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Simulation features of the impeller in a centrifugal pump

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Abstract:

To ensure the operability of machinery and equipment for the oil and gas industry, it is important to study their operation with subsequent improvement. This scientific work is devoted to highlighting the operation simulation of the impeller in a submersible centrifugal pump, because the pump itself is the main equipment in oil production. The main parts of a submersible centrifugal pump are its stages, consisting of an impeller and a guide vane. When the impeller rotates, a force interaction of the flow with the impeller blades occurs, while a pressure difference in the fluid flow on both sides of each blade arises. The pressure forces of the blades on the flow create a forced rotational and translational motion of the fluid, increasing its mechanical energy. It should be noted that the movement of fluid in pump sections is a rather complex process that is difficult to accurately describe analytically. However, today there are various computer programs (SOLIDWORKS FlowSimulation, ANSYS CFD, etc.) based on the finite volume method (FVM). To study the operation of a submersible centrifugal pump impeller, there has been built its three-dimensional model. As a result of calculations, the distribution of pressure and velocity in the cross section of the impeller was obtained.

Keywords: impeller, pressure, simulation, speed, submersible centrifugal pump

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1. Introduction

In the oil and gas industry, pumps with different principles of operation and structure are usually used. However, in the production and transportation of oil, in most cases, dynamic pumps (mainly centrifugal pumps) are used [1,2].

In all dynamic pumps, the liquid is accelerated (its speed increases) in the inter-blade channels of the rotor, thanks to the blades, and it is decelerated (the speed decreases) in the channels of the stator (guide vane), that is, the kinetic energy of the liquid is converted into potential energy in the stator. The acceleration and deceleration process can occur once in one pump stage or repeatedly or sequentially in several stages of a multistage pump [3,4].

Fig. 1 shows a diagram of a sectional (one section) centrifugal pump [5].

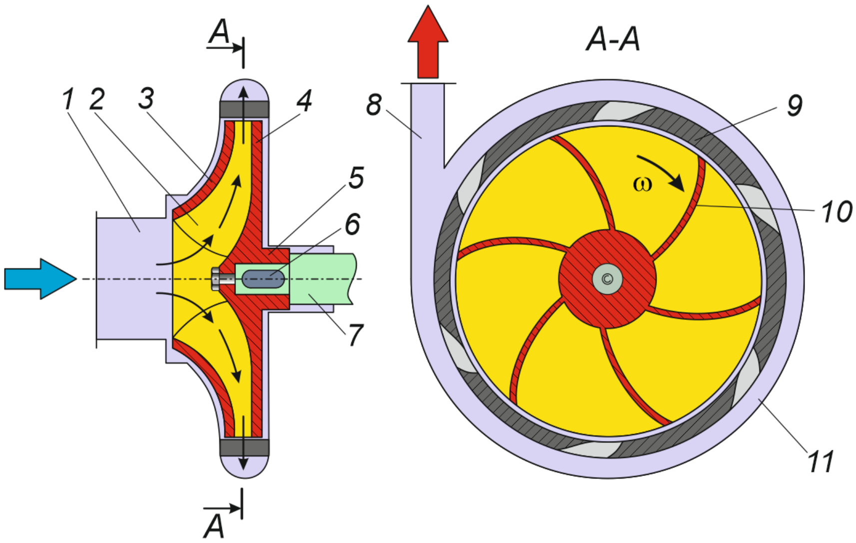

Fig. 1. Scheme of a sectional pump (one section)
1 - inlet pipe; 2 - impeller; 3,4 - impeller disks; 5 - hub;
6 - key; 7 - shaft; 8 - outlet pipe; 9 - guide vane;
10 - blades; 11 - annular branch

In sectional pumps, a guide vane element (stator) is used, in which the set of channels in the direction of fluid movement expands, leading to the transformation of the kinetic energy of the fluid into the potential one. In scroll pumps, this process takes place in a volute chamber [6].

When the wheels are connected in series, each of them creates a part of the total head, and the value of the pump head increases from impeller to impeller to the total value at the outlet (Fig. 2, Fig. 3) [7].

