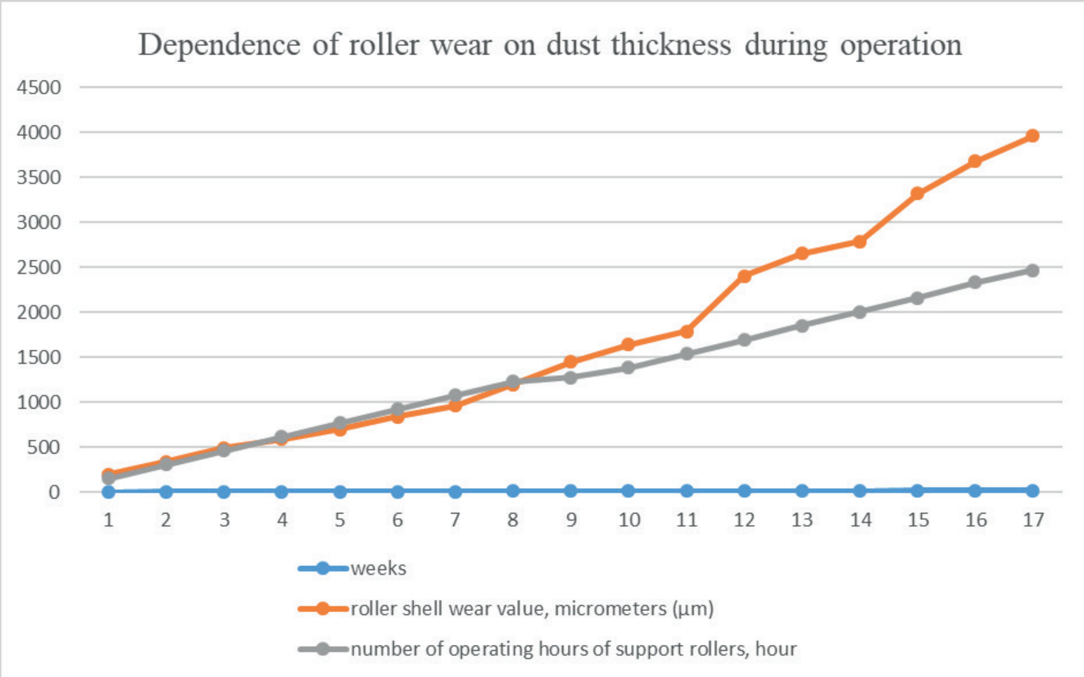

Figure 10 *Dependence of roller wear on dust thickness during operation*

Table 4 *Average values of accumulated dust layer thickness*

Day of the week after the next dust removal	The complex operating time, hours	The accumulated dust layer thickness, mm
1	22	28
2	44	42
3	66	57
4	88	78
5	110	85
6	132	104
7	154	118

According to the values in Table 3, the diagram shown in Figure 10 is constructed.

According to the data shown in Table 2, it is clear that the actual average workload of the studied rollers is 2600-2700 hours, although according to the established state standard 57841-2017 "Mine belt conveyors. Rollers" roller conveyors of the considered type (108 millimeters in diameter) with a belt speed of 2 meters per second, must work at least 8000 hours of machine time.

7 Processing the experimental results

Based on the results of shift monitoring within the period from September 2020 to September 2021, the average values of dust accumulation and roller wear were determined. They are shown in Table 2 for each conveyor.

During the operation of the crushing and screening plant conveyors, dust accumulates and is removed at intervals of once every seven days.

Based on the results of the observations, the average values of dust layer thickness by days of the week, for a period of 121 days are established.

Observations of weekly dust accumulation are shown in Table 4.

It was mentioned above that the dust collection was carried out every seven days, so the number of measurements of dust accumulation and wear of roller shells is seven.

Let us determine the empirical dependence of dust accumulation on time. The empirical dependence is defined as an exponential dependence [13]:

$$y = a \cdot e^{b \cdot x}, \quad (1)$$

where:

x is the value of the argument (time);

y is the function value (the thickness of the layer of accumulated dust).

