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Keeping mining machinery in operation based on energy factors

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Abstract:

Mining machinery maintenance strategy based on the current dynamic condition of the equipment not only improves reliability, reduces repair and renovation costs, but also affects electricity costs. Due to the use of modern monitoring and diagnostic systems, as well as advanced control and supervision methods, it is possible to improve the efficiency of devices and thus reduce energy costs. Due to the high power of the devices, even a slight decrease in efficiency translates into significant financial resources. Taking into account the prices of electricity as well as ecological aspects, investments in modern solutions give specific financial and social savings.

Keywords: maintenance, technical diagnostics, energy indicator

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1. Introduction

One of the main costs in the mining plant includes the costs of electric energy. In relation to the mine specificity they constitute 20-48% of all the costs which shape the production efficiency directly [1]. The main expenses cover dewatering, ventilation and run-of-mine haulage as well as its preparation systems. In the case of ventilation devices, their unit powers vary in the section from 750 kW to 1.5 MW. A few (2-3) fan stations and air treatment stations are operated in the central ventilation system. Pumps of the power 1-2 MW are used for the mine central dewatering system and their number depends on an inflow of underground water. The haulage process incorporates armoured face conveyors equipped with 3 drives of the power 300 kW, a beam stage loader of the power about 200 kW, the sectional haulage system consisting of a few (3-5) conveyors with a double drive of 200 kW and the main haulage system composed of a few (2-5) belt conveyors with multiple (2-4) drives of the power in order of 200 kW. The presented specification is of exemplary character. The parameters depend on the type of operation, the distance of the longwall under mining and the specificity of a given mining plant. Only main receivers of electric energy, which will be used for indicating guidelines of operational maintenance based on energy indicators, are mentioned.

Each electric machine transforms electric energy into a different kind of energy, including mechanical, potential energy with a certain, finite efficiency. The devices, mentioned above, are complex and the energy is transformed in them in a few stages. For example, the energy factor of dewatering will indicate electric energy consumption needed for pumping a determined amount of water from the assumed depth within the assumed time. As the depth of the main dewatering operations can be regarded as the constant, so for a given case this factor will be expressed in kWh/m^3 [2]. Electric energy is transformed into torque of the pump shaft at a given angular velocity, then onto energy of hydrostatic pressure. This pressure causes a flow of water in the collector which rises the water mass to a given height and velocity of its outflow at the collector outlet. Similarly, a complex transformation takes place in other devices [3]. In the case of the haulage system, at a given longwall, the energy factor will be expressed in kWh/t of transported run-of-mine [4]. Obviously, the value of this factor will depend on the distance of the working from the transport shaft, however in the case of a given location, together with a geometry of the haulage route, this factor will be connected with efficiency of individual components of the haulage system.

Relative values of presented energy factors, to a large extent, depend on efficiency coefficients of individual components transforming energy. The efficiency of these components depends, among others, on their technical condition. Therefore, a maintenance of machines in a good technical conditions has a direct impact on the costs of electric energy. Although this thesis seems to be common, it is not always noticed. A general analysis of a few selected systems in an exemplary mining plant will be conducted to illustrate these costs. Taking into consideration a contemporary geopolitical situation, increasing costs of electric energy as well as prospects of power transformation, the presented analysis can be useful in the scope of taking strategic decisions connected with maintaining operations.

2. Materials and Methods

Exploitational costs of a longwall shearer-equipped system

In complex systems of energy transformation, the total efficiency is a product of partial efficiencies. Therefore, an efficiency improvement of any component has a direct impact on the total efficiency and thus on the energy efficiency. Taking into consideration exemplary devices in the longwall shearer-equipped system (Fig. 1), the following energy consuming devices can be indicated, together with their power (Table 1) and main energy transforming systems.

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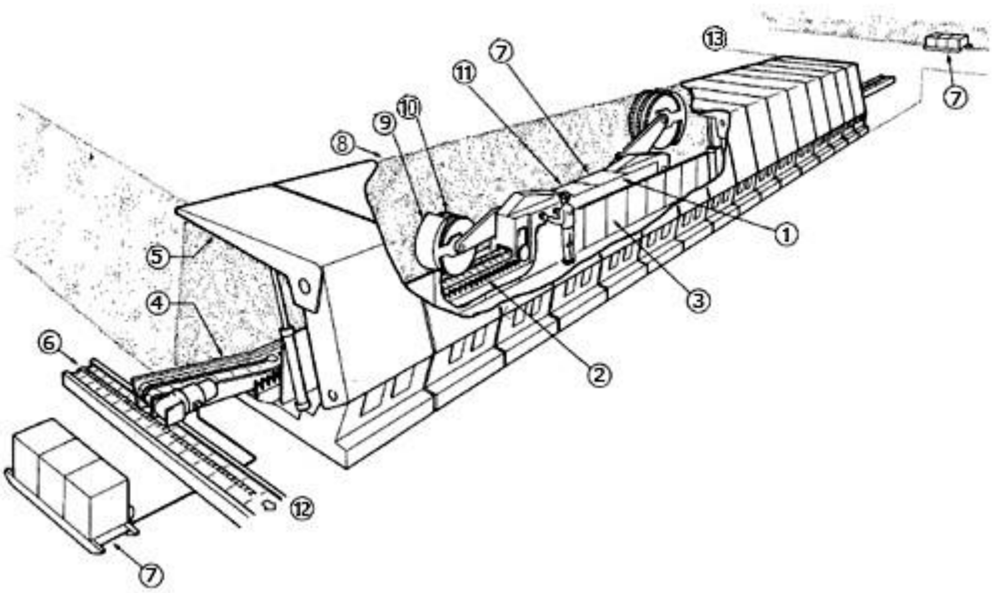

