

Identification of mine rescue equipment reduction gears technical condition

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Abstract. The article presents the reasons for adopting intelligent service of mine belt conveyer drives concerning evaluation of their technical condition based on the diagnostic techniques instead of regular preventative maintenance. The article reveals the diagnostic results of belt conveyer drive reduction gears condition taking into account the parameters of lubricating oil, vibration and temperature. Usage of a complex approach to evaluate technical conditions allows reliability of the forecast to be improved, which makes it possible not only to prevent accidental breakdowns and eliminate unscheduled downtime, but also to bring sufficient economic benefits through reduction of the term and scope of work during overhauls.

1. Introduction

Tough working conditions of mining machines and high level of dynamic load lead to decrease in equipment service life. Quantitative estimation of equipment reliability concerning one of the parameters (resource) has become widely spread in all industries. Technical diagnosis is one of the most important methods of reliability enhancement in the operation conditions. The aims of the technical diagnosis are the following [1 - 3]:

- technical condition control (whether the parameters of the equipment comply with the technical documentation objectives) and determination on the basis of this data of the technical condition type at the given moment;
- determination of the place and cause of equipment failure (malfunction);
- forecast of technical condition.
- According to NPAOP-10.0-3.01-90 "Safe Operation of Face Machines, Complexes and Aggregates Standards" the following requirements to the technical diagnosis are determined:
- mining machines and equipment have to comprise diagnostic software subsystem which will implement safe control over technical condition via parameters indication and measuring on machines, automatic mechanisms, electrical, hydraulic and pneumatic systems, lubrication systems and also bearing assemblies;
- the diagnostic software subsystem, as a rule, should consist of the following: non-destructive control of the units technical condition, determination of sudden and parametric failures of mining machines and their systems, detection of gradual failures by means of forecasting of monitored parameters changes, continuous and periodic technical condition monitoring.



- All parts of the mining machines and equipment, depending on service conditions and type of wearing-out process, can be divided into the following groups:
- digger teeth and cutting edges of excavator buckets; prop bases, cribs, conveyer worms, coal cutter bars, bulldozer blades; tracks, apron rolls, pins, bushings, driving gears track sprockets of crawler track machines, etc. Service life of these parts depends on the abrasive wear;
- the second group includes parts with screws and grooves, tooth couplings, rolling bearing housings on shafts, machines, surfaces of gear drives, etc. Their service life is determined by mechanical wear of the surfaces of these parts;
- the third group consists of the parts of internal combustion engines of dumpers, bulldozers, scrapers, mine diesel locomotives, machines for thermal rock destruction and flame-jet drilling, etc. Their service life is limited by molecular chemical and corrosion mechanical wear;
- the fourth group includes rolling and sleeve-type bearings, shocks, springs, rods, connecting-rod bolts, etc. Their service life depends on metal fatigue limit.

2. Problem description

At present moment there are many belt conveyers working in coal mining companies [4]. The performance of Kuzbass coal mining industry depends on their operational condition. Soon it is expected that there will be an increase in power supply capacity and technical provision of belt conveyers, their performance and the rock mass transportation length. Partial controlled-velocity electric drives are becoming more widely spread in the industry [5, 6].

Increasing coal extraction volume in fully-mechanized working faces and better work environment safety conditions lead to the necessity of reliable transportation systems development. High efficiency and uninterrupted operation as well as decrease in energy consumption comprise the main goal which is set for the producers of mine belt conveyer continuous flow lines. Another but not less important goal is to reduce costs of maintenance and repair [7, 8]. To ensure fault-free performance of belt conveyer as long as possible it is necessary to determine the causes why its different parts fail [3, 9].

Analysis of equipment outages which were due to belt conveyer reduction gear failure reveals that they account for 7.4% - 18.2 % of failures and on average it is 12 %. Besides average time needed for repair is 24 - 48 hours. It is necessary to point out that the most frequent cause of equipment failures is belt break (up to 50 %), and on average it takes 1.5-2 hours to eliminate the failure. Consequently, identification of real technical condition of mine belt conveyers is a present-day objective.

