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Cooling system for high-power drives in belt conveyors

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Abstract:

In mining plants (underground and on the surface), high-power machines are used. Electric motors and the gears driven by them have a specific cooling system as a flow system with an internal heat exchanger. The role of the heat exchanger is to collect the thermal energy generated during the unit operation. The refrigerant with the received thermal energy must be led away from the motor and gear unit, where it will be cooled. In the drives used in underground hard coal mines, water is the cooling medium, supplied through a fire-fighting pipeline. The water used for cooling is often discharged directly to the floor or to sewers, and further it is transported to the surface. The article presents a solution that uses tanks for cooling liquid with highly efficient air-water coolers in surface and underground applications.

Keywords: high-power drives, mining industry, cooling, efficiency, automation of work

1. Introduction

Both in underground coal plants and in surface solutions, machines powered by high-power electric motors (even up to several megawatts) are commonly used. Water cooling system is often a characteristic component of these motors and the gears they drive. Motors and gears are equipped with a flow system with an internal heat exchanger, which collects the thermal energy generated during the unit operation [1-6]. The cooling medium with the collected thermal energy is discharged outside the unit and either cooled in another heat exchanger or replaced with "fresh" cooling liquid [7, 8].

Electric motors used in underground hard coal mining are of explosion-proof manufacture and usually require forced cooling [9-11]. This cooling system uses water supplied through a fire-fighting pipeline. [12-14]. The used water is discharged directly to the floor or to the sewers. In such a case, water consumption is high, which adversely affects the economy, for example due to the need to pump it from the mine underground to the surface.

Observation of the market demand for cooling systems of drive units shows a tendency to use drives with more and more installed power. Therefore, a technical solution was proposed for two cooling systems for high-power belt conveyor drives (up to several MW), both for surface and underground applications.

2. Materials and Methods

2.1 Assumptions

The assumptions are based on a sample documentation of two technical solutions for the cooling systems for high-power, long range belt conveyor drives. One of them concerns the cooling unit used on mine surface conditions, while the other one - the unit located in mine underground workings of potentially explosive atmosphere.

Cooling system for use on the mine surface

It was assumed that on the mine surface, a belt conveyor with four drives (two at each end) with total power of 4,000 kW will be used. Supply voltage will be 400 V, and the operating temperature will range from 258 K (-15°C) to 313 K (+ 40°C).

Cooling system for use in underground mine workings

Two main drives and one auxiliary drive will be used in the operation of a belt conveyor assumed for the underground conditions of the mine. Total power of the drives will be 2,400 kW. As in the previous case, it was assumed that the supply voltage would be 400 V, while the operating temperature would range from 298 K (+25°C) to 303 K (+30°C).

In both cases it was assumed (based on manufacturer's catalogue cards) that the efficiency of electric motors is 93%, while the efficiency of the gear is 85%. The air-and-water cooling system should guarantee that the temperature of the electric motor cannot exceed 353 K (+80°C).

2.2 Determination of power losses

Possibility of selecting the cooling system solution was based on calculations for the amount of generated heat for the adopted drive systems.

Power loss for surface cooling system

It was assumed that the conveyor would be driven by two pairs of driving units located at its ends. Due to the fact that it is a long range conveyor, the distance between the drive units will be significant. Thus, the cooling system will consist of two subsystems located near the drive units. For one dual power unit servicing subsystem (two twin gearbox engines) the calculations are as follows:

$$N_{US} = N_Z \cdot \eta_S \tag{1}$$

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and:

$$N_{UP} = N_{US} \cdot \eta_P \tag{2}$$

where:

$N_{US\,(UP)}$	power output of the electric motor (gear),	
N_Z	installed capacity	1.000 kW,
η_S	motor efficiency	93%,
η_P	transmission efficiency	85%.