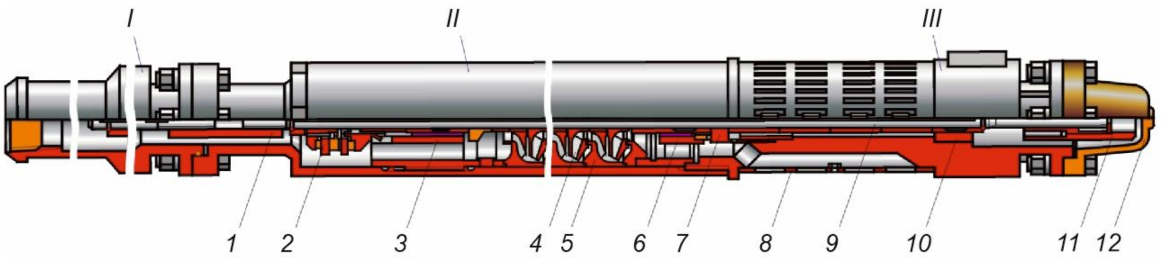

Fig. 2. Submersible centrifugal pump
I - head module; II - module-section; III - input module;
1 - splined coupling; 2 - knot of a support claque; 3, 6 - radial bearings;
4 - impeller; 5 - guiding element; 7 - support for the lower claque; 8 - mesh;
9 - shaft; 10 - radial bearing; 11 - splined coupling; 12 - protective cover

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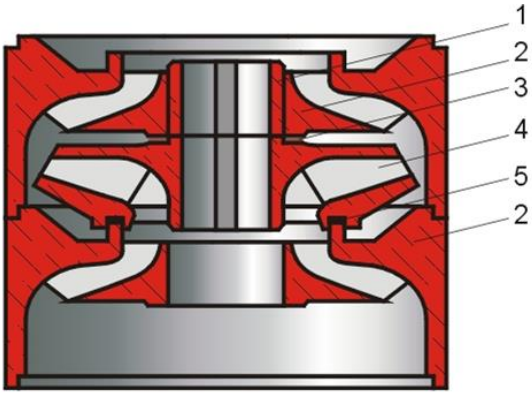

Fig. 3. Stage of a submersible pump
1 - protective sleeve; 2 - guiding device; 3 - top washer;
4 - impeller; 5 - lower washer

In centrifugal pumps, used in oil production, closed impellers are usually used. They most often contain 6 ... 8, and sometimes up to 12 vanes.

The geometric shape of the rotor blades has a significant effect on the head, flow and power of the pump. Centrifugal pumps mainly use backward curved vanes.

The movement of a real fluid in the interblade impeller channels is a rather complex hydromechanical process. Therefore, it is not possible to obtain the equation of motion in a purely theoretical way for a real centrifugal pump. For ideal conditions, the theoretical equations of fluid movement in the interblade channels of dynamic hydraulic machines (vane pumps and hydraulic turbines) were obtained by L. Euler. In such an impeller, the fluid moves in elementary streams (there is no phenomenon of a relative vortex), and the flow velocities, relative to the stationary walls of the housing channels, are the velocities of absolute motion. The scheme with an unlimited number of vanes in the impeller of a centrifugal pump leads to an elementary theory of the kinematics of the flow in the impeller.

When the fluid moves through the channels of the impeller with a limited number of blades, the nature of the flow changes significantly (Fig. 4). The relative movement in the interblade channels can be schematically considered as the sum of the movements: I - the movement of the fluid in the moving channels; II - vortex motion inside the interblade channels.

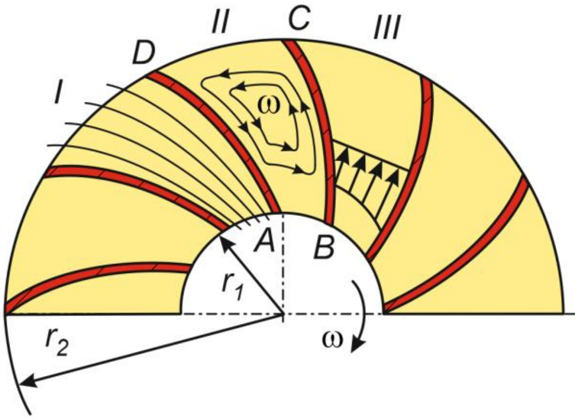

Fig. 4. The movement of fluid in the interblade channels of the impeller
I - fluid movement in the moving channel; II - vortex motion in the interblade channel;
III - velocity diagram in the interblade channel

The purpose of the work is to highlight the simulation features of the operation of a submersible centrifugal pump impeller.