Numerical values of a and b are determined from the results of observations, which are shown in Table 3

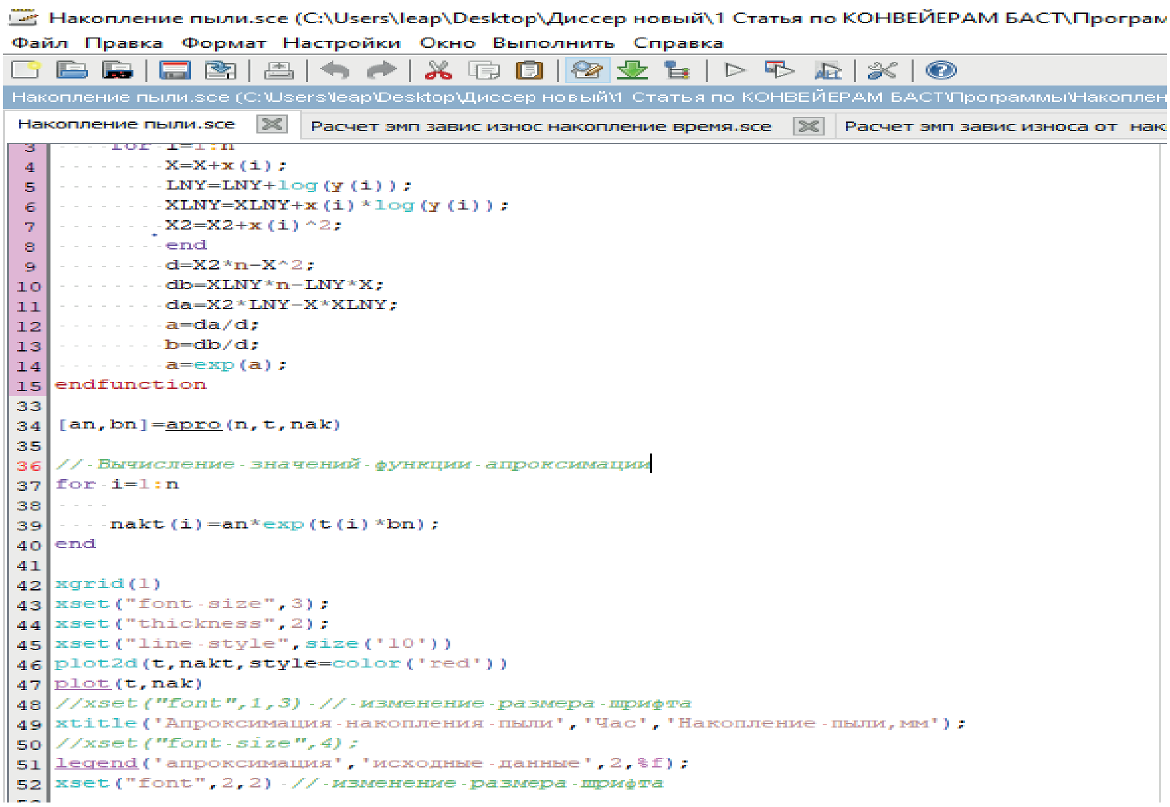

Figure 11 *Screenshot of the Scilab program environment*

Table 5 *Average values of dust thicknesses affecting the rollers and the wear rate of the rollers under the influence of the dust by day of the week*

Measurement No.	Dust accumulation, mm	Wear of the roller shell, mm
1	29.235	0.0265
2	44.35	0.0224
3	61.59	0.0211
4	73.88	0.0259
5	89.76	0.033
6	106.59	0.039
7	122.59	0.039

by the method of least squares, for which the program code in Scilab environment was developed [13]. In Table 3 average values of dust thicknesses acting on the rollers and wear rate of the rollers under the influence of the dust are shown. Observations and measurements were carried out over a period of seventeen weeks. At the end of each week all parts of each conveyor were cleaned along the entire conveyor line.

