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Analysis of mechanical equipment failure at the hard coal mine processing plant

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Abstract

The paper presents an analysis of mechanical equipment failures in the mechanical treatment plant of a hard coal mine using the Pareto-Lorenz diagram. Then, changes were proposed to reduce the failure rate and the possibility of earlier detection of malfunctioning machines.A detailed analysis of the processenrichment of coarse assortments on a grain washer is presented.
One of the quality management tools – the Pareto-Lorenz diagram – was used to analyze the equipment failure rate during the thick product enrichment process.
It is important to assess the mechanical failure of equipment and to show which machines cause the most problems.
The research found the devices most influencing the elements of theprocesses causing the failures. These include heavy liquidconcentrator and screens.
Based on the information provided by the mine, such as repair, inspection and maintenance sheets, equipment records an evaluation of the most frequent mechanical failures during the operation of equipment in the process of thicker products enrichment was conducted. An attempt was made to assess
the failure rate of equipment on a grain washer. Then, changes were proposed to reduce the failure rate and improve their detectability.

Keyword

hard coal mine, operation, failure, analysis, repair

Introduction

Hard coal is extracted to the surface in the form of various sizes of coal grains and waste rock: stone, sand, slate (Biały, 2013; Biały, 2014; Biały et al., 2018). In order to be a valuable commercial product, it must be adapted to the user's needs. Such adaptation occurs in processing plants and consists of removing useless components (mineral substance) of the excavated material. The extracted coal is subjected to enrichment processes. The mineral substance is undesirable in the technology of using coal. It lowers the quality of raw material. Consequently, the quality of product causes corrosion of machines and increases transport costs. To a large extent, the excavated steam coal meets the guarantee parameters of boilers and does not require enrichment. Enriched steam coal is characterized by higher calorific value and lower emission of sulphur oxides (Fuerstenau et al., 2007; Lutyński & Osoba, 2009).

The main task of mechanical processing is the enrichment of useful minerals, which consists in separating from the raw material, excavated in a deep mine, the possibly pure useful grains, possible adhesions of the useful mineral with waste rock, and the possibly pure grains of waste without a useful component. The enrichment process should be technologically developed and then technically solved in such a way as to obtain in concentrate the maximum amount of valuable, useful mineral grains with the least possible waste losses.

In order to obtain optimum enrichment results, the raw material is thoroughly tested beforehand to determine its mineralogical characteristics, physical and technological properties, such as densimetric composition, susceptibility to gravitational enrichment, electrical and magnetic enrichment, susceptibility to flotation enrichment, ease or difficulty of enrichment, degree of concentration of useful grains, etc. (Saga et al., 2020; Vaclav et al., 2017). Based on these tests, a full technology is developed, determining which subsequent technological processes should be applied in order to obtain optimum results in raw material enrichment.

The technology developed for enrichment of useful minerals should take into account the full technological requirements of further processing or direct use of the separated concentrates, eliminating the need for additional processing operations or the use of costly additional treatment methods in the processing technology, if their elimination is possible by appropriate selection of raw mineral enrichment technology. Technological processes should be selected and applied in such a way that even the smallest amount of raw mineral is not diverted for further use, even if it could be used in this form as a low-value raw material with economic losses of another branch of the national economy or causing damage to the natural human environment. For example, combustion of unenriched fuels with high ash and sulphur content causes very large losses in the energy economy and enormous pollution of the natural human environment. The process of raw material enrichment is preceded by preparatory processes, such as: screening the material into grain classes established by the technological design, crushing, rinsing, hydraulic or aerodynamic classification, etc. Preparation operations aim to bring the raw material to such a state that the enrichment process achieves a maximum concentration of useful grains. In most cases, simple technological characteristics of useful raw minerals are sufficient to prepare them once for the enrichment process, obtaining the optimum effect of their enrichment. In the case of complex mineral characteristics, a single preparation for enrichment is usually insufficient, as only a part of the useful minerals are obtained, and the rest of useful minerals remain in the form of adhesions with waste rock. In such cases, a series of intermediate products must be separated in turn, prepared (by crushing and screening), and then enriched again until the maximum assumed degree of extraction of the mineral's useful grains is reached. Repeated preparation of raw material and subsequent enrichment mainly concerns minerals occurring in the form of injections of useful grains – of varying grain sizes – into the waste rock and into multimetallic ores, from which each useful component must be separated separately.

