MONITORING OF MINING EQUIPMENT FAILURE BASED ON SELECTED QUALITY MANAGEMENT TOOLS

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Summary: The article includes an analysis of the failure of 4 belt conveyors working in one of the coal mines. The mechanical, electrical, plumbing and so called other failures were distinguished, and then using the Pareto-Lorenz diagram - a traditional quality management tool, the causes of each failure were found and on that grounds the actions were set out aimed at reducing the belt conveyors failure rate.

Keywords: failure, belt conveyors, Pareto-Lorenz diagram, quality management, mining.

1. Introduction

The coal extraction process is the primary area of activity of the mine, and therefore the task of maintenance services is to ensure continuity of operation of the operated machines and equipment. All efforts should be directed to ensure a trouble-free, efficient operation of the machinery and mining equipment. In the event of disruption in the machinery operation the whole coal extraction process is disrupted, and huge losses are generated. Therefore, the relevant departments should ensure a reliable, energy-efficient and safe operation of the mining machines. While analyzing quality of the mining machinery and the transportation system, attention is paid to the utility quality of machine, which is defined by its physical parameters and the implemented technical and technological processes. In relation to mining machinery the requirements are defined that regard to the operation, operational safety, ergonomics, reliability and durability of the system. [1, 9]

Reliability of the mining equipment means its ability to perform the preset functions within a specified time, and under certain environmental conditions [3]. The reliability is often characterized by a set of component features of the object such as its [5]:

- durability,
- fitness,
- conservatism,
- repair susceptibility.

Durability of the machine, called also shelf-life of the machine, is its ability to meet the desired functions until the first damage or a full physical wear. The shelf-life may be divided into the functional shelf-life, which is a feature whereby a correct functioning of the machine is possible, without damage in a wider range of time, and the operational shelf-life, which is a natural number of, e.g., some repetitive operations.

The functional **fitness** of the machine is a feature through which a further use the machine after its repair is possible.

Conservatism is ability of the machine to operate without forced repairs after prolonged storage.

Susceptibility of repair or of machinery is a feature that results from the assumptions in the design and the ability to quickly repair the machine. The mining machines in all are classified as serviceable objects, and only some elements as irreparable such as ropes, gear wheels.

Here, also the difference between the damage and failure should be explained. The damage is a disability of machine that requires a repair without having to replace major assemblies [2]. While failure is a broad, serious damage, which spans many elements and assemblies [8]. The failure analysis of the selected mining machinery shall be presented further in this paper. The failures occurring during operation of machines are divided into:

- mechanical failures - caused by damages of the mechanical parts of the machine,
- electrical failures - caused by damages of the electrical system components,
- plumbing failures - caused by damages of the plumbing system components,
- other - not associated with direct work of the machine, independent of man.

Also here the difference between the damage and failure should be explained. The damage to a disability of machine that requires a repair without having to replace major assemblies. While failure is a broad, serious injury, which spans many elements and assemblies. Furthermore, the attention should also be paid to the concept of system and component. The system is an ordered set of elements which are mutually functionally related to each other. The element is an object that cannot be divided into further parts. An example of the system can be the longwall complex, which consists of a harvester, housing, conveyor, and its elements are machinery and equipment. Each of these devices can also be treated as a system whose elements are then parts such as engine, tractor [5].

2. Description of the research object

In this article, the belt conveyors were assessed in terms of their failure rate. The belt conveyors are used, in mines for the coal haulage from the wall the most often are the following types of belt conveyors Gwarek. Due to the wide range of unified assemblies, subassemblies, the overall similarity and the principle of operation of Gwarek -1200, belt conveyor shall be discussed (Fig. 1).

Fig. 1. Gwarek-12001 belt conveyor [10]

These conveyors are designed for haulage transport on main roads in the coal mines with high extraction. The conveyors can be powered by one, two, three or four engines with a capacity of 75, 90, 100 or 132 kW each, depending on the load of spoil, length and inclination.