3. Results and discussion

Vibration control method has proven to be a good way to control technical condition of mechanical equipment [3, 8, 10]. Vibration diagnosis is used to control current condition of equipment, identify of possible faults, evaluate residual operation time, determine dates and scope of repair work. Analysis of Russian and foreign experience concerning control over technical condition over systems with rotational movement of power assemblies shows that control over equipment condition concerning vibration parameters is the most efficient one (up to 77 %) in detecting possible faults [11]. Besides, when other functional diagnostics methods such as oil spectrum analysis [12] and heat monitoring [13] are used with this method the accuracy of identification why the fault has appeared increases up to 95%.

Functional diagnosis from the viewpoint of ensuring safe operation of mining machines has to play a key role in R&D areas, production and control over quality of technological equipment (figure 1). And if such forms of technological equipment service which consider real condition of equipment are more and more spread in coal mining and ore mining industries [2, 3], in the sphere of such equipment manufacturing in spite of GOST ISO 9000-2011 standards implementation, new forms of quality control are still not used.

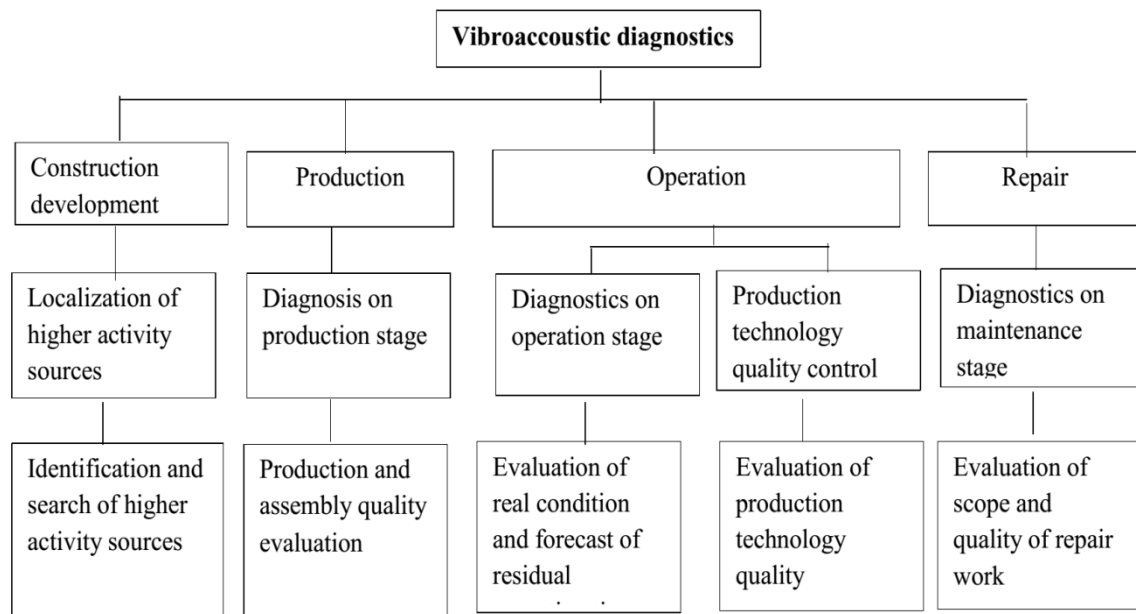


Figure 1. Spheres of using vibration diagnostics on different stages of machine operation life.

The defects which appear at the moment in reduction of gear production can be divided into defects which appear when its parts are manufactured during reduction gear assembly (figure 2) [14, 15].

Full analysis of technical condition of a reduction gear after its assembly and testing on test bed will allow not only manufacturing defects to be identified and localized, but will also eliminate the possibility of low-quality equipment delivery to the customer. Besides, the obtained data can form the basis for further development of automatic quality control systems.