The processing technology uses the physical and physicochemical properties of the useful minerals and wasterockgrains, differentiating them from each other and enabling their separation.The problem of producing pure coal is quite a complex one. On the one hand, these are technical possibilities of coal enrichment. On the other hand, these are the needs of coal users, who set conditions as to its quality in their contracts. Coal for energy purposes directed to the domestic market is significantly diversified in terms of quality. It depends primarily on the extent of mechanical enrichment of this coal. A large part of the coal sold is not enriched, especially in those cases where the quality parameters of raw coal meet the users' needs (Blaschke & Nycz, 2003; Blaschke & Nycz, 2007; Bozek & Turygin, 2014).

Overview of the coal processing

In the Mechanical Coal Processing Plant, the nominal capacity of which is 750 Mg per hour, coal in class 120 ÷ 16 mm in a heavy liquid is enriched, while the raw coal after separation of grain class 4 (6) ÷ 0 mm is enriched in jiggers. The processing plant is supplied with thermal coal.The excavated material is directed to WK1 vibration sifter with 120 mm holes. After passing through the screening belt, the upper product of screen is crushed in the KWK-100UM crusher for granulation below 120 mm. Whereas the bottom product of screen and the crushed grain class + 120 mm are combined and collected in two raw coal tanks (A and B) with a total capacity of 3600 Mg (A 800 Mg and B 2600 Mg).

The coal is fed to the initial classification node, equipped with a PZ 3090 screen with 16 mm holes from tanks. The plant has a possibility of pre-separation of the raw coal dust stored in a tank with a capacity of 800 Mg.

For this purpose, there are two screens, which are probably built in PWP 1-2 × 4.5 equipped with seams with holes of 16/20 and 16 mm respectively. The upper product is directed to the initial classification node from the last screen, while the lower products of both screens can already be directed alternatively, for loading into carriages, on the dike or to a heat and power plant. The upper product of PZ 3090 screen, i.e. grain class + 16 mm, is enriched in a two-product heavy liquid enricher, type Drewboy 3.2. The enrichment is carried out in a suspension enrichment in a heavy liquid with a specific gravity of 1.6 g/cm^3. The resulting carbon concentrate is dehydrated on a solid sieve, and vibration screen PWP1 with 1 mm slotted sieves (Blaschke, 1984; Blaschke, 2009). Drainage from the solid sieve and the first part of PWP1 screen is directed to a tank of working fluid for re-use in the enrichment process, while the drain from the second part of the screen, which is mainly the result of using showers – part of the suspension after recuperation and water from clean water tanks are treated as a product for regeneration (Brodny & Tutak, 2018; Brodny & Tutak, 2019). By means of a conveyor system, the dehydrated concentrate is directed to a fixed grate with 30 mm holes. Grain class + 30 mm is fed to PWP1 1.5 × 3.75 screen with 40 and 80 mm holes. The upper product (cube) is collected in tanks, and the lower products of the screen are classified on two 1.8 × 5.25 PWP1 1.8 × 5.25 screens with the following holes: the first 20 mm and the second 25 and 31 mm, respectively. Grain classes separated in this way are already commercial products and are directed to appropriate tanks. The lower product, which has been separated on a solid grate, is directed to WE vibration screens, deposits of which are equipped with screens with 8, 25 and 30 mm holes. Separated grain classes are commercial products that are components of commercial products and directed to suitable tanks.

Class > 30 mm is crushed by means of KD twin-roller crusher and returned to the screens again via B-300 bucket elevator (Baranov et al. 2017; Brodny, 2012).

The described node is used to increase the classification efficiency of medium grades of enriched coal into individual commercial classes and to eliminate the upper class, i.e. grains above 30 mm.

Coarse-grained waste from the enrichment unit is collected by means of a chute and fed to PWP1 2.2 × 4.5 screen with 1 mm slotted sieves. After dehydration, the waste is collected in stone tanks on the wash. Drainage from the first part of PWP1 screener is directed to a tank of working fluid for re-use in the enrichment process, while the drain from the second part of the screener, resulting mainly from the use of sprays, is treated as a product for regeneration (Akatov et al., 2019).