Specifications of Gwarek -1200 belt conveyor:

1. Belt speed obtained by changing two-speed gear transmissions [m/s]: 1.6, 2.0, 2.5, 3.0. Adequate performance [t/h] 600, 800, 1000, 1200
2. The maximum length of the conveyor in the level of max. performance at V = 3 m/s with drives of a capacity of 4x132 kW is 3000 m.
3. Gear ratio: 46.96; 25.68; 39.02; 24.961.
4. Conveyor route: rope, made of channel section, standing on the floor or suspended
5. the type of belt-approved type of strength 800 - 2500 kN/m depending on the installed capacity and speed of the belt.

The method of sealing is: curing, cold bonding, by means of steel wire ropes, metal or plastic staples.

Gwarek-1200 belt conveyors consist of the following main units:

1) drive with the boom,
2) loop,
3) tensioning station,
4) route,
5) back,
6) additional and electrical equipment.

Description of individual conveyor components [11]:

- **drive with the boom:**
  The boom consists of a head and two stable segments bolted to walls of the hull or the addition, it can be extend up to 6 segments, repetitive after 5m each. The drive consists of drive hulls one or two motor units which are disjoint. The drive hull is mounted of divided walls mounted to a rigid skid. A driving drum is located on the walls, with protruding pivots on which the power raingears are mounted. The gear unit is mounted on the drum shaft by means of type Stüwe clamping rings. The ZRHT/5E jaw or plumbing brake is attached to the gear.
- **loop:**
  The loop is a belt storage tank, it allows the storage of elastic and permanent elongations resulting from the operation. It also enables the extension or shortening of the structure without the need for additional insertion or release of the belt. The loop supporting structure is made up of segments, the amount of which can be varied within the range of 3-17 pcs. The loop over the entire length is protected by guards.
- **tensioning station:**
  The tensioning station is built behind the loop and connected by a rope with a loop trolley. Its task is to provide a constant tension in the belt in the belt descending from the drive drums.
  The tensioning station can be slow-running or tensioning and supporting.
  The main component is a winch composed of the following parts:
  - electric motor,
  - flexible coupling,
  - worm-helical gear or cylindrical-conical,
  - the cable drum.

The winch control can be done by the lever or plumbing system. When tensioning, the manual tension control is done by observing the pressure gauge control.

- **route:**

  The route of the conveyor can be:

  a) the rope type, suspended,

  b) from the channel bar, standing on the floor or suspended.

  The nominal distance between the upper brackets of the type is 1.2m. The trestle that constitutes the support of the load-bearing elements conducting the bottom belt are spaced every 3m.

- **back.**

The back with the chute is a final part of the conveyor. It consists of: hull with the turning drum, superstructure with rubbered feed idlers, permanent chute and systems cleaning the belt and turning drum.

- **additional and electrical equipment:**

  - belt motion sensors,
  - temperature sensors,
  - excavated material accumulation sensors,
  - sprinklers on the pouring stations,
  - automatic fire extinguishing unit SAG-a.

3. Analysis of the belt conveyors failure rate

Analysis of failure rate of the belt conveyors operating in one of the extraction walls in the audited entity, was carried out based on daily reports collected by the mine dispatcher, during the period from January to December 2010, the report included the following replacing data:

- date of failure,
- duration of failure,
- cause of failure,
- place of failure.

During the research, in the wall designated to be analyzed 4 belt conveyors operated forming a soil transport system. 169 failures were recorded, which were divided by their type, number of failures of the type, duration and cause of failure. The belt conveyor's failures were divided into:

- mechanical failures,
- electrical failures,
- plumbing failures,
- other failures (not associated with the direct operation of the belt conveyor on the wall. The downtime arising from such operations as: supplementing the lack of water, oil supplementing and replacement of damaged methane meter.

To assess the failure of machinery the Pareto-Lorenz diagram was used, which belongs to the traditional quality management tools and allows clear, graphical arrangement of the factors affecting the examined phenomenon, and also allows showing the relative and absolute distribution of errors, problems or their causes. The Pareto diagram can be easily read as to what is the biggest problem, what types of errors should be reduced to improve the production process [4].