In view of the above:

$$N_{US} = 1.000 \cdot 0.93 = 930\ kW$$

and:

$$N_{UP} = 930 \cdot 0.85 = 790\ kW$$

Total loss:

$$N_{losses} = N_Z - N_{UP} \tag{3}$$

therefore:

$$N_{losses} = 1.000 - 790 = 210\ kW$$

For two units:

$$N_{losses-2} = 2 \cdot N_{losses} \tag{4}$$

thus:

$$N_{losses-2} = 2 \cdot 210 = 420\ kW$$

The same power loss was assumed for the second zone. Thus, two separate cooling systems should be built to remove 420 kW of thermal power from each of the zones. A total of 840 kW of thermal power.

Power loss for the underground driving system

In this case, also two cooling zones were established. The first is the motor with a gearbox (installed power - 800 kW) and the second one is a set of two electric motors with gears (installed power - 2 x 800 kW). As before, the sum of the drive power losses was calculated. It is 168 kW for the first zone and 336 kW for the second. Thus, the total power losses in driving systems intended for installation in underground will be 504 kW.

3. Results – Concept of the cooling system design

3.1. Determining the method of cooling the drives

For determination of the method for cooling the drives, it was assumed that the maximum allowable temperature of water flowing from them would not exceed 353 K (+ 80°C). It was also assumed that the maximum ambient temperature will not exceed 313 K (+ 40°C). For these parameters, the heat exchange driving temperature will be as follows:

$$\mathrm{T_W} = \mathrm{T_{WATER}} - \mathrm{T}_{AMBIENT} \tag{5}$$

Then:

$$T_W = 80 - 40 = 40 \text{ K}$$

<u>Selection of coolers for the cooling system used in a conveyor operating in surface conditions.</u>

Two large-size coolers (for example: A 330 manufactured by AKG) were selected to discharge heat in of power 420 kW to the atmosphere (double drive unit for the first case). The view of the cooler is shown in Fig. 1.

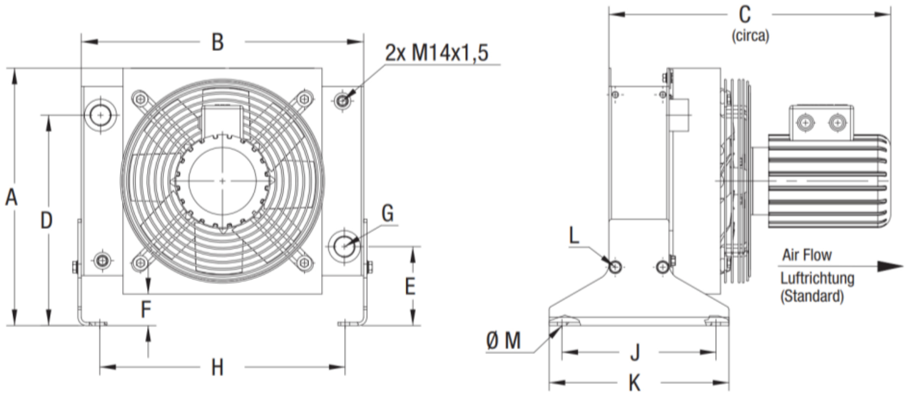

Fig. 1. View of A type cooler [15]

For this type of cooler, cooling power is about 6 kW/K of temperature difference, with a cooling liquid flow of about 300 dm^3/min. For T_W = 40 K and liquid flow as stated, the cooler will receive a thermal power of about 240 kW. Thus, two coolers receive all the thermal power generated by the twin power unit. Cooling power, depending on the cooling liquid flow for the sample coolers is shown in Fig. 2, while Fig. 3 shows the cooling power depending on the flow rate for sample coolers and for the heat exchange driving temperature of 40 K.