2. Materials and Methods

Today, special computer programs based on the finite element method can be used to study the motion of a fluid flow in an impeller. These include, for example, SOLIDWORKS FlowSimulation, ANSYS CFD, etc. [8-11].

For the study, a three-dimensional model of a submersible centrifugal pump section (Fig. 5) was built. Fig. 6 shows a model of the impeller 2, located in the guiding device 1. It should be noted that the guiding device 2 (Fig. 3) is of an arbitrary shape, since the characteristics of the impeller are of interest for this study. In the future, it is planned to investigate the liquid movement through the whole section of the centrifugal pump.

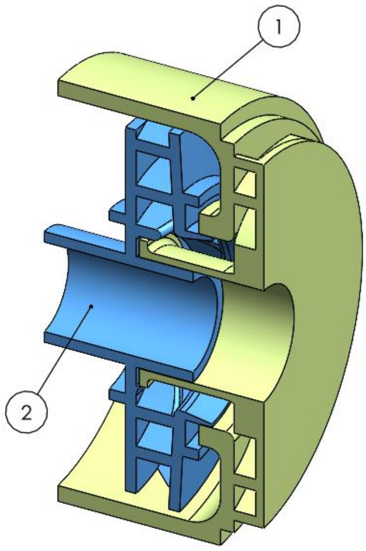

Fig. 5. A three-dimensional model of a submersible centrifugal pump section
1 - guiding device; 2 - impeller

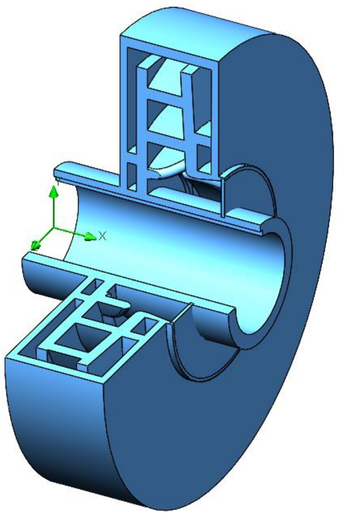

Fig. 6. Impeller model for the simulation

The input data for simulation are taken as follows: working medium - water; outlet pressure - atmospheric (1 atm); the flow rate of the working medium - 0.002 m^3/s; impeller rotational speed - 2820 rpm.

The design scheme is shown in Fig. 7. A feature of specifying the rotation of the pump impeller is that the program sees the entire model as a rotating one. Next, it is needed to choose the surfaces of the model that should not rotate and indicate them in the program window (Fig. 7). In our case, all internal surfaces of body 2 are chosen (Fig. 8).