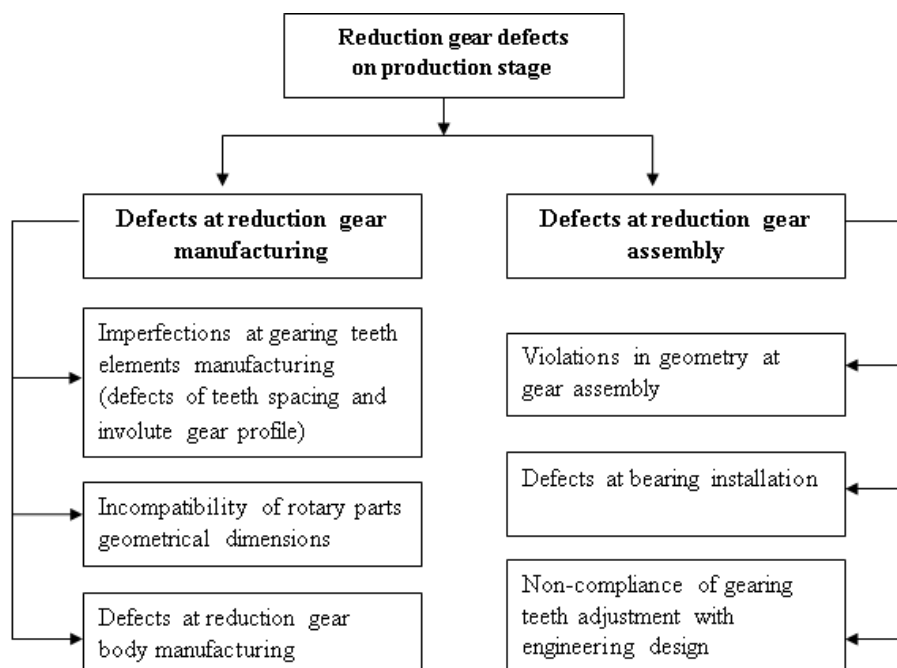


Figure 2. Defects appearing in reduction gears during manufacturing.

Analysis of vibration control methods allows us to make a conclusion that it is reasonable to use the support mask method to automate the control over manufactured products to be used in coal mining industry. This method is based on the assumption that defects which appear as a result of assembly work generate vibration in some set frequency bands with particular correlation between the controlled parameters.

Support mask method allows the width of frequency band, its position and values of assessment criteria, which are compared with current values at random, to be determined. Analyzing the changes of the controlled parameter within the frequency band (number of frequency bands can vary from 6 to 30), one evaluates and forecasts the condition of equipment [16].

Frequency ranges of spectrum mask (band width) usually take the values due to the following conditions [17]:

- “high energy” spectrum component that indicates that there is imbalance or misalignment – $(0.5...1.5) \times f_r$ and $(1.5...2.5) \times f_r$;
- “low energy” spectrum component that indicates that there are defects connected with rolling bearing – $(7.5...15.5) \times f_r$;
- $(2.5...10.5) \times f_r$ — general failure of system rigidity;
- first mid-range frequency band $(3...15) \times f_r$;
- second mid-range frequency band $(15...40) \times f_r$;
- first high-range frequency band $40 \times f_r...20 \text{ kHz}$;
- $(0.1...0.9) \times f_r$ – to detect the defects of an oil wedge of rolling bearings;
- $(n \pm 1) \times f_r$ – to indicate the damage on couplings.

Usage of modern technologies that allow control over equipment technical condition to be automated makes it possible to implement individual approach to each machine produced while evaluating its technical condition and to establish the threshold level for initial, operational and marginal state.

Figure 3a gives an example of vibration signal spectrum in 1 control point in reduction gear RKTS-400 produced by JSC “Anzhermash” (figure 4). Figure 3b presents an example of average spectrum mask. All measurements were made with vibration analyzer “Corvet” and processed using software Safe Plant, developed by scientific development and production center “Diatech”. On the given figure frequency range (2; 3000 Hz) is divided into 27 bands. Each band is numbered according to mean square value of vibration velocity V_{CKZ} , determined at direct and reverse rotation of the output shaft.