The bottom product of PZ 3090 screener, which is a raw product with granulation of 16 ÷ 0 mm, is directed to LIWELL LF – 3.0 × 8.82 screeners with 4 (6) mm holes. On the PWP 1 screener with a slot of 0.75/0.5 mm, the coal concentrate is initially dewatered, and finally on centrifuges: WOW-1.3 and NAEL-3A, which are equipped with sieve baskets with 0.35 mm holes. The obtained intermediate product is dehydrated on a bucket elevator. It is characterized by high ash content, thus it is directed to waste; if necessary, it can also be directed to a feeder and re-enrichment. The coal waste is dehydrated on the bucket elevator. Concentrated coal is directed to heaps or to raw coal.

The final production of the processing plant consists of:

a) concentrated products:
    - coarse-grained concentrate,
    - coal concentrate,
    - concentric coal,
    - raw coal 16 (20) ÷ 0 mm,
    - raw coal 4 (6) ÷ 0 mm,
b) waste:
    - coarse-grained waste,
    - coal waste,
    - coal waste (from filter presses).

The plant has tanks for commercial products with a total capacity of about 1200 Mg located at the loading points and tanks with a capacity of about 400 Mg at the point of general cargo sales. Commercial products' basic sale is carried out by loading them on railcars and cars, in the point of sale of general cargo – by road transport. There is also a possibility of directing particular coarse-grained products, raw material and commercial products to heaps and then loading them on the cars or into railcars. The capacity of coal heaps is at the level of 90000 Mg.

Commercial products produced by the mine:

- nut coke,
- pea coke,
- pea coke II,
- breeze coke M I ,
- energy mixes M II .

Coarse-grained and coal waste is directed to three tanks with a total capacity of 300 Mg, and then transported by car or railcars to an external waste heap. Immediately after dehydration, sludge waste from filter presses is transported by road to this heap.

Analysis of the failure rate of hard coal processing equipment

The equipment used in the above process is subject to continuous production operations. They are subject to cyclical wear and increased failure rate. The most common cause of unexpected production interruptions is machine failure (Biały, 2017; Biały & Fries, 2019; Biały, 2019; Brodny & Szurgacz, 2017).

The Pareto-Lorenz diagram was used to analyze the failure rate of grain scrubbers during the enrichment process of thick products. In this case, it is important to assess the mechanical failure of equipment and show which machines generate the most failures.

The analysis stages were conducted using the Pareto-Lorenz diagram:

1. Collection of data on repairs of grain scrubbers devices (maintenance, overhaul and repair sheet).
2. Ranking the data by assigning individual repairs to specific devices.
3. Calculation of cumulative percentages for individual failures.
4. Preparation of Pareto-Lorenz diagram.
5. Interpretation of prepared diagram.

Total of all failures on particular units has been summarized in Table 1.

Table 1. Total equipment repairs

Equipment number	Equipment name	Total repairs
1	Trapezoidal feeder WPT 3.02	12
2	Screening machine PZ 3090	21
3	Belt conveyor B-1040	2
4	Screening machine PWP1 2.2 × 4.5	16
5	Heavy liquid enrichment DREWBOY	27
6	Screening machine PWP1 3 × 5.25	22
7	Belt conveyor B-1000	4
8	Belt conveyor B-1010	4
9	Pomp OŁ 150	11
10	Pomp OŁ 80	10
11	Recuperator reserve	1
12	Recuperator	7
13	Pomp OŁ 150	2
14	Hydrocyklon Krebs D-15	2
15	Mill MK 900 × 900	1
16	Screening machine PWP 1K 1.5 x 3.75	12
17	Screening machine PWP 1K 1.8 ×5.5	13
18	Screening machine PWP 1K 1.8 × 5.5	6
19	Belt conveyor B-800	5
20	Belt conveyor B-630	3
21	Belt conveyor B-1030	4
22	Belt conveyor B-1020	7

The next step was to calculate the cumulative repair percentages, Table 2.