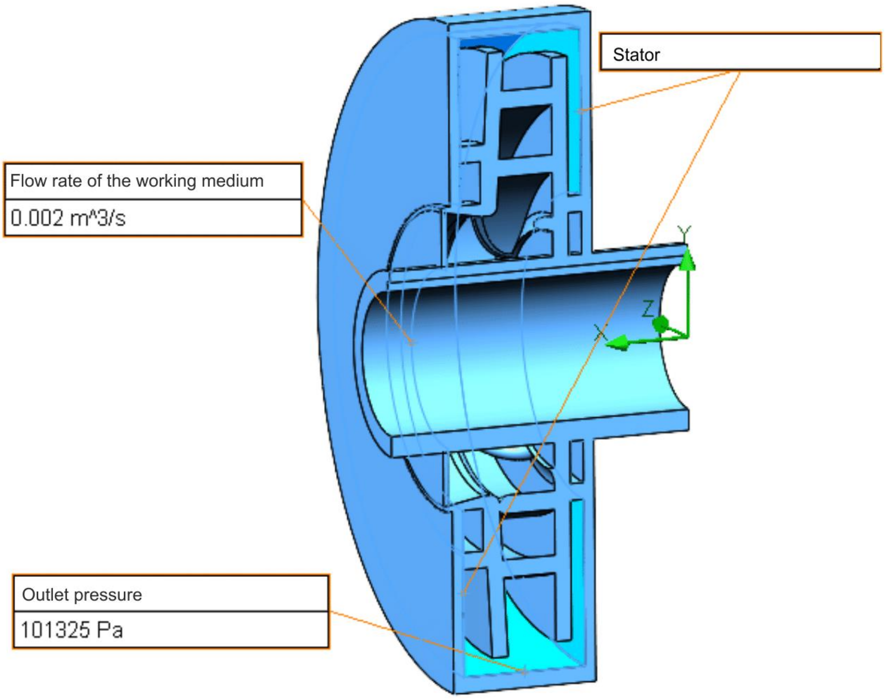

Fig. 7. Design scheme

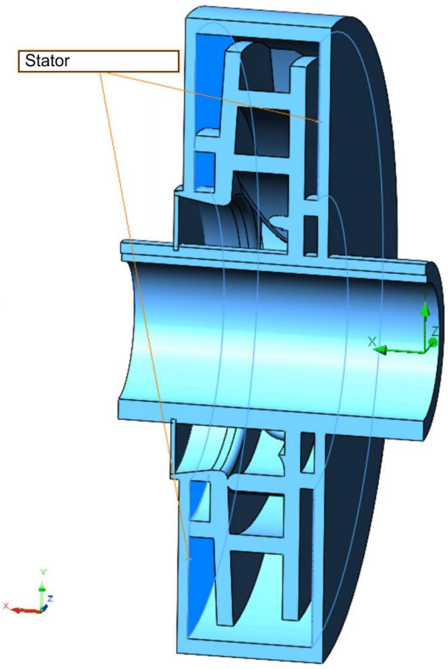

Fig. 8. Selecting model surfaces that should not rotate

After applying all the constraints and tasks of the initial data, the simulation process of the centrifugal pump impeller is started.

3. Results

Let us analyze the simulation modelling results presented in the form of the corresponding diagrams. Fig. 9 shows pressure distribution in the cross section of the studied centrifugal pump impeller, and in Fig. 10 - velocity distribution in the same section.