To calculate the parameters a and b of the empirical dependence (1), a programme code has been developed in the Scilab environment [14], a screenshot of the programme page is shown in Figure 11:

The first column of the Table 5 shows the days of the week, the second and third columns show the average values of the wear intensity of the rollers and the thickness of the process dust.

As a result of the calculations, an empirical time dependence of the thickness of process dust accumulation is obtained $\boldsymbol{n_d}$, which has the form:

$$n_d = 25.75 \cdot e^{0.02096 \cdot t}, \quad (2)$$

where: $\boldsymbol{t}$ is the observation time, hour.

Graphical representation of the observation results and graph of the empirical relationship are shown in Figure 12.

The obtained empirical dependence of the working surface of roller bearing wear on time has the form:

$$\boldsymbol{Z_t = 0.705\, e^{0.0353 \cdot t}}, \quad (3)$$

where: $\boldsymbol{Z_t}$ is the roller working surface wear;
$\boldsymbol{t}$ is the time of observation.

A graphical representation of the results of

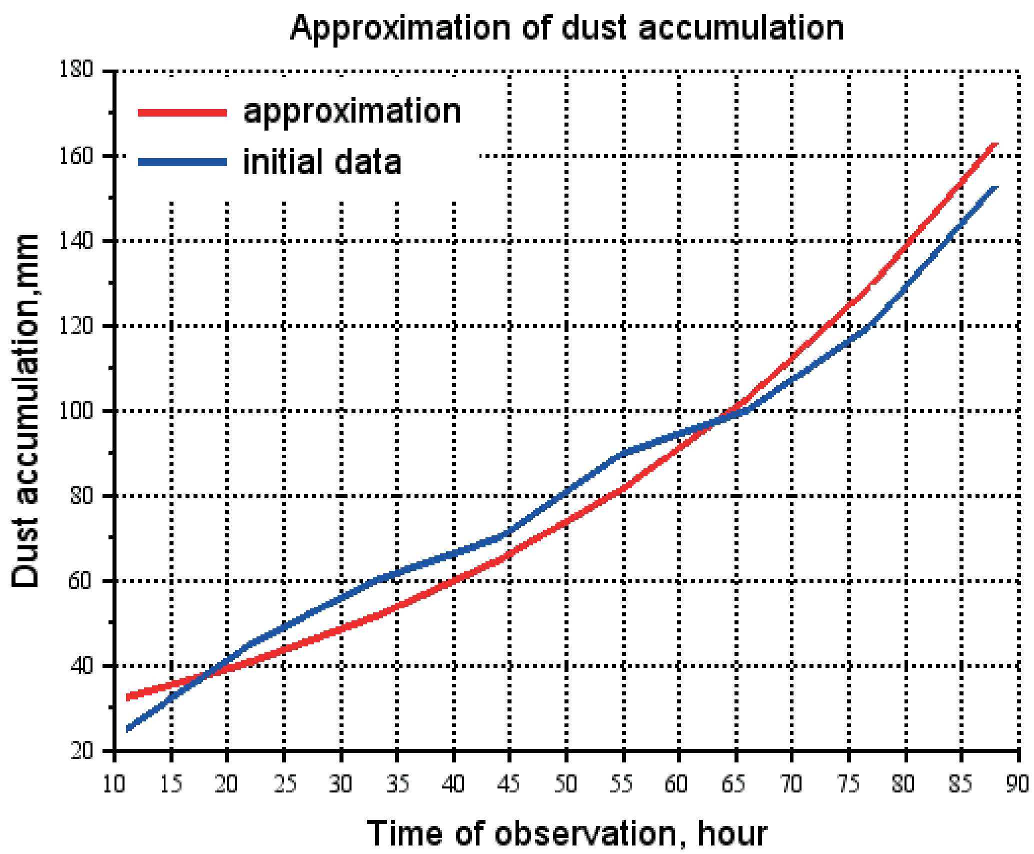

Figure 12 *The dust accumulation empirical dependence on time*

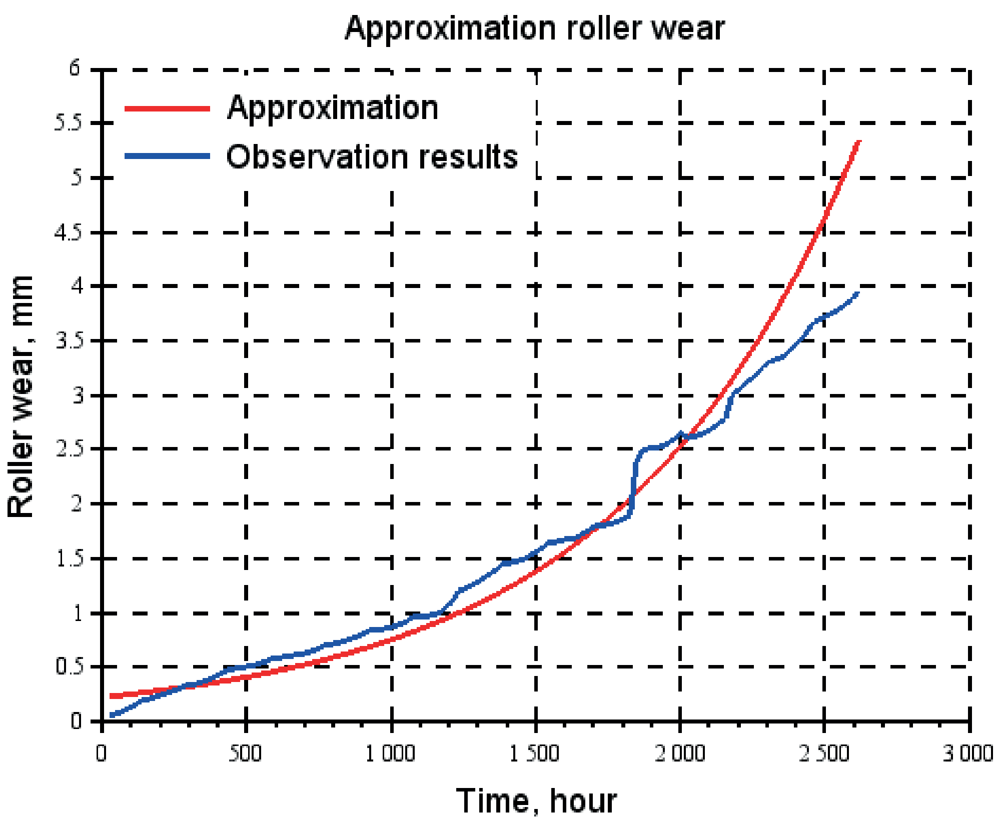

Figure 13 *The roller working surface wear dependence on time*

observations and a graph of the empirical dependence are presented in Figure 13.