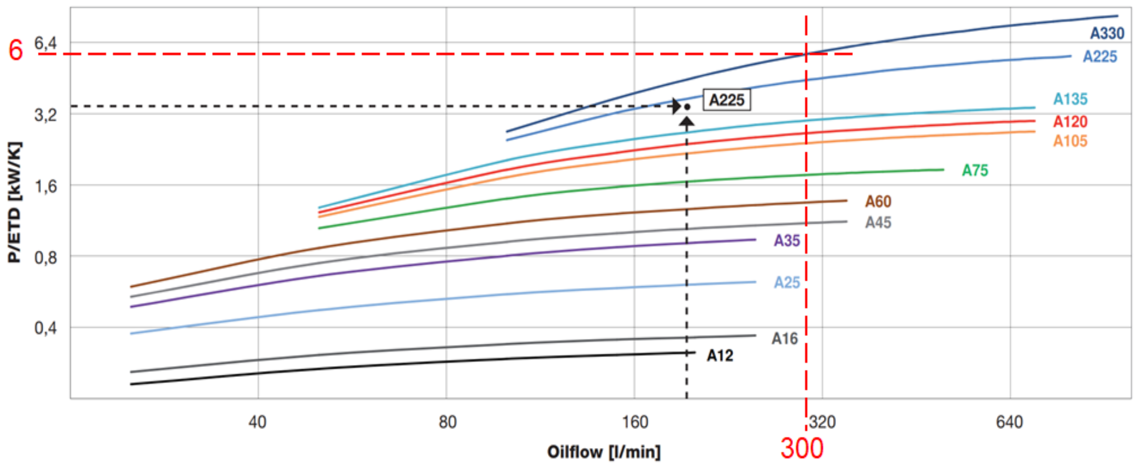

Fig. 2. Cooling power depending on the flowrate of the cooling liquid per 1 deg. of temperature difference [15]

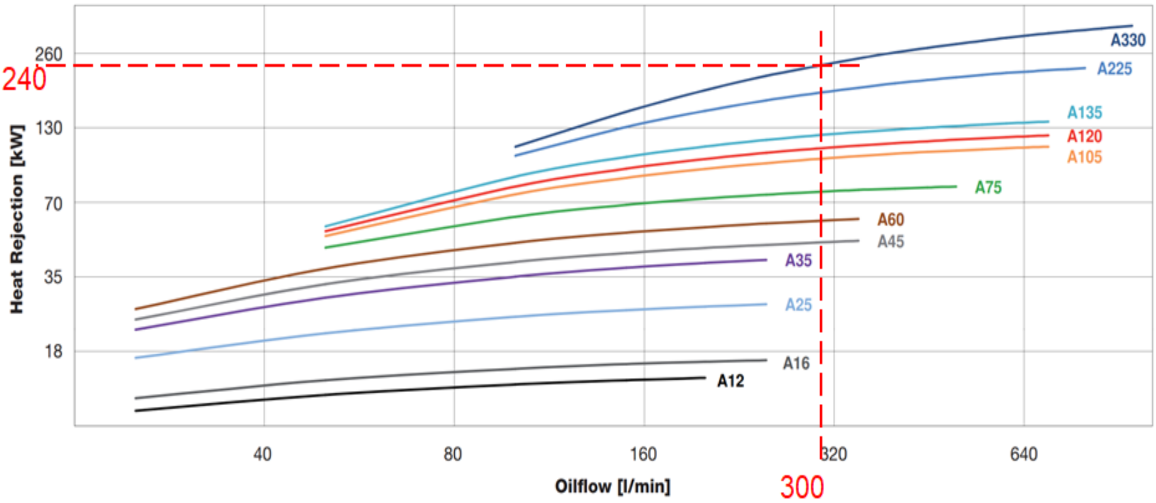

Fig. 3. Total cooling power depending on the coolant flowrate [15]

Selection of coolers for the underground cooling system.

Due to the specific work conditions and necessity of discharging to the atmosphere heat of power 336 kW (double unit from the drive side) and 168 kW (single unit from the return side), basing on calculations, it is necessary to use an ATEX-certified cooler with an electric fan drive (for example OAC2000 from KTR). This cooler is shown in Fig. 4.