Table 2. Cumulative percentages for equipment repairs

Equipment number	Equipment type	Number of repairs	Percentage rate
5	Heavy liquid enrichment DREWBOY 3.2	27	14.1%
6	Screening machine PWP1 3 × 5.25	22	11.5%
2	Screening machine PZ 3090	21	10.9%
4	Screening machine PWP1 2.2 × 4.5	16	8.3%
17	Screening machine PWP 1K 1.8 × 5.5	13	6.8%
1	Belt conveyor WPT 3.02	12	6.3%
16	Screening machine PWP 1K 1.5 × 3.75	12	6.3%
9	Pomp OŁ 150	11	5.7%
10	Pomp OŁ 80	10	5.2%
12	Recuperator	7	3.6%
22	Belt conveyor B-1040	7	3.6%
18	Screening machine PWP 1K 1.8 × 5.5	6	3.1%
19	Belt conveyor B-800	5	2.6%
7	Belt conveyor B-1000	4	2.2%
8	Belt conveyor B-1010	4	2.1%
21	Belt conveyor B-1020	4	2.1%
20	Belt conveyor B-630	3	1.6%
3	Belt conveyor B-1030	2	1.0%
13	Pomp OŁ 150	2	1.0%
14	Hydrocyklon Krebs D-15	2	1.0%
11	Recuperator reserve	1	0.5%
15	Mill 900x900	1	0.5%

The analysis of the Pareto-Lorenzo diagram (Fig. 1) shows that the highest number of repairs – 78.6 % is generated by 9 machines:

1. Heavy Liquids Enrichment TREWBOY 3.2
2. Screener PWP1 3 × 5.25
3. Screener PZ 3090
4. Screener PWP1 2.2 × 4.5
5. Screener PWP 1K 1,8 × 5,5
6. Trapezoidal power supply WPT 3.02
7. Screener PWP 1K 1.5 × 3.75
8. Pump OŁ 150
9. Pump OŁ 80.