The empirical dependence of the wear of the working surface of roller bearings on the intensity of accumulation of process dust, based on the type of the graph of observation data, we determine by the parabolic dependence of the form *y=ax2+bx+c*. The specific form of the parabolic empirical dependence, the coefficients of which are determined by the least squares method, is represented by the following formula:

$$z = 0.03119n_p^2 - 0.40670n_p + 3.52417 \cdot 10^{-5}, \qquad (4)$$

where: z - is the roller working surface wear, [m];
n_p - is the thickness of the accumulated technological dust layer, [mm].

A graphic representation of the results of observations and a graph of the empirical dependence of the working surface of the roller bearing wear on the intensity of the accumulation of process dust are shown in Figure 14.

8 Conclusion

Based on the results of experimental studies carried out from September 2020 to September 2021 on six MMP CSC conveyors transporting crushed ore, it was found that the rotation units and working surfaces of the roller bearings were the most vulnerable for wear. To identify a causal relationship, technical and operational documentation was studied (aggregate logs of each conveyor for the last 3 years, complaints issued to manufacturers and their representative offices in our country, manufacturer's operating manuals, reference books and other technical literature), according to the results which it was found that 40 percent of the parts and assemblies of conveyors served out the service life set by the manufacturer by 60 percent, and 30 percent of the equipment work out only for a third of the machine hours.