Fig. 1. Devices in the longwall shearer-equipped system:
1 – Shearer, 2 – Toothed Bar, 3 – Spill-plate, 4 – Armoured Face Conveyer, 5 – Longwall Support, 6 – Beam Stage Loader, 7 – Electric Apparati Box, 8 – Longwall Face, 9 – Loader, 10 – Cutting Drum, 11 – Haulage Unit, 12 – Tail-end Gate, 13 – Head-Gate

Table 1. **Exemplary power of devices in the longwall system**

Drive of Shearer	1.0 MW
Hydraulic Supply of Supports	0.1 MW
Armoured Face Conveyor	0.8 MW
Beam Stage Loader	0.2 MW
Crusher	0.1 MW

From the specification, given above, it can be concluded that the power consumption of the longwall system, subject to an analysis, reaches 2.2 MW. In in-situ conditions the current consumption varies from 1.5 MW to 2.5 MW, in the case of complex and difficult seams. The given electric power, is transformed in electric motors into torque. Efficiencies of contemporary electric drives of medium power exceed 94% and for big powers - even 97%. It is a reaction to the European Union Directive EuP 2005/32/EC and to the Regulation of the European Commission 640/2009 ordering an application of energy – saving motors. The rated efficiency can be different from the exploitational efficiency. Different factors such as: a number of start-ups, cooling systems, dynamics of mechanical loading etc. [5] have an impact on the exploitational efficiency. For example incorrect parameters of motor cooling can reduce its efficiency by even 6%. The efficiency decreases when the operational period decreases and each general overhaul can reduce the efficiency by 4%. The condition of bearings, the condition of winding, the rectilinearity of the shaft line also have an impact on the motor efficiency. A poor technical condition of these components reduces the efficiency even by 10%.

3. Analysis of exploitational costs - Results

An exemplary longwall system of the rated power 2.2 MW showed the energy consumption on the level of 1 GWh during the monthly accounting period. This value depends on many external factors, so it cannot be the condition estimator. However, based on this information some savings, resulting from the exploitational policy, can be achieved. For example, an incorrect operation of the cooling system of the longwall shearer motor, which causes an increase of the motor temperature below the warning thresholds, can cause an efficiency drop on the level of 2% [6-7]. Assuming a proportional

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electric energy consumption by a shearer, its monthly consumption will reach 0.45 GWh. An efficiency drop by 2% causes an increase of consumption on the level of 9 MWh during the monthly period. This cost would be connected only with an incorrect servicing of the cooling system. Similar calculations can be performed for other mechanical components and in the case when several irregularities occur, an increase of energy consumption in the range of several dozen MWh will be experienced.

As it is not possible to show irregularities in drive systems based on energy factors, other methods based on monitoring and diagnostics of mechanical systems [8-12] should be applied. A detection and a repair of even small irregularities at the first sight will give serious savings in the scope of electric energy consumption [13].

In the case of the central dewatering systems, the cost of electric energy dominates. Basic components of the dewatering costs have been estimated on the example of the main dewatering pump having typical parameters as given below:

- capacity Q = 500 m^3/h,
- height of rise H = 800 m.

Dewatering costs are composed of:

- investment costs;
- costs of electric energy for the pump drive. The pump of given parameters consumes the power in the order of 1.5 MW. A typical main dewatering pump is operated about 10 hours per day, i.e. 300 hours monthly. It gives the monthly energy consumption in the range of 450 MWh.
- costs of repairs;
- costs of servicing.

From the assessment, presented above, the following conclusions can be drawn:

- The cost of energy, generating over 90% of total costs, dominates in the total cost of dewatering operations with use of a typical main dewatering pump. Therefore, a reduction of dewatering costs should concentrate on a reduction of energy consumption.
- The cost of consumed energy depends on energy efficiency of pumps to a large extent. In difficult mine conditions the initial efficiency of the pump assembly, delivered by the producer, is subject to a change and in a longer period the cost of consumed energy depends on the overhaul policy, which has a decisive impact on an average efficiency of pumps during their operation.