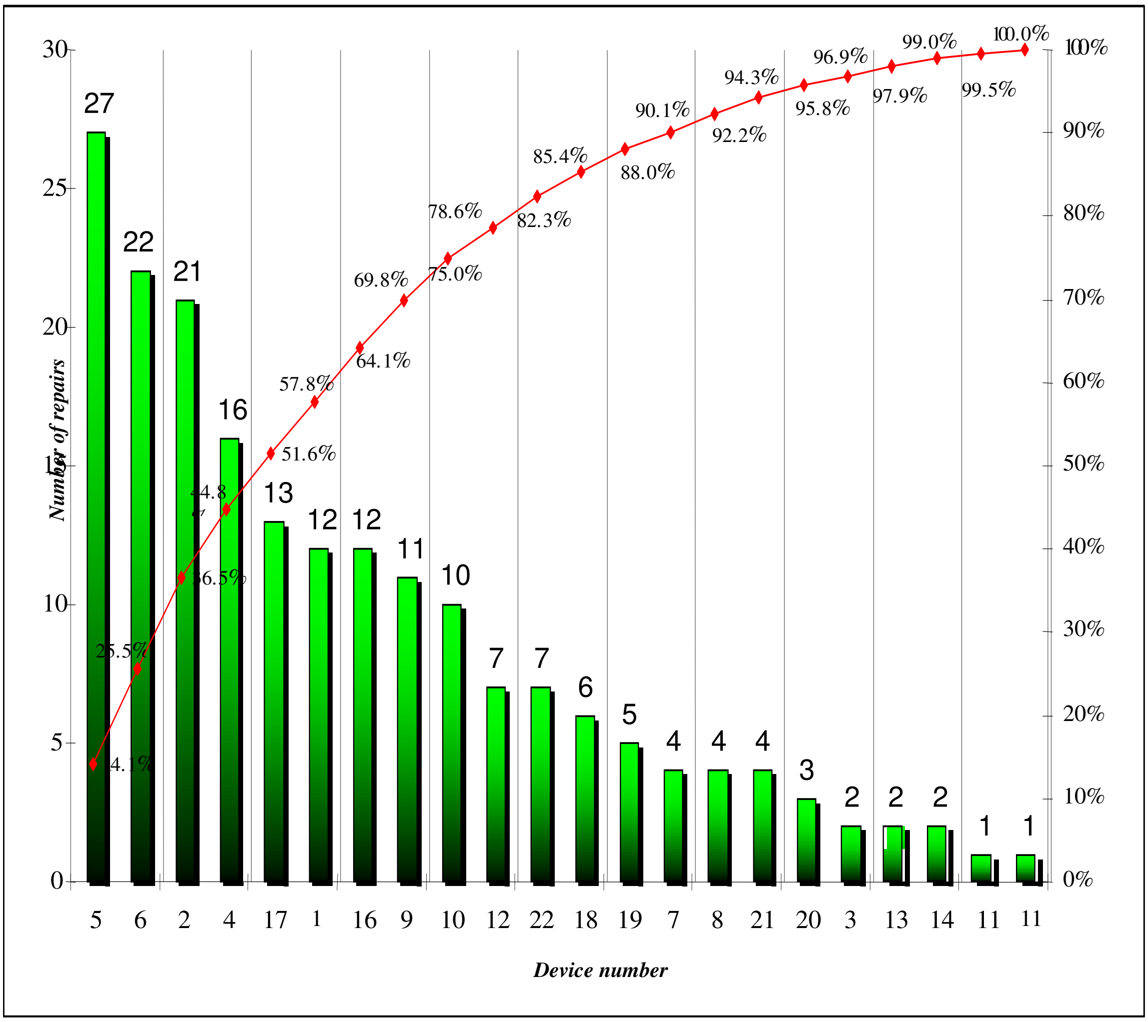

Fig. 1. Pareto - Lorenz diagram

Taking into account the percentage of these 9 machines, it can be concluded that a total of 45.5 % of the machine types causes as much as 78.6 % of failures. The remaining 12 machines cause 21.4 % of repairs.

It follows that the first 9 machines should be analyzed in the first place.

The most worn-out machine on the washer is Drewboy 3.2 (Fig. 2). The Drewboy 3.2 type two-product suspension enrichment is used to work with suspended heavy magnetite liquid. Thanks to the high reliability of Drewboy 3.2 enrichment and the accuracy of the heavy liquid specific gravity stabilization system, the process of coal enrichment is characterized by high movement reliability and accuracy of enrichment.

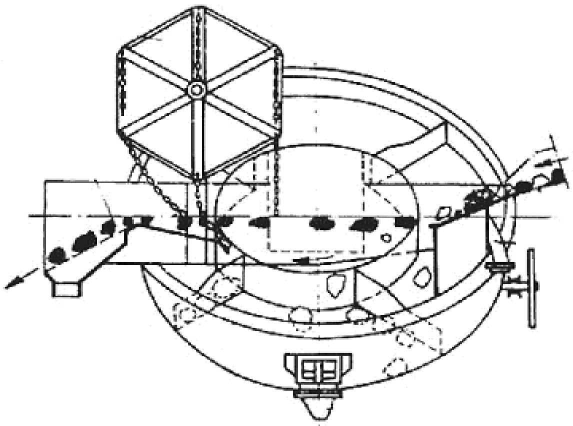

Fig. 2. Drewboy 3.2 Heavy liquid enrichment

The enrichment unit consists of a work-box with an oblique bottom, on the side of which a vane wheel, inclined at an angle of 50° from the vertical, is built in a suitable cover. The lower part of the wheel cover is directly connected to the inside of work-box. The lifting wheel's box structure protects the bottom of the wheel cover against friction caused by the waste slides on its surface. Raw coal is fed to the enrichment unit through a chute on the surface of the heavy liquid mirror (Krenicky, 2015). The concentrate is collected through an overflow threshold on an inclined chute, which is made of a slotted sieve. Under the sieve, a grab box is mounted, which flows down from the enricher along with the concentrate. The scraper built over the overflow threshold is equipped with loosely hanging chains, which act as scrapers of floating concentrate grains (Kuric et al., 2019). The heavy liquid is fed to the enricher through a feed spigot, while in the lowest point of work-box, there is a spigot allowing to empty the enricher from the heavy liquid. The waste collected by the wheel taken out of the enrichment is discharged outside via a chute, which is located at the highest point of wheel rotation. A worm gear drives the lifting wheel. In order to achieve the expected efficiency of this equipment, it is necessary to keep it in the first efficiency class at all times. In the group of machines causing the most repairs, there are up to 5 screens (Fig. 3), which is 50 % of the most failure.

The elements of screens are exposed to constant friction and vibrations; thus, their parts wear out quite quickly.