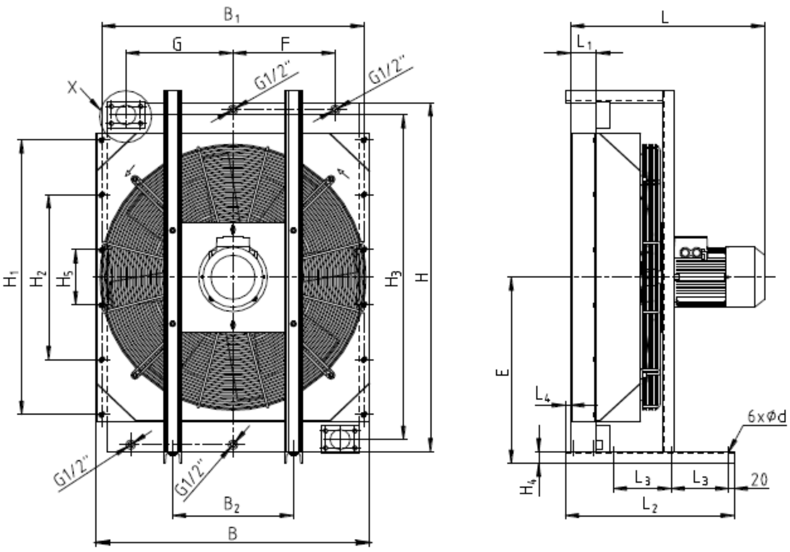

Fig. 4. View of the cooler for use in a potentially explosive atmosphere [16]

For this type of cooler, cooling power is about 4.75 kW/K, with a coolant flowrate of about 300 dm^3/min. For T_W = 40 K and liquid flow as stated, the cooler will receive a thermal power of about 190 kW. Thus, two coolers on the double drive side and one on the single drive side receive all the heat output generated by the driving unit. Cooling power depending on the cooling liquid flowrate for the sample coolers is shown in Fig. 5.

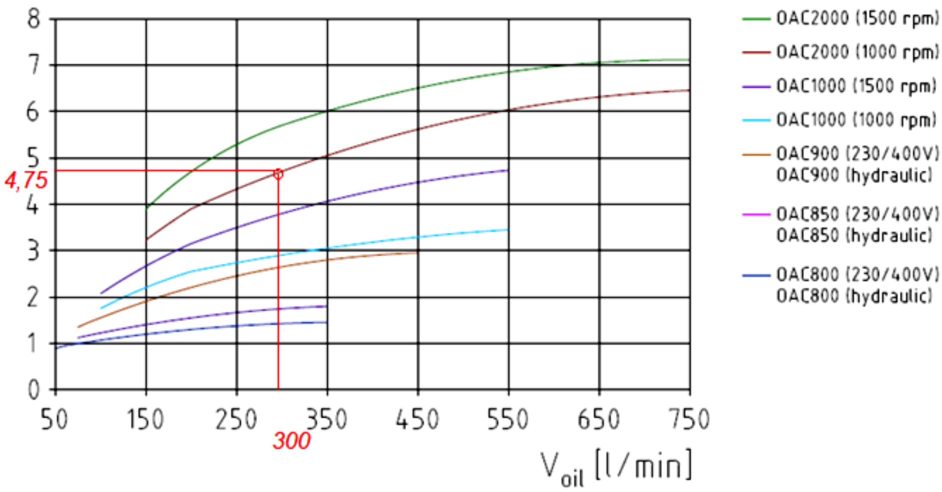

Fig. 5. Cooling power depending on the coolant flowrate for the sample coolers [16]

3.2. Design of the cooling system

An over 500 dm³ liquid tank was accepted for the cooling unit. The tank will work without overpressure and will be equipped with a venting system and liquid level measuring system. For surface applications, the tank (its design and materials used) should comply with the boundary conditions, i.e. maximum operating temperature (maximum 353 K) and resistance to the cooling liquid. However, for underground applications, the tank must be made of steel with the surface properly protected against weather conditions, or of stainless steel (for example, the BNK tank by KTR). An example of a tank is shown in Fig 6.