The Pareto-Lorenz diagram was constructed as a result of implementing the following steps [6, 7]:

1. Data regarding the downtimes due to failure of the tested machines operating in the analyzed wall was completed.
2. The data was assigned to specific machines, such as: longwall harvester, scraper conveyor and belt conveyors.
3. The cumulative percentages for each failure was calculated.
4. On the basis of the results the Pareto-Lorenz diagram was drawn up.
5. Interpretation of the drawn up diagram was conducted.

To calculate the cumulative percentage of individual failures the following formulas were used:

$$PIE_j = \frac{100}{IE}$$

$$SPIE_j = PIE_j + PIE_{j-1}$$

$$PIA_j = \frac{100 \cdot IA_j}{\sum_{i=1}^{IE} IA_j}$$

$$SPIA_j = PIA_j + PIA_{j-1}$$

where:

PIE_j – percentage number of elements,
$SPIE_j$ – cumulative percentage number of elements,
IE – number of elements,
PIA_j – percentage number of failures,
$SPIA_j$ – cumulative percentage number of failures,
IA – number of failures.

In addition to the causes of the failure, a very important factor is the time interval in which the individual failures occurred.

The following is a summary of the belt conveyor failure, due to the its average duration.

Tab. 1. The average duration of each failure of the belt conveyors

Cause of the failure	**Average duration [min.]**	**Percentage duration of all failures**	**Cumulative percentage duration of all failures**
Mechanical	201,5	63,8	63,8
Other	48,8	15,4	79,2
Electrical	33,5	10,6	89,8
Plumbing	32,2	10,2	100

An analysis of the data contained in Table 1 shows that the longest average duration of failure was observed in the case of mechanical failure, which amounted to 201.5 minutes. The comparable average duration was observed in case of electrical and plumbing failures, which respectively amounted to: 33.5 and 32.2 minutes.

Based on data contained in Table 1 the Pareto-Lorenz diagram was drawn up (Fig. 2) for the average duration of each failure of the belt conveyors.

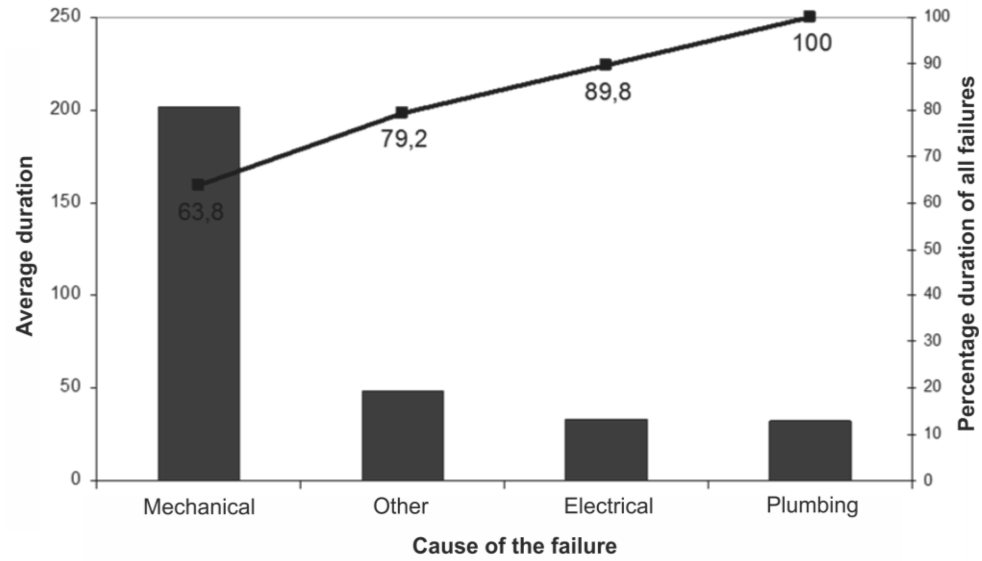

Fig. 2. The Pareto-Lorenz diagram for the average duration of failure of the belt conveyors

The Pareto-Lorenz diagram shows that the longest duration of failure of belt conveyors were the mechanical failures, which constitute 63.8% of all failures.