For the parameters, given above, the efficiency of the pump assembly should be at least on the level of 75%, for which the power consumption will reach 1453 kW. However, if the assembly efficiency of such parameters reached 70%, then the power consumption would increase to 1557 kW and for the efficiency of 65% - to 1676 kW. As it can be seen, in the case of above given parameters such a reduction of efficiency means an increase of power consumption in the range of 200 kW. If a pump operates for 10 hours daily, i.e. 300 hours monthly, it gives an increase of power consumption in the order of 60 MWh.

From the point of view of energy efficiency, the amount of energy consumed for pumping 1 m^3 is essential. There is a certain unit value of energy, which should be consumed for pumping the liquid to the height H_g. A minimal value of the e_1 indicator – a consumption of power pumping 1 m^3 of liquid, expressed in kWh/m^3, is its measure [14]. Minimal value of this indicator – $e_{1,min,}$ assuming an ideal flow of liquid is determined by the formula:

$$e_{1,min} = N_{min}/Q = 3{,}6 \cdot 10^{-3} \cdot \gamma \cdot H_g$$

where:

N_{min} – minimal power of pump assembly, kW,
Q – capacity of pump assembly, m^3/h,
γ – liquid specific gravity, kN/m^3,
H_g – geometric height to which the water is pumped, m.

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This factor enables to assess the energy efficiency of a given dewatering system by comparing the real energy consumption for pumping one cubic meter with the minimal consumption. Getting below this minimal unit energy consumption is impossible physically. However, during an exploitation it should be attempted that the real unit energy consumption is higher than the minimum to the possible smallest degree. As it can be concluded from the analyses presented above, the energy demand depends on:

- real efficiency of the pump assembly η_z, which is smaller than one. The overhaul policy and a selection of the pump for the system have the biggest impact on the value of energy efficiency of the pump assembly,
- values of losses in pipelines,
- exploitational policy.

In the case of the main dewatering system, the loading of the system is stationary and therefore the unit energy indicator is a measure of the system efficiency [2]. The following factors have a significant impact on the energy efficiency:

- technical condition of the motor,
- condition of the motor and pumps bearings,
- axiality of shafts lines, condition of clutch,
- rigidity of machine foundation,
- sludge content in water gates,
- collaboration of pumps operated on one collector,
- condition of filters and flaps,
- condition of pipelines.

Each of the mentioned factors has an impact on general efficiency and each 1% of the efficiency drop causes additional monthly costs in the range of 4.5 MWh as in the presented example.

Fan stations are equipped with fans of the power in the range of 750 kW÷1.1 MW. Mining plants possess 2-3 upcast shafts, so the total power of the ventilation system is 2÷3 MW. Fan stations are operated in a continuous mode, so it is possible to indicate a monthly energy consumption of electric energy on the level 1.5÷2.2 GWh. This calculation does not take into an account the systems for air treatment as well as methane drainage systems. An output of the ventilation system depends on the arrangement of underground gates, used local ventilation systems and additional flow resistance occurring in the mine. Due to this reason, the energy factor cannot be used for an assessment of fans technical conditions, however this condition has a direct impact on energy demand. Environmental factors, affecting the output of ventilation system, are regarded to be slow-changing and therefore sudden changes of the energy indicator can signal an incorrect operation of fan station.

Fan stations give a possibility of controlling exploitational parameters which depend on environmental conditions. Due to that it is possible to optimize costs by appropriate control algorithms [15, 16]. In this case savings can even reach 5% of the energy demand.

Another factor, enabling to improve the energy factor, includes diagnostic systems [17, 18]. Due to an early detection of failures the system reliability is increased, which is the priority in this case. It is possible to prevent against destructive processes which have an impact on energy factor. Calculating an average power of a fan station on the level of 1 MW, the monthly demand of electric energy is 720 MWh. Therefore, each 1% of efficiency causes about 7 MWh of additional energy costs.

4. Conclusions

Efficiency of high power machines, operated in a continuous mode, directly and significantly influences electric energy consumption and therefore the costs of exploitation. In relation to the machine class, the policy of its exploitation, loading and control, a series of methods enabling, in an indirect or direct way, to monitor efficiency parameters, can be indicated. In these cases even a minor irregularities can cause essential costs. Therefore, an immediate maintenance personnel's reaction can contribute to an improvement of the economic balance. The most important methods include:

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– specialistic diagnostic and monitoring systems of technical condition,
– advanced control systems, optimized from the point of view of reducing energy consumption,
– exact compliance with the requirements specified in the technical manual, with particular attention paid to overhauls, check-ups and maintenance activities,
– care about exploitational materials, lubricants,
– high competences of servicing personnel.

The presented recommendations and methods are more and more significant in the context of increasing costs of electric energy as well as climatic policy.

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