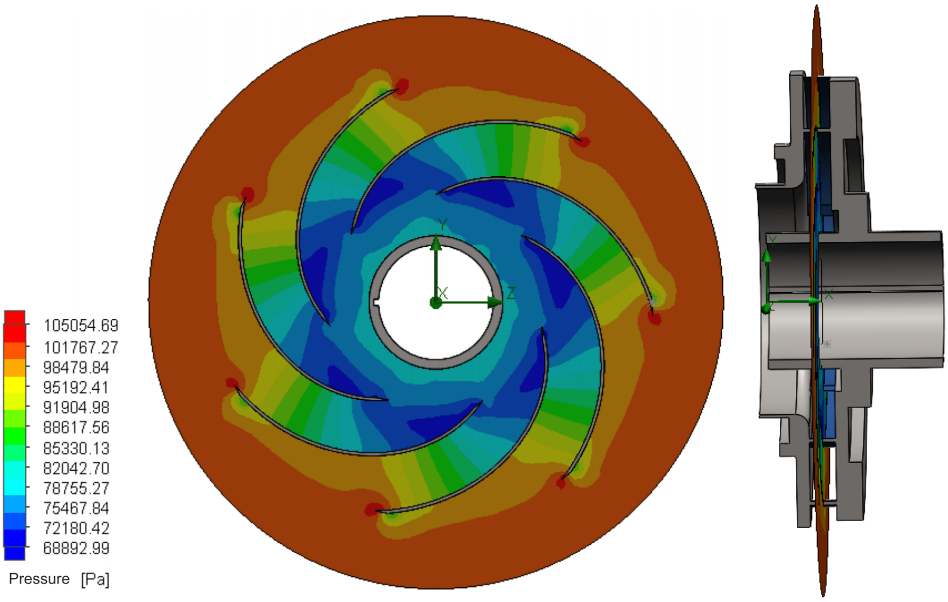

Fig. 9. Pressure distribution in the cross section of the impeller

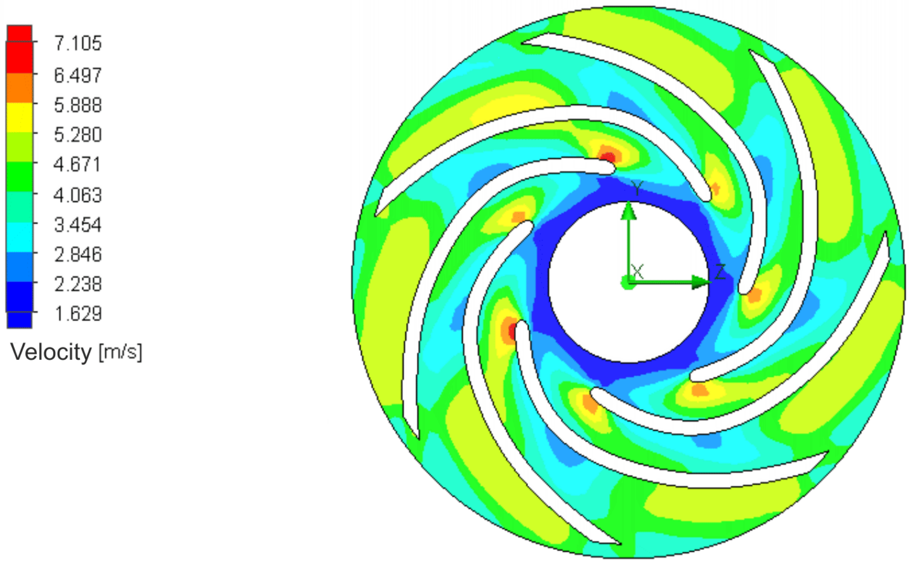

Fig. 10. Velocity distribution in the cross section of the impeller

4. Discussion

The given diagrams show the zones of change of the considered parameter with a wide range of colours. Considering the diagram of Fig. 9 changes in the pressure distribution, it can be seen that in the path of fluid flow through the interblade channel of the centrifugal wheel there are areas with minimal values of pressure at the beginning of the blade with a gradual increase in pressure towards the periphery. It is interesting that the pressure decreases from the inlet towards the beginning of the centrifugal wheel blade with its subsequent growth. Regarding the distribution of fluid flow velocity in the cross section of the impeller, there are areas where the velocity increases sharply. These zones are concentrated near the wheel blades at the inlet of the fluid. This phenomenon leads to an increase in the hydraulic resistance of the fluid flow, and as a consequence to a decrease in the hydraulic efficiency of the pump stage. Also in the zones of speed increase, depending on the pressure, the phenomenon of cavitation can occur, which negatively affects both the impellers and the characteristics of the pump as a whole. It should be noted that the results obtained correspond to the theory of fluid motion in the interblade channels of the impeller. The proposed method of simulation tests allows to design and optimize the design of the impeller depending on the required parameters at the pump outlet, taking into account the characteristics of the pumped liquids.

5. Conclusions

From the research work described in this paper, the following conclusions can be drawn:

- features of simulation enable to determine the amount of pressure generated by the wheel of the centrifugal pump depending on the required parameters of fluid flow at the pump outlet;
- the above simulation algorithm can be used when studying the movement of fluid through the section of the centrifugal pump, taking into account the real conditions of its operation (temperature, physical properties of the fluid, etc.); optimization of the geometric parameters of the impeller in order to increase its efficiency can be conducted.

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Concept of a CDR resonance screen

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Abstract:

Review of existing solutions of resonance screens, including their technical parameters are presented. The following resonance screens are discussed: GHH type, multi-mass ZDR type, GRO-1 type, EGK-2 type, CDR-8 type, etc. On this basis, the strengths and weaknesses of the discussed solutions of resonance screens are identified. Conclusions resulting from the analyzes of the applied solutions were used in KOMAG to develop the concept of the CDR-85K resonance screen. The assumptions made during development of the concept of a new resonance screen solution are presented, and then its structure and principle of operation are discussed. A general drawing of the designed screen with selected parts is provided. The attention was paid to the innovative solutions used in its design.

Keywords: CDR resonance screen, minerals classification

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1. Introduction

Mechanical processing is one of the basic branches of technology for mining the useful minerals. Its task is to refine the extracted raw minerals and prepare them for further use in the form of raw materials, and even to prepare the finished product.

The mineral extracted from the deposit requires preparation, before it is directed to industrial use or for direct sale, consisting in the maximum increase of the useful component content per volume (or mass) unit. Almost all useful minerals, such as hard coal, lignite, iron and non-ferrous metal ores and many others are processed mechanically. Mineral processing, due to their nature, can be divided into the following: preparatory, main, complementary, auxiliary and service [1, 2, 3].

Mechanical classification enables separating the raw material or beneficiation products into the required grain size classes. Mechanical classification is also known as screening. During many years of designing work supported by operating experience, a large number of various design solutions for screens were created. There are two main groups of sieves: screens and grates. This article focuses on resonance screens that belong to the group of vibrating screens [4, 5, 6, 7].