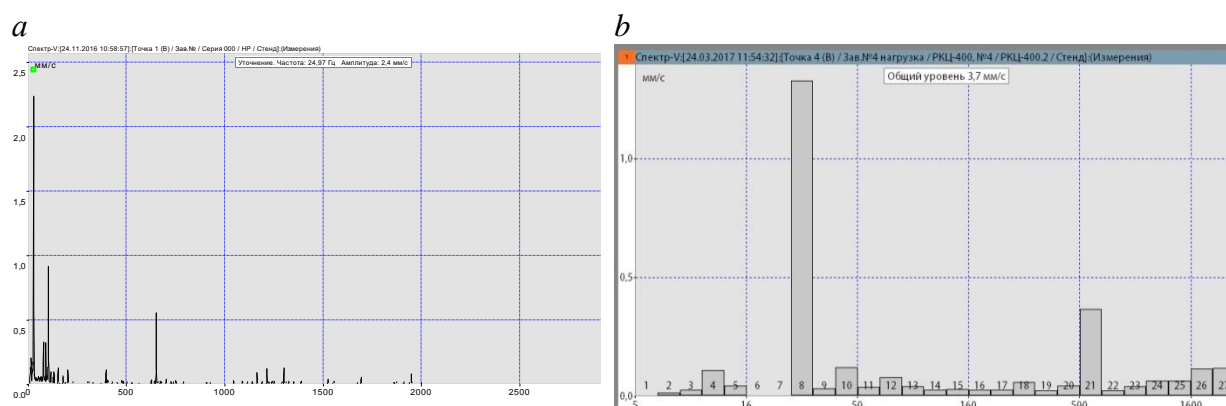


Figure 3. Vibration signal spectrum (a) and average spectrum mask of the vibration signal (b).

Complex approach which presupposes evaluation of technical condition of mine belt conveyor drives 3 LL1600 (transportation length $L=850$ m, technical performance $Q=3500$ ton per hour, belt speed $v=0-4$ m/sec) was implemented on industrial site (Taldinskaya Zapadnaya mine of JSC “SUEK-Kuzbass”) in compliance with parameters determined for lubrication oil, vibration and heat control.

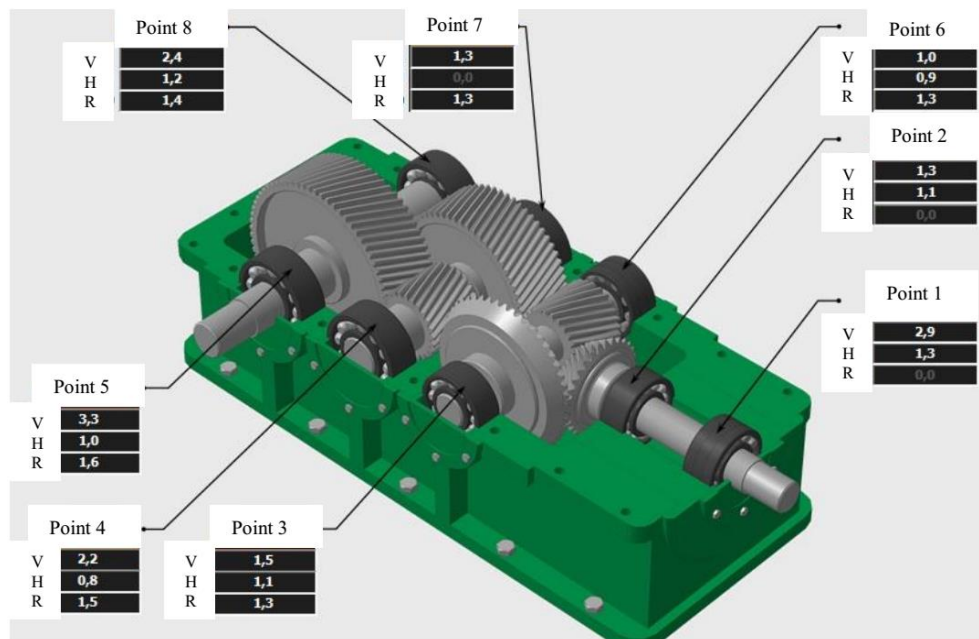


Figure 4. Vibration measurement control points in reduction gear RKTS-400

Figure 5 presents conveyor 3LL1600 design and shows the placement of reduction gears with conventional names P1 – P3.

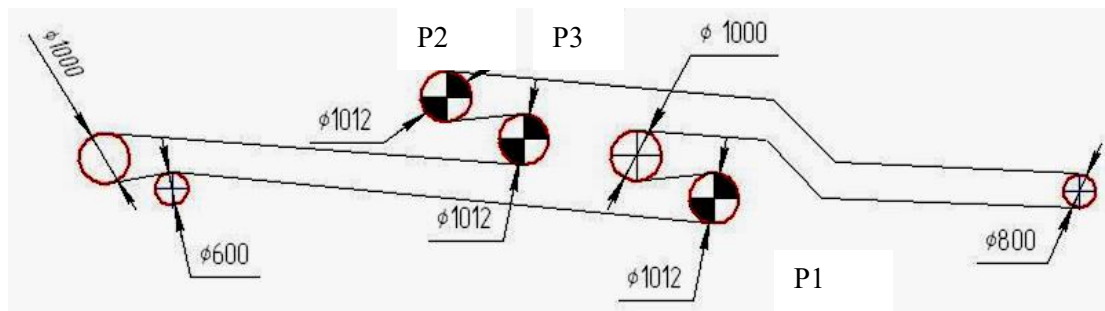


Figure 5. Conveyor 3LL1600 design and drives P1, P2 and P3 placement.