Vibration screens (Fig. 3), single-deck PWP type are used for classification of coal and other loose materials in wet and dry processes as well as for desludging and dewatering etc.

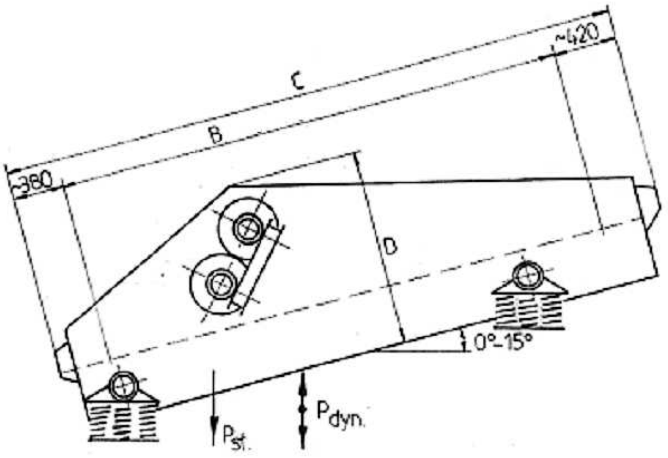

Fig. 3. Vibration screen

PWP1 type screens are used in coal processing plants for pre-classification processes in tandem arrangement with PWP1K type screens. PWP1K screens can be used for final classification and for dewatering of magnetite enrichment and flushing products (Table 3). Each screen has a modular design and consists of the following assemblies connected by screw joints:

- riddle,
- screen modules,
- 2 inertia drives,
- screener drive.

Table 3. Straight-line vibration screens PWP1 and PWP1K

Parameter	**Technical data**			
	PWP1 2.2×4.5	**PWP1 3.0×5.25**	**PWP1K 1.5 × 3.75**	**PWP1K 1.8 × 5.25**
Efficiency in classification	400 Mg/h	720 Mg/h	720 Mg/h	240 Mg/h
Maximum grain size in the feed	Up to 200 mm			
Sieve mesh size	for 10 mm - 80 mm classification for 0.25 mm - 2.00 mm dewatering		12 - 80	12 - 80

OŁ type pumps (Fig. 4) are also subject to frequent repairs.

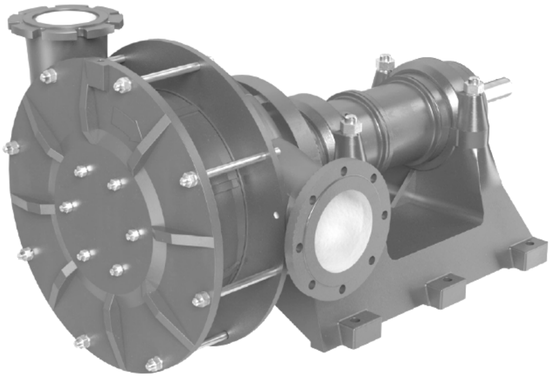

Fig. 4. OŁ pump

Reliability and efficiency improvement

The efficiency of production process depends largely on the failure-free operation of equipment at the mechanical coal processing stage, where commercial products are produced. Raw, unenriched product is not sold. In order to maintain the appropriate quality level of processed product, it is necessary to verify the correctness of equipment operation included in the coal enrichment process (Słaboń, 2008). The enrichment process for coarse grains was selected for analysis (Vasko et al., 2020). After the analysis using the Pareto-Lorenzo diagram, information was obtained on the machines that generate the most failures.

Machines requiring frequent repairs:
- Enrichment Drewboy 3.2,
- Trapezoidal feeder,
- Screener,
- OŁ pumps.

The most common repairs on these machines are:

a) Enrichment Drewboy 3.2:
- Replacement of metal sheets
- Replacement of sieves

b) Trapezoidal feeder:
- Replacement of the crushing plates of excavated material
- Bearing replacement

c) Screeners:
- Beam replacement
- Bearing replacement

d) OŁ pump
- Pump replacement
- Rotor replacement.

The basic tasks of machine diagnostics are to detect emergency states and identify them (Turygin et al., 2018).