2. Materials and Methods

A resonance screen is a device used in mechanical processing as part of mechanical classification (screening). Technological activities on raw material and processing products are intended to give them such properties that enable their further industrial use.

These types of screens belong to a group of flat screens, the largest group of machines used for screening raw materials and beneficiation products.

The design of flat screens allow, regardless of the dimensions of the openings in the screens, a very high degree of screening accuracy and selecting the characteristics of vibrating motion of the screen box or screen, which enables screening of difficult-to-screen material, i.e. containing a significant amount of the finest grains with a relatively high content of surface water. A significant increase in screening efficiency is also achieved by introduction of new design of screens, especially those self-cleaning from the moist fine grains adhered to them [1, 8, 9].

Design of the screen that would allow reaching the best accuracy of screening, regardless of the assumed quality parameters of the raw material, is not possible. This is because these parameters affect the screening accuracy [10].

It is necessary to increase the vibration frequency of the screen to improve screening efficiency. The forces acting on each grain during the screening process range from 4 to 5 G. Screen structure should be analyzed and simulated during the designing process, together with identification of phenomena appearing during operation [11, 12, 13, 14].

Flat screens, regardless of their design and the drive type, are equipped with practically all the components of a typical screen, i.e. screen boxes properly supported or suspended on a supporting structure, a separate supporting structure with a more or less complex structure, drive and parts transmitting movement from the drive to the sieve box or boxes, or transferring the movement to the sieve (sieves) with stationary sieve boxes [2, 15, 16].

Unlike the other flat screens, resonance screens do not have a rigid connection of drive joints with screening boxes. Only in some designs, connection between joint and the screen box holder was made flexible by rubber cushions or rubber ring inserts. Such elastic inserts were intended only to reduce the load to the drive shaft at the moment of changing the direction of the screen box movement and did not affect the nature of the screen box vibrations or the overall dynamics of the screen movement. However, they made it possible to increase the frequency of screen box vibrations and to achieve a more powerful lift of the screened material layer and its better loosening [1]. The principle of operation of the resonance screens is presented in Fig. 1. The set of rubber bands 3, set in a pendulum motion, drives the upper and lower riddle 1 and 2, which, due to the flexible suspension on leaf rockers, swing in opposite directions. The screening process takes place on the screens installed in the riddle.

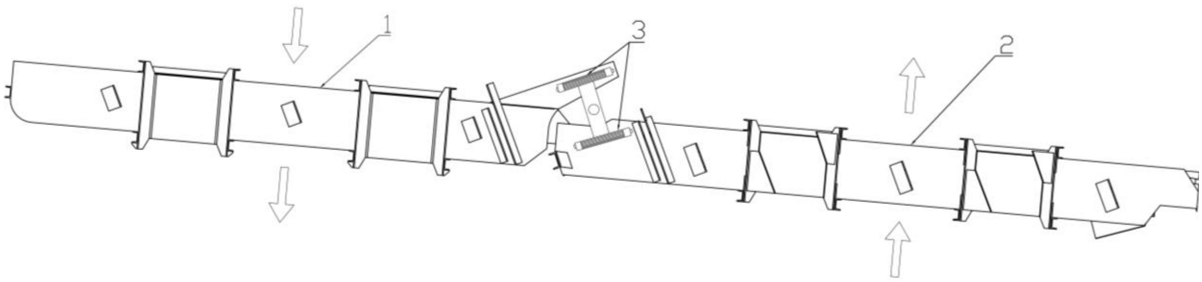

Fig. 1. Principle of operation of resonance screens

Introduction of dynamically balanced vibrating mass systems and flexible (elastic) suspension of the drive unit made it possible to increase vibrations of the screen boxes, as well as to limit the harmful effect of inertia forces on the screen parts and their transfer to the supporting structure of the building. However, in the screens designed in such a way, a significant amount of energy supplied to generate the vibrating motion of the screen boxes is used to overcome inertia forces of accelerated masses of the vibrating system at the moments of constantly changing direction of these boxes fluctuations. Magnitude of these forces is the greater, the larger and heavier the screen boxes and the amount of material fed to them are, and the greater is the stroke of the boxes and the greater the frequency of vibrations (to increase the lifting energy and at the same time accelerate the movement of the screened material layer and increase their efficiency) [1, 11].