Reduction gears “Moventas Santasalo” (conventional names P1, P2, P3) are used in conveyor drives:

- Cone cylindrical type D3RST82XO (analogue RKTS-400);
- Gear ratio, $i=20,6128$;
- Design mechanical power of the reduction gear at service factor $FS=1$ $P_{m.design}=995$ kW;
- Design thermal power of the reduction gear at service factor $FS=1$ and ambient temperature $t_{amb}=20$ °C $P_{t.nom}=779$ kW;
- Oil temperature limit $t_M=90$ °C;
- Adjusted engine power $P=500$ kW;
- Frequency of high speed shaft rotations $n=1500$, rotations per minute (25 Hz).

After conveyor commissioning vibration parameters were measured for 2 months depending on the load and conveyor belt speed (see figure 6, 7). Information about the load and speed was recorded upon the indications of frequency conversion station CHPSAH displays, which is designed to be used for continuous control of speed and rotation torque on mono- and multirotor belt conveyor drives.

General vibration level was monitored by vibration analyzer “Agat-M” and analyzed using software “Dominant”.

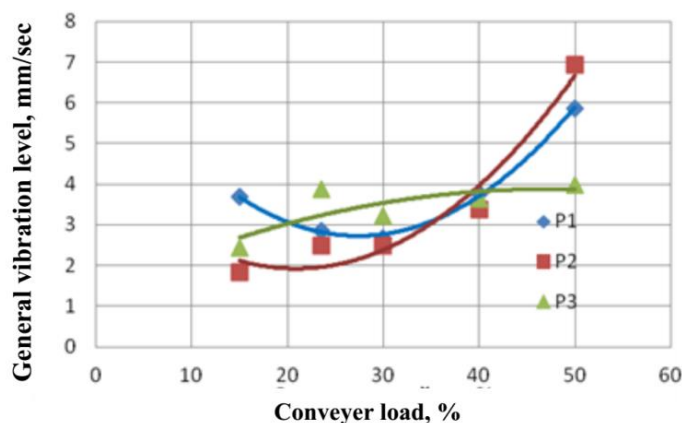


Figure 6. Dependence of general vibration level within the range 100-2000 Hz on conveyor load.

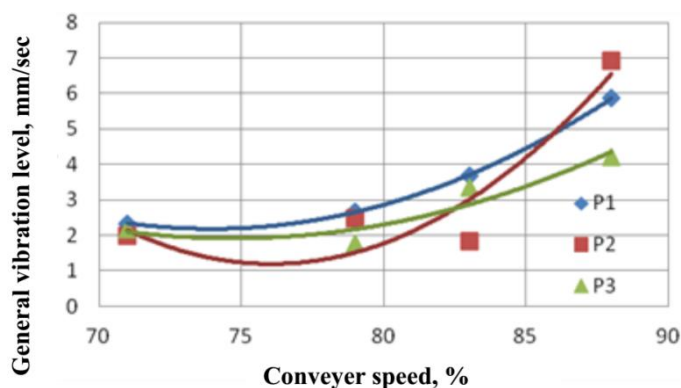


Figure 7. Dependence of general vibration level within the range 100-2000 Hz on conveyor belt speed.

The peculiarity of drives with adjustable rotation speed is dependence of vibration levels on rotation frequency of the driving engine. On debugging stage minimum vibration levels are indicated when load level is 25-30%.

Vibration load analysis was conducted simultaneously with analysis of operating oil parameters depending on the belt conveyor operating time.

Tables 1-3 give examples of wear products accumulation in reduction gears P1 – P3 oil and maximum acceptable values of their content. Their analysis shows that almost in all samples silicon content exceeds maximum acceptable level and indicates that the packings used in the reduction gears are not working well enough.

Table 1. Wear products in oil of reduction gear P1, gram/tonne.