In order to improve the reliability of equipment, it is recommended to inspect the machines that have generated the most repairs more frequently (Semrád et al, 2020). It is important to avoid malfunctions during the operation process (Michalski & Kunart, 2017). A portable infrared camera can be a helpful device during the inspection. It is ideal for maintenance and scheduled electrical and mechanical inspections (Draganová et al., 2020). As every mechanical component generates heat before it fails, it is easy to find damage (Blaschke, 1984; Tutak & Brodny, 2019). The guarantee of high equipment durability and reliability during operation is the application of technical diagnostics, which correctly determines the technical condition of machines (Biały, 2017; Biały & Fries, 2019; Brodny & Tutak, 2018; Cacko & Krenicky, 2014; Kuric et al., 2019). The measurements allow determining the technical condition of machines and equipment effectively, thus reducing emergency states, generations of service costs and avoiding losses in the company (Gajdzik & Sitko, 2018; Urbaniak, 2004).

Computer visual and thermographic analysis of the tested objects is possible thanks to the software supplied with the camera (Słaboń, 2008; Szurgacz et al., 2019). The camera converts thermal radiation or invisible infrared into thermograms ready for analysis. LEDs illuminate the object under test, which enables efficient operation in an unlit environment (Górniak et al., 2018). This device performs non-contact temperature measurement and also has a digital photography function.

Recommendations and methods of dealing with failures

As a result of the failure analysis, the following measures are recommended:

1. Carry out periodic inspections of the mechanical processing equipment

Inspect and maintain the mechanical processing units according to the inspection and maintenance schedule and in accordance with the equipment's operating and technical documentation.

The person responsible for the preparation of inspection and maintenance schedules is the senior mechanical treatment supervisor responsible for maintenance management.

2. Provide information on malfunctioning of mechanical processing equipment

In accordance with the workplace instructions, the employee shall check the correct functioning of machines before start-up.

The persons responsible for providing information are:
Technical support employees
Traffic maintenance employees.

3. Indicate the date of repair

The Branch Foreman, on the basis of previously obtained information, shall indicate the date, manner and person responsible for the equipment repair

Decide when to carry out a major overhaul or replace the equipment with new ones. The overhaul plan is based on the technical and economic plan.

4. Prepare the documentation for a major overhaul

Prepare documentation for a major overhaul

The documentation should include specification of the scope of works, selection of the method for performance of works

Supervise the repair of mechanical processing equipment

Execution time: on an ongoing basis or in accordance with the scheduled repair date.

5. Overhaul or replace the equipment with a new one

Indicate the person authorized to carry out a major overhaul

This person is appointed by the department heads

If a defect is found during acceptance, action must be taken on an ongoing basis to rectify the identified defects.

Conclusion

The efficiency of production process depends largely on the trouble-free operation of machines at the mechanical stage of coal processing, where final products are produced. To maintain high efficiency and reliability, it is necessary to look at the correct operation of machines included in the coal enrichment process.

Technical diagnostics of equipment greatly impact the efficiency of detecting irregularitiesand defectsin the coal enrichment process. After the analysis, using the Pareto-Lorenz diagram, information was obtained on the machines that generate most failures.

It can be concluded that a total of 45.5 % of the machine types causes as much as 78.6 % of failures. The remaining 12 machines cause 21.4 % of repairs. It follows that the first 9 machines should be analyzed in the first place.

The devices with the highest amount of downtime include heavy liquid enricher and screens.

Machines that needed frequent repairs include:

- Drewboy enrichment 3.2,
- trapezoidal feeder,
- various types of screens,
- two OŁ pumps,
- recuperator.

In order to improve the efficiency of these machines, more frequent inspections on the machines that generated the most failures are recommended. It is important to avoid failures during the equipment operation.

A guarantee of high equipment durability and reliability in operation is the use of technical diagnostics, which correctly determines the technical condition of the machine.

It is recommended to carry out inspections, observations between main inspections using machines such as a vibration pen and thermal imaging camera to detect irregularities.

In order to avoid breakdowns caused by failures, the following solutions are proposed:

- use of rubber-coated steel sheets, which should reduce the level of wear and tear and the downtime associated with their replacement, as well as improve working conditions by reducing noise,
- replacement of perforated metal sheets with polyurethane (PU) screens, which will increase the time between screen changes and reduce the downtime associated with screen replacement and cleaning
- of the screen deck.

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