Electrical, plumbing, and “other” failures represent 36.2% of all failures of the belt conveyors operating in the tested wall of one of the coal mines.

3.1. Electrical Failures

The largest group among the failures are the electric failures of the belt conveyors, which were recorded 59 times during the tested period. In Table 2 the causes leading to electrical failure are summarized.

Tab. 2 Causes of the electric failure of the belt conveyors

Cause of the failure	Number of failures	Percentage of failures	Cumulative percentage of failures
Faulty electric conveyors	56	94,9	94,9
Lack of control	2	3,4	98,3
Faulty temperature sensor	1	1,7	100

The analysis of data from Table 2 shows that 56 failures were caused by causes that in the reports were classified into the following category: electrically inefficient conveyors. This is a very general category, and therefore cannot accurately determine what the cause of the individual failures was.

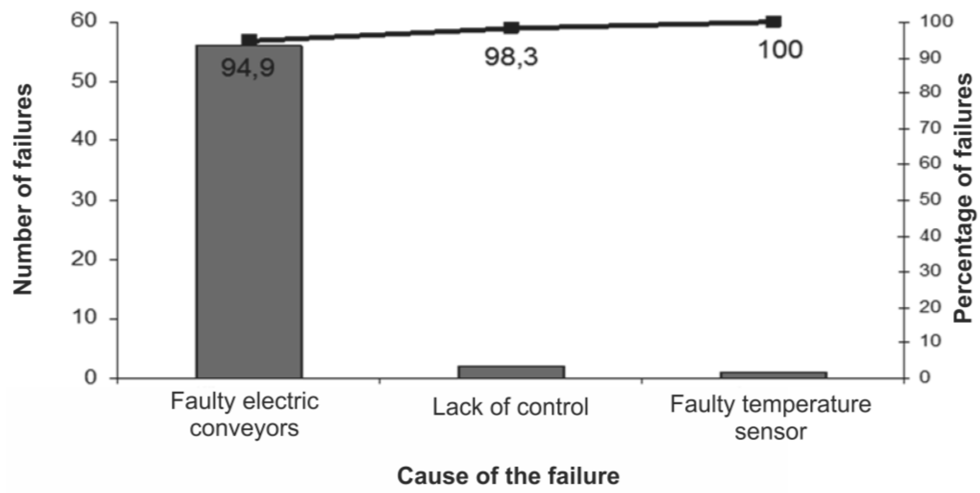

Fig. 3. The Pareto-Lorenz diagram for the electrical breakdown of the belt conveyors

On the basis of data included in Table 2 the Pareto-Lorenz diagram was drawn up (Fig. 3) for the electric failures of the belt conveyors. The diagram shows that 94.9% of the causes of failure are classified as: electrically inefficient conveyors. Causes as lack of control and faulty temperature sensor represent only 5.1% of all the electrical conveyor failures.

3.2. Mechanical Failures

In the case of operation of the belt conveyors, 52 failures were reported caused by the mechanical factors. The summary of these factors is presented in Table No. 3

Tab. 3 Causes of the mechanical failures of the belt conveyors

Cause of the failure	Number of failures	Percentage of failures	Cumulative percentage of failures
Broken belt	17	32,8	32,8
Damage to the sealing	13	25	57,8
The loop is out of order	5	9,6	67,4
Faulty mechanical conveyors	4	7,7	75,1
Damaged wiper	3	5,8	80,9
Drum replacing	3	5,8	86,7
Defective brakes	2	3,8	90,5
Gear replacing	1	1,9	92,4
Failure of the drive	1	1,9	94,3
Clutch damage	1	1,9	96,2
Defective drum pad	1	1,9	98,1
Rollers replacing	1	1,9	100

While analyzing the data of Table 3 it can be concluded that the most common cause of the mechanical failure was the broken belt - 17 failures and damage to sealing - 13 failures. Transmission, clutch, drive, lining drum and roll were damaged 1 time during the tested belt conveyors operation period.