Element	Maximum acceptable value	Sample				
		29.08.14	19.02.15	12.03.15	06.07.15	20.11.15
Fe	200	40.34	160.12	204.8	171.52	326.32
Si	35	37.64	33.88	44.55	39.83	43.29
Cu	150	5.53	0.48	8.96	1.65	2.16
Al	7	1.52	1.54	2.38	2.00	2.09
Cr	5	0.68	1.30	1.07	1.15	1.62
Pb	-	2.55	3.45	4.23	2.48	3.44
Sn	-	5.78	9.34	7.90	6.98	10.52

Table 2. Wear products in oil of reduction gear P2, gram /tonne

Maximum acceptable value	Sample				
	29.08.14	19.02.15	12.03.15	06.07.15	20.11.15
200	26.85	30.5853	32.3602	32.50	55.04
35	33.11	31.0649	37.1218	39.42	39.64
150	7.07	2.8362	2.1811	6.42	14.75
7	1.10	1.2960	1.7622	1.79	1.67
5	0.95	0.5097	0.7743	1.03	1.34
-	2.63	2.5013	2.8376	4.14	2.60
-	7.94	6.0796	7.0574	5.68	7.65

Table 3. Wear products in oil of reduction gear P2, gram /tonne.

Element	Maximum acceptable value	Sample				
		29.08.14	19.02.15	12.03.15	06.07.15	20.11.15
Fe	200	73.17	314.64	384.1	322.45	876.71
Si	35	36.07	34.49	38.66	40.81	40.77
Cu	150	13.67	11.98	15.7125	9.81	30.63
Al	7	1.43	1.76	2.4578	2.50	2.48
Cr	5	0.87	2.54	3.1097	2.19	10.50
Pb	-	1.75	3.69	1.7229	3.46	2.28
Sn	-	6.89	10.99	12.88	13.31	27.97

Summarized data concerning temperature, viscosity and general vibration level is given in table 4.

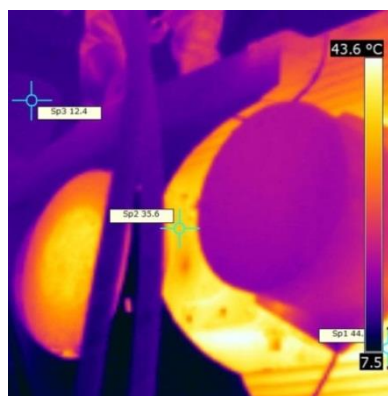
Table 4. Values of temperature, viscosity of oil and general vibration level.

Reduction gear No	Equipment body temperature, °C		Kinematic viscosity, mm ² /s at 40°C, according to GOST 6258-85	Operational viscosity, mm ² /sec at oil maximum temperature T_{max} , °C	General vibration level, mm/sec
	T_{max}	T_{avg}			
P1	47.0	35.6	345	290	5.9
P2	50.7	42.0	353	270	7.2
P3	44.2	37.4	329.7	300	4.2

Analyzing thermoplastic records, taken at operational load (figure 8), one can come to the conclusion that the most sufficient heating takes place in the lower part of the output shaft cover. Besides, temperatures of reduction gears differ. Based on the results of these measurements one can obtain operational viscosity of oil.



(a)



(b)

Figure 8. Thermoplastic records of belt conveyor reduction gears:

(a) reduction gear P2,

(b) reduction gear P3.

Figure 9 presents the dependence of kinematic viscosity change on running time corrected taking body temperature and drive operation time into account.

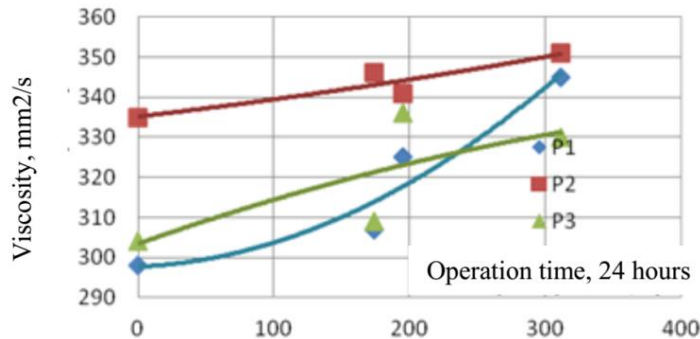


Figure 9. Operational changes in oil kinematic viscosity in relation to drives operation time.