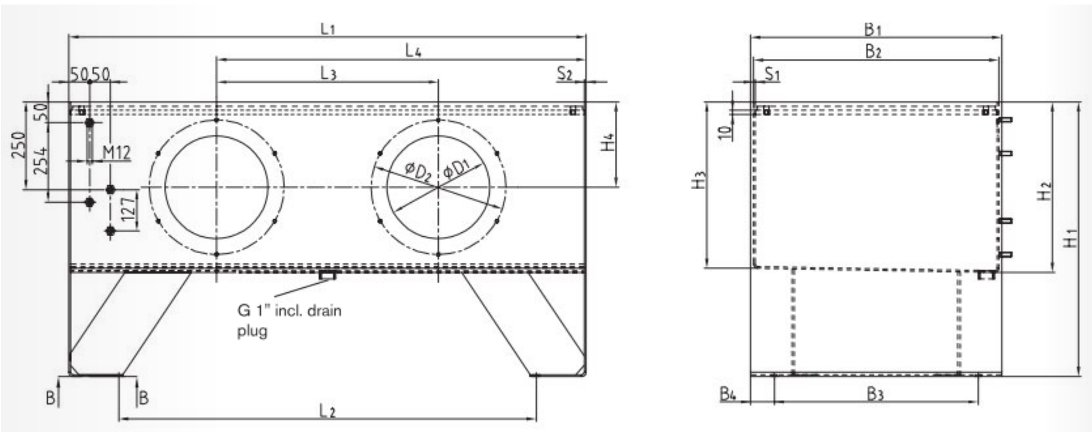

Fig. 6. Sample tank for a coolant [17]

Centrifugal pumps with a capacity of 150 dm^3/min were used to ensure proper circulation of the liquid coolant in each system. In the case of a dual cooling system, the pumps will operate in a twin system, connected to the coolant collector. The pump (or pump system) will pump the coolant first to the flow cooling system of the electric motor, and then to the flow cooling system of the gearbox. Sensors for the flow and temperature of the cooling liquid will be installed on the discharge pipeline, behind each pump. If the cooling system is installed on a double conveyor drive system, the motor-gear units will be supplied in parallel. A coolant temperature sensor will be installed at the outlet of each unit. Streams of liquids flowing out of the cooled objects will be combined, and the total stream will be led to the air-water cooler (or the system of coolers). A pressure sensor will be installed in front of the inlet to the radiator (system of coolers) to protect the radiator against excess pressure. Water will be drained off through a filter with an indicator of insert contamination. For such a large system, it is planned to use one additional pump, which would be turned on automatically after

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detecting a failure of one of the main pumps. Cooling systems will be equipped with a device measuring the coolant level in the tank and signalling its low level (in the case of leaks in the installation) and temperature sensors informing about the correct operation of the installation. In the case of incorrect operation the control system activates emergency pumping unit. The entire operation of the system will be supervised by the central control system.

Fig. 7 shows a diagram of the surface cooling system of conveyor belt drives with a cooling capacity of 2 x 420 kW, while Fig. 8 shows a diagram of an underground cooling system for belt conveyor drives with a cooling capacity of 345 and 168 kW (for each site, respectively).