Based on data from Table 3, the Pareto-Lorenz diagram was drawn up (Fig. 4) for the mechanical failures of the belt conveyors.

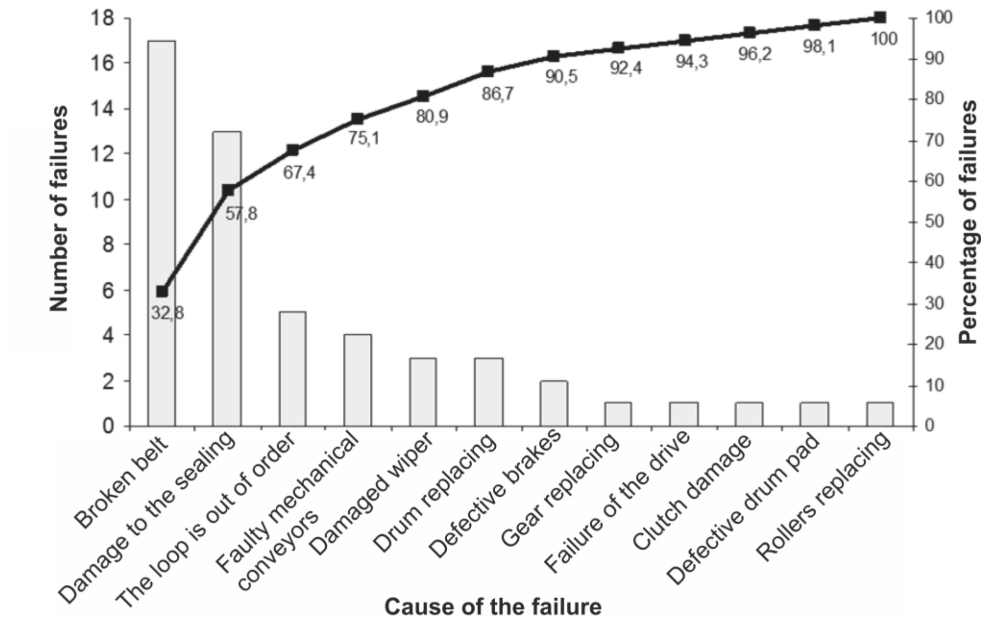

Fig. 4. The Pareto-Lorenz diagram for the mechanical failure of the belt conveyors

The diagram shows that 57.8% of causes of the mechanical failures are caused by a broken belt and damaged sealing. The remaining 10 factors are 42.2% of all failures of the belt conveyors operating in a distinguished wall in the audited entity.

3.3. "Other" failures

"Other" failures recorded 49 times during the testing period, they form the third group in terms of number of their occurrence. The causes of the "other" failures of the belt conveyors are contained in Table 4.

Tab. 4 Causes of the "other" failures of the belt conveyor

Cause of the failure	Number of failures	Percentage of failures	Cumulative percentage of failures
Buried belt	15	30,6	30,6
No current	7	14,3	44,9
Stoppage	7	14,3	59,2
Adjustment	6	12,3	71,5
Jam on the conveyor	5	10,2	81,7
Rewound belt	2	4,1	85,8
Lack of water	2	4,1	89,9
Breaking of the hanging chain	2	4,1	94
Brushing securing	1	2	96
Lock on	1	2	98
Replacing of aprons	1	2	100

Based on the analysis of data from Table 4 it can be stated that the biggest failure of the group "others" was caused by the belt burial - 15 times. In isolated cases brushing securing, lock on and aprons replacement occurred.

Based on data from Table 4 the Pareto diagram -Lorenz was drawn up (Fig. 5) for the "other" failures of the belt conveyor.