In the course of shift monitoring the equipment with the use of instrumentation and tools, it was found that the cause of the above problems was technological dust generated during crushing the mineral ore, loading and unloading, as well as further transportation by conveyors. A thick dust-air mixture that settles on the rotating mechanisms of conveyors reaches the bearing units and the surfaces of friction gears, which accelerates several times the process of parts wear.

The set objectives of the study have been fulfilled:

1. The dependence of dust accumulation on time is described by the empirical Equation (2).
2. Dependence of wear of the working surface of the roller bearing on time is described by the empirical Equation (3).

Dependence of wear of the working surface of the roller bearing on the intensity of accumulation

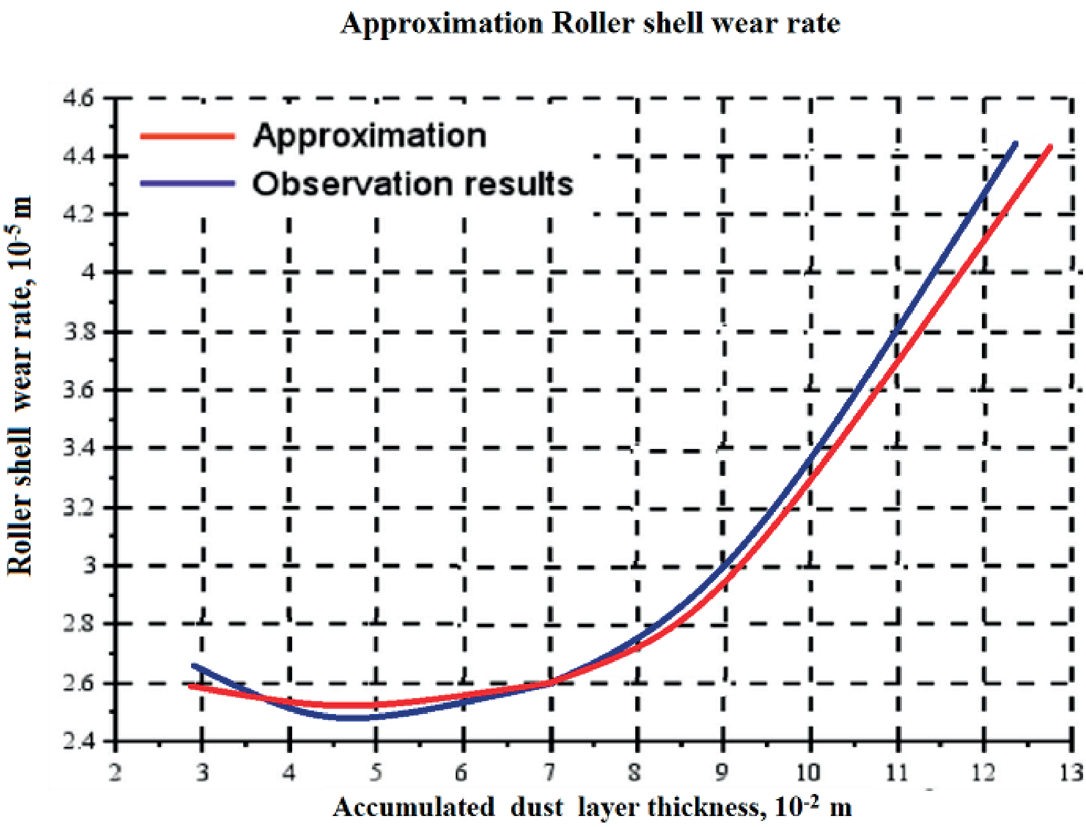

Figure 14 *The roller working surface wear empirical dependence on the intensity of the technological dust accumulation*

of process dust is described by the empirical Equation (4).