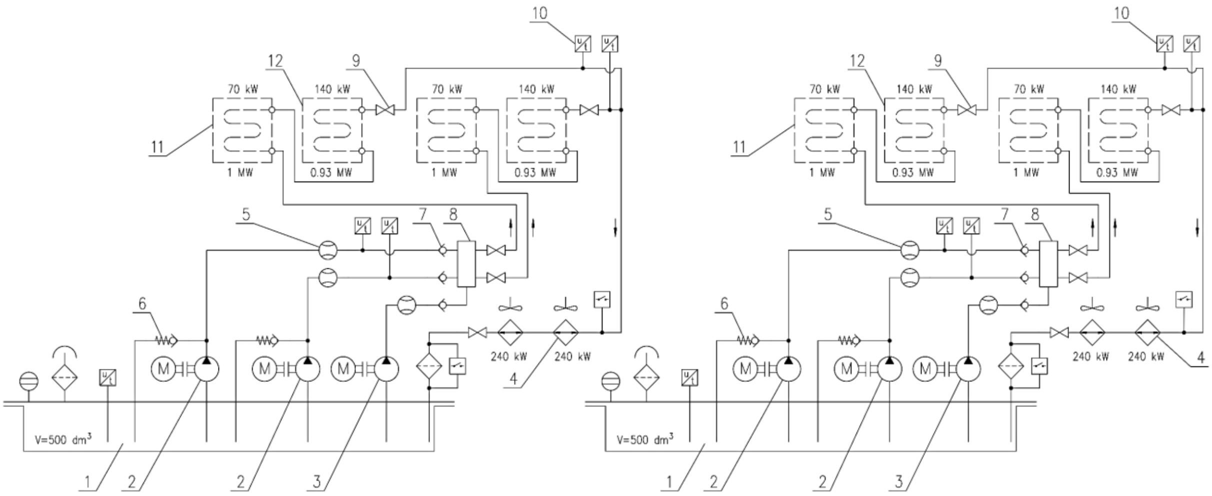

Fig. 7. Diagram of the surface cooling system of conveyor belt drives: 1 - tank, 2, 3 - pump units, 4 - air-water cooler, 5 - flow meter, 6, 7 - check valves, 8 - collector, 9 - cut-off valve, 10 - temperature sensor, 11 - electric motor flow system, 12 - gear flow system

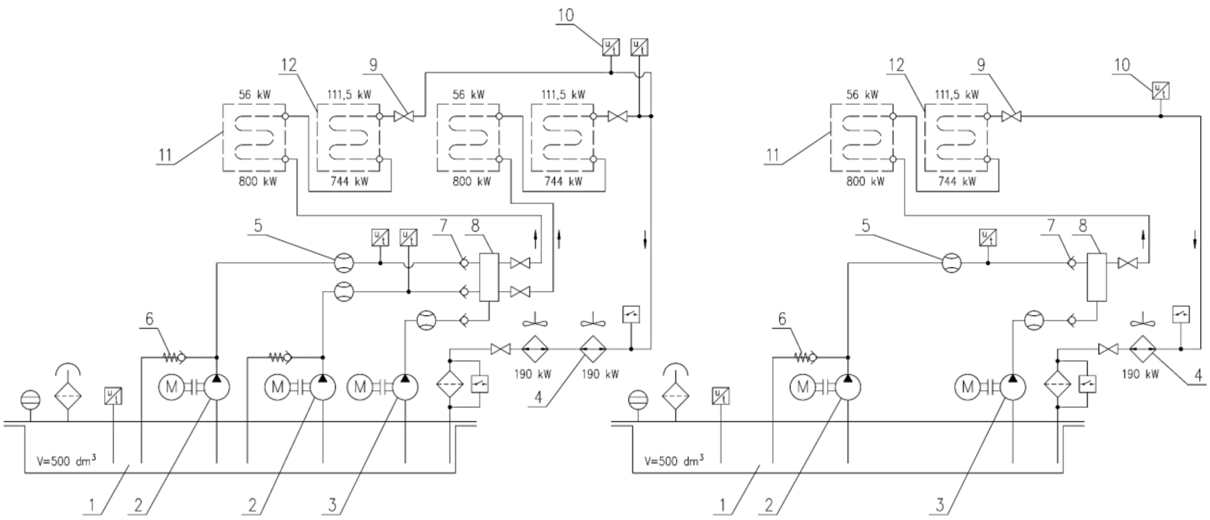

Fig. 8. Diagram of the underground cooling system of conveyor belt drives: 1 - tank, 2, 3 - pump units, 4 - air-water cooler, 5 - flow meter, 6, 7 - check valves, 8 - collector, 9 - cut-off valve, 10 - temperature sensor, 11 - electric motor flow system, 12 - gear flow system

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4. Analysis of the possibility of modifying the cooling system when changing the operating parameters of the drive system - Discussion