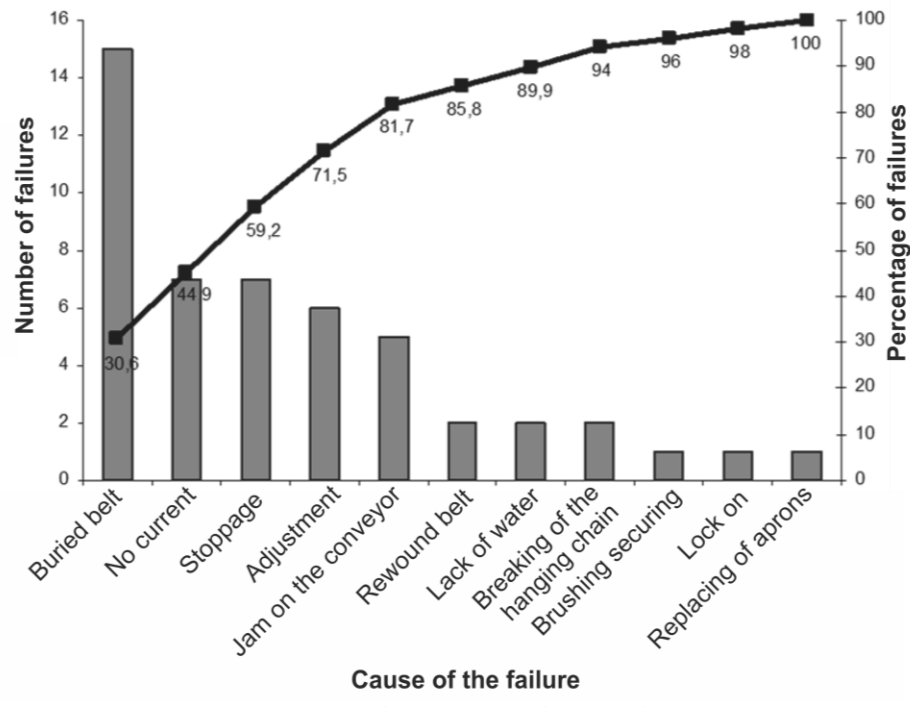

Fig. 5. The Pareto-Lorenz diagram for the "other" failures of the belt conveyors

Based on the analysis of the Pareto-Lorenz diagram it can be concluded that the buried belt, lack of electricity and rewound of the belt represent 59.2% of the reasons causing the "other" failure of the operating conveyors in the analyzed tested wall of the test. The remaining eight reasons is 40.8% of all "other" failures of the belt conveyors.

3.4. Plumbing Failures

The belt conveyors, plumbing failures constitute the smallest group of failures. They have been reported 9 times, and the only reason for their occurrence was the lack of cooling of the conveyor. It can be concluded that the reason for this is 100% responsible for the plumbing failure of the conveyor operating in the wall, which was analyzed.

4. Conclusions

Based on the analysis of failure of the belt conveyors, it can be concluded that:

- in the period from January to December 2010 there were 169 failures of 4 belt conveyors operating on one of the walls of the analyzed coal mine,
- the longest downtime was caused by the mechanical failures, which lasted for an average of about 200 minutes. In the event of electrical, plumbing, and “other” failure averages, their duration was comparable and amounted respectively, to: approx. 335, 32 and 48 minutes,
- the largest group are the electrical failures 59 reported, followed by the mechanical failures 52 reported, followed by the so-called other failures 49 reported. The last group are only 9 plumbing failures.

In order to reduce potential failures of the mining machinery, the following appropriate action should be taken:

- increase of monitoring and control of the mining machinery in operation through the creation of an appropriate maintenance schedule, maintenance and inspection of machinery, with particular emphasis on their critical elements,
- establishing appropriate procedures for the maintenance of individual machines, and control of their execution with the use of checklists,
- development of an appropriate database on the number and causes of failures of the mining machinery,
- application of reliability theory, which will allow to design a repair database and develop of the maintenance schedules, which will extend the time of trouble-free operation of machines,
- modifying of the elements of design solutions that mostly are subjected to the failures, due to the use of detailed data about the causes and the number of failures contained in databases,
- conducting periodic diagnostic measurements, ensuring proper control of individual units of machinery and it will increase the reliability and durability of these machines,
- appointment and training of the relevant departments responsible for a trouble-free process of the coal mining.

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