The design of resonance screens was developed to solve the problems of dynamic loads and excessive energy consumption needed to overcome the inertia forces in the direction changes/vibrations of the screen boxes, not used for the operation of the screen. Resonance screens belong to the group of flat screens, with the pendulum movement of the screen boxes, therefore, during their working motion, inertia forces also appear, when direction of vibrations of the screen boxes changes [1, 11, 17, 18].

In connection with the work undertaken on a new solution of the resonance screen, several types of resonance screens, differing in design were analyzed in literature.

2.1. GHH resonance screen

The GHH resonance screen (Fig. 2) is a resonance two-mass vibrating system.

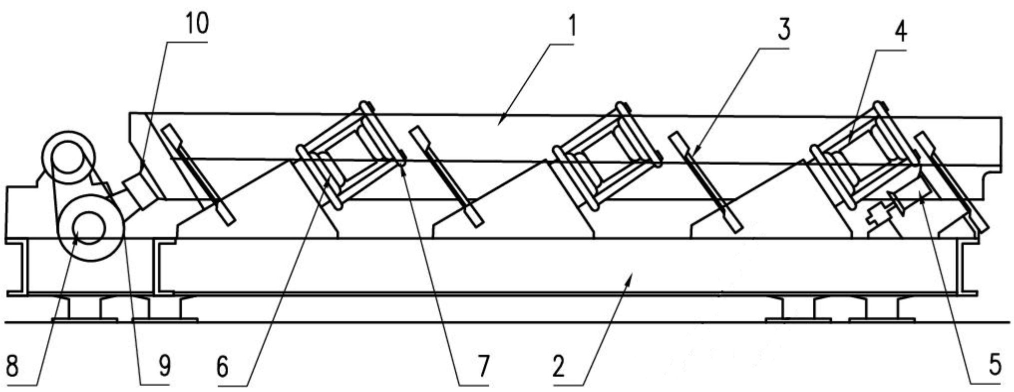

Fig. 2. GHH resonance screen

The horizontal screen box 1 is set on inclined spring slats 3 on a lower steel frame 2 made of profile steel with a closed box cross-section. Three pairs of buffer position limiter 4 are fastened to the screen box. The screen box and the frame vibrate freely in the range close to the stroke of the system of both vibrating masses. When the direction of vibrations changes, the buffer supports hit the elastic rubber cushions in which kinetic energy (as potential energy) is stored. This energy is transferred to the vibrating system after passing the turning points of the vibrating masses.

Elastic rubber cushions 6 are attached to the trestles by threaded bolts 7, enabling their middle positioning in relation to the buffer resistance 4. The rubber cushions are fixed in special mountings for plates, the position of which is determined by nuts on the bolts 7. Total width of both slots is slightly smaller than the stroke of the screen box.

The screen box is coupled to the frame 2 with an elastic rubber cushion 5. The drive motor set on the frame 2 drives the cranked shaft 8 with a system of V-belts, on which the drive couplings 9 are placed. These links are connected to the screen box by double-sided elastic rubber cushions 10. This system is known as a free coupling. The vibrating frame 2 is set on the foundation on sets of elastic rubber cushions, allowing it to vibrate freely.

These types of screens are designed with a screen working width from 1000 to 2200 mm and the length from 4500 to 7500 mm [4].

2.2. ZDR multi-mass resonance screen

ZDR screens are marked by high efficiency, low power consumption, high screening efficiency due to good loosening of the screened material layer and negligible dynamic impact on the building.

Diagram of ZDR resonance screen is shown in Fig. 3.

Its design consists of two screen boxes 1 and 2 placed on sets of elastic slats 3 on two separate frames 4 and 5, balancing weight of the screen boxes. The frames are set on elastic rubber rings 6 and 7 and additionally fixed to the base by sets of springs 8 and 9, bent in the shape of the letter S. The arrangement of these springs provides additional protection of the entire vibrating system against excessive vibrations. Screen boxes and the frame are additionally coupled with flexible couplings 10 and 11. Each screen box is equipped with two pairs of sets of elastic rubber rings 12 and 13, built into trestles 14 and 15 fixed to the frames. The rubber ring assemblies rest against buffers 16 attached to the screen boxes. Stroke of the boxes is limited by rubber bumpers 17.

The motor 18 drives the shaft on which the eccentrics are wedged through the V-belt transmission. Driving connectors 19 are