Comparing the results of complex study when technical condition of reduction gears working on mine belt conveyor 3LL1600 were considered one can confirm the following:

- according to the general vibration level, technical condition of drive P1 is considered as satisfactory one [GOST ISO 10816-1-97. Machine state control based on the vibration of non-rotating part measuring. Part 1. General Requirements];
- technical condition of reduction gear P2 is considered as acceptable (according to general vibration level, high temperature of body and low operational viscosity of oil). Rated value of oil viscosity reaches the highest point in reduction gear P2 that indicates that there is evaporation of fractions with low boiling points;
- according to the general vibration level and its spectrum content (figure 10), technical condition of drive P3 is estimated as marginal acceptable. In vibration spectrum one can notice evident wear of high speed shaft bearings elements. This is confirmed by considerable quantity of mechanical impurities.

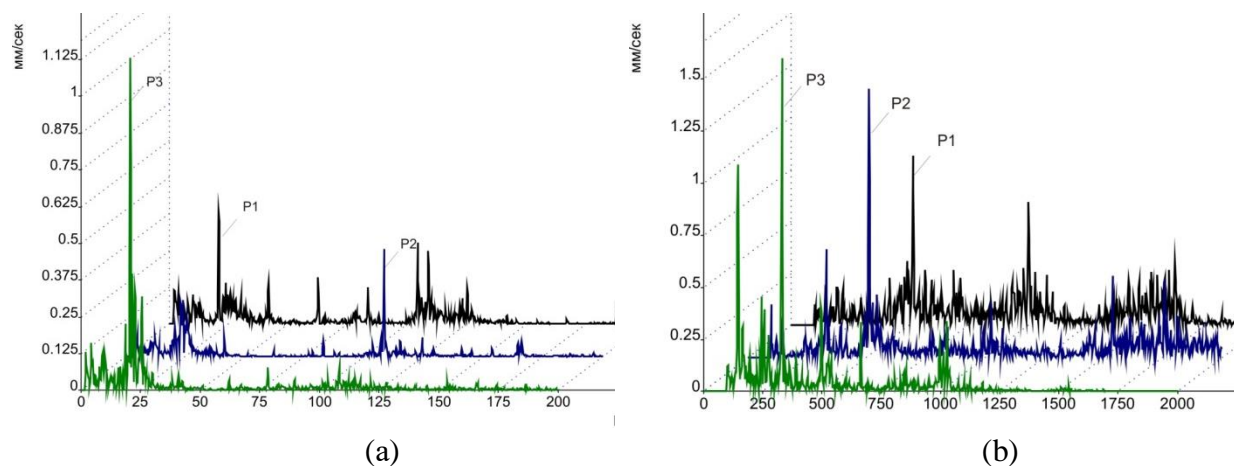


Figure 10. Comparison of vibration spectra in low frequency (2...200 Hz) (a) and medium frequency (200...2000 Hz) (b) ranges.

Reduction gear producer “Moventas Santasalo” recommends to make the first oil change in 800 – 1000 working hours, and then every 10 000 hours of work or once a year. In fact the first oil change did not take place. In 5 000 working hours there was oil refilling. oil condition at present moment is unsatisfactory (apart from reduction gear P2). Chief mechanic department of mine administration has

received the recommendations that oil in reduction gears P1 and P3 has to be changed and high speed shaft bearing should be replaced.

4. Conclusions

The suggested approach to the standardization of parameters of mechanical vibrations can be used in practical work when a company develops standards for vibration of the produced equipment to include in the datasheet.

Development of multiple spectrum masks for wide standard range of mining equipment is one of the conditions of high quality mining equipment production by mining machinery manufacturers. It also makes possible to switch to new ways of mining machines maintenance and repair.

Results of belt conveyer 3LL1600 drives technical condition evaluation (using complex method based on vibration acoustic signals parameters monitoring), analyzing emission spectrum content of bearing oil and heat monitoring of major nodes of rolling bearing allow to trace the changes of reduction gear elements technical condition depending on its load and operating speed. The suggested approach allows not only the accuracy of mining equipment reduction gears technical condition to be determined, but also activity aimed at development of methodological regulatory basis for construction of prediction models to be organized that will help observe changes in technical condition based on sufficient statistic data about the development of some belt conveyer reduction gear defects.

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