Higher reliability of the conveyor drive would limit generation of heat. This enables manufacture of smaller and less energy-consuming heat exchange systems. Nord gearboxes (MAXXDRIVE XT), the design of which does not require additional cooling are a good example. They are designed for the conveyor belt drives, and the cooling power reaches up to 2,100 kW. The gears can operate at an ambient temperature of up to 313 K (+40°C), have steel bodies and ATEX certificates, which allow the drive unit to be used in mine underground. They have a greater efficiency, which reduces power losses reducing at the same time generation of heat. low-noise operation, which is also important in workings is an additional advantage. Fig. 9 shows sample gear unit and Fig. 10 shows sample drive unit.

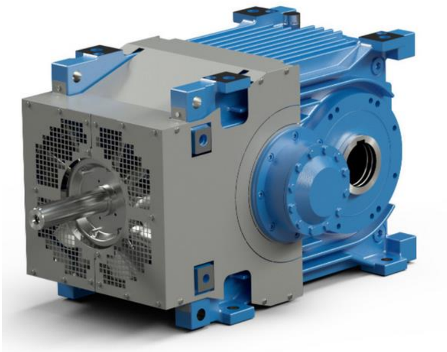

Fig. 9. Helical-bevel gear requiring no additional cooling [18]

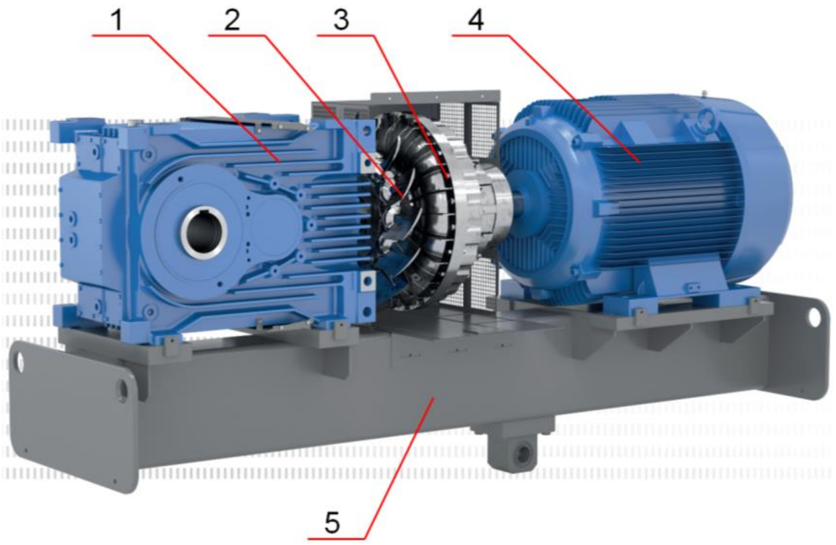

Fig. 10. Sample of Nord drive unit [18]
1 - gear, 2 - fan, 3 - hydrokinetic gear, 4 - electric motor, 5 - base

The gears are cooled only with air and therefore there is no need to collect heat generated by the gear and only electric motors would require external cooling. This will significantly simplify the manufacturing of the cooling system, and thus reduce the cost of investment and subsequent servicing. The diagram of more efficient cooling system of the underground drive, is shown in Fig. 11.