The analysis of the empirical dependences of roller bearing shell wear on dust accumulation shows that in order to achieve stable operation of cyclic-flow transport in severe conditions, it is necessary to protect the most vulnerable components and parts of the conveyor against the impact of the abrasive and aggressive environment. One of the general methods of protecting conveyor equipment is the aggressive environment removal with the further use of mineral dust as a dressed polymetal concentrate.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] YARDLEY, E. D., STACE, L. R. History and economics of conveyor applications [online]. Chapt. 2. In: *Belt Conveying of Minerals*. Woodhead Publishing Series in Metals and Surface Engineering, 2008. ISBN 978-1-84569-230-8. p. 4-16. Available from: https://doi.org/10.1533/9781845694302.4

[2] HOMISIN, J., GREGA, R., KASSAY, P., FEDORKO, G., MOLNAR, V. Removal of systematic failure of belt conveyor drive by reducing vibrations. *Engineering Failure Analysis* [online]. 2019, **99**, p. 192-202. ISSN 1350-6307, eISSN 1873-1961. Available from: https://doi.org/10.1016/j.engfailanal.2019.02.028

[3] DABEK, P., KROT, P., WODECKI, J., ZIMROZ, P., SZREK, J., ZIMROZ, R. Measurement of idlers rotation speed in belt conveyors based on image data analysis for diagnostic purposes. *Measurement* [online]. 2022, **202**, 111869. ISSN 0263-2241, eISSN 1873-412X. Available from: https://doi.org/10.1016/j.measurement.2022.111869

[4] FISET, M., DUSSAULT, D. Laboratory simulation of the wear process of belt conveyor rollers. *Wear* [online]. 1993, **162-164**(B), p. 1012-1015. ISSN 0043-1648, eISSN 1873-2577. Available from: https://doi.org/10.1016/0043-1648(93)90113-Z

[5] RAVIKUMAR, S., KANAGASABAPATHY, H. MURALIDHARAN, V. Fault diagnosis of self-aligning troughing rollers in belt conveyor system using k-star algorithm. *Measurement* [online]. 2018, **133**, p. 341-349. ISSN 0263-2241, eISSN 1873-412X. Available from: https://doi.org/10.1016/j.measurement.2018.10.001

[6] ZHAO, L. Typical failure analysis and processing of belt conveyor. *Procedia Engineering* [online]. 2011, **26**, p. 942-946. ISSN 1877-7058. Available from: https://doi.org/10.1016/j.proeng.2011.11.2260

[7] YANG, M., ZHOU, W., SONG, T. Audio-based fault diagnosis for belt conveyor rollers. *Neurocomputing* [online]. 2020, **397**, p. 447-456. ISSN 0925-2312, eISSN 1872-8286. Available from: https://doi.org/10.1016/j.neucom.2019.09.109

[8] GALKIN, V. I. *Modern theory of belt conveyors of mining* enterprises. Moscow: Izvo MGGU, 2005. ISBN 978-5-98672-209-2.

[9] Photos and diagrams created during experiments at the Maksut mine of the BAST joint stock company.

[10] SHAKHMEISTER, L. G., DMITRIEV V.G. *Probabilistic methods of calculation of transporting machines*. Moscow: Mashinostroenie, 1983.

[11] MONASTYRSKY, V. F. *Bulk and roller supports dynamic efforts interactions obtaining for mine belt conveyer*. Kiev: Geo-Technical Mechanics, 2012.

[12] RUUD, P. A. *An introduction to classical econometric theory*. New York: Oxford University Press, 2000. ISBN 9780195111644.

[13] NAGAR, S. Introduction to Scilab: for engineers and scientists [online]. 2017. Available from: https://doi.org/10.1007/978-1-4842-3192-0

[14] ALEKSEEV, E. R., CHESNOKOVA, O. V., RUDCHENKO, E. A. *Scilab. Solution of engineering and mathematical problems*. Moscow: ALT Linux; BINOM. Laboratory of Knowledge, 2008.