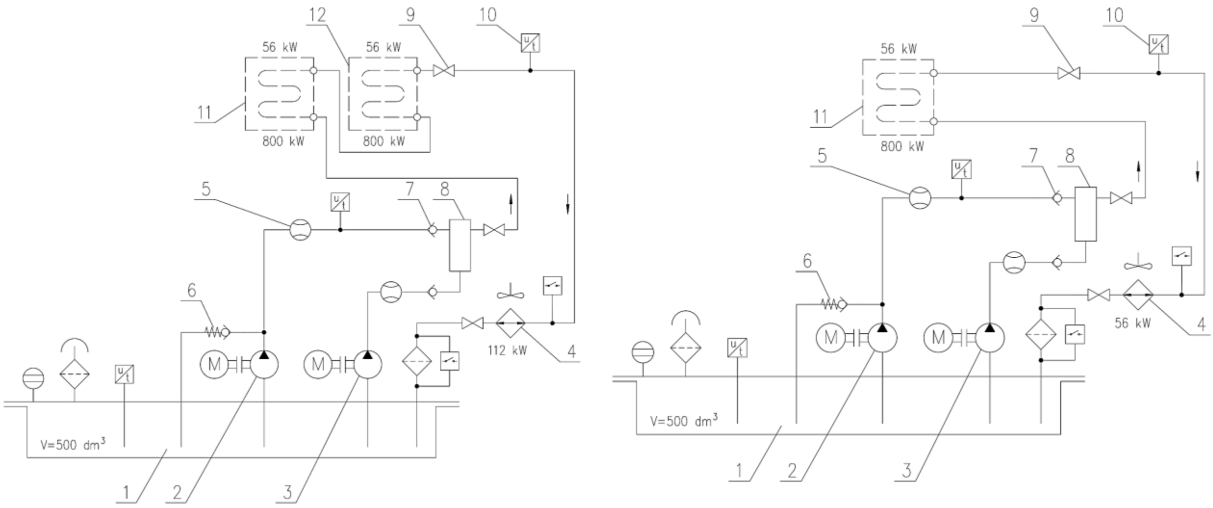

Fig. 11. Diagram of the cooling system of the underground drive with the use of a gear with higher efficiency: 1 - tank, 2, 3 - pump units, 4 - air-water cooler, 5-flow meter, 6, 7 - check valves, 8 - collector, 9 - cut-off valve, 10 - temperature sensor, 11 - electric motor flow system, 12 - gear flow system

We can also verify the electric motors themselves, as each manufacturer tries to improve their efficiency. Currently, the efficiency of state-of-the-art electric motors made for the mining industry reaches 94.5%, and the efficiency of electric motors manufactured according to energy-saving procedure - even 96%.

5. Conclusions

The concept of a closed cooling system for machines powered by high-power electric motors, intended for use in mine underground and mine surface was presented. The use of a closed cooling system, in which the coolant will circulate from the tank through the cooled object to the cooler, will eliminate the need for water intake from the fire pipeline. In a closed system, it will be possible to use a coolant with anti-corrosive additives that will preserve the machine's cooling systems. This should reduce the costs of using and servicing the machines powered by electric motors. Despite the independence of the closed circuit unit from water supply via a fire protection system, its main disadvantage (in relation to the open system) is the significantly higher manufacturing cost, related mainly to the need to use a cooler and a coolant tank. An important element when using high-power cooling systems in underground workings is that the heat collected from the system and released to the atmosphere, in the case of narrow underground tunnels generates the need for intensive ventilation. Assuming that air temperature at the input to the cooling zone of a closed system with cooling power of 345 kW is about 303 K (+30°C), and at the output it cannot exceed 313 K (+40°C), the minimum flowrate of the ventilated air should be determined. Thus, for the air heat capacity of 0.32 Wh/m^{3}K, assuming a temperature increase of 283 K (+10^{O}C), the air should pass through the cooling system zone with flowrate of about 30 m^3/s. For example, for the working cross-section area of 17.6 m^2 (the ŁP10 roof support), the minimum air flow speed should be about 1.7 m/s in the full cross-section of the working. In narrow workings, this speed increases. Simple calculations show that there is a problem to dissipate such large amount of heat. Especially due to the fact that the air receiving heat from the cooling system continues to migrate in the mine workings, significantly worsening the comfort of personnel work and conditions for machines operation.

As the analysis of the possibility of modifying the system showed, even a small percentage reduction of losses at such high power causes a significant reduction in the cooling system and a significant reduction in the costs of its implementation. Thus, in the final selection of the cooling system, it is necessary to precisely define the conditions of its operation and its impact on the atmosphere in mine workings.

The use of state of the art drive units, consisting of highly efficient electric motors and gears, will enable constructing the smaller cooling systems of lower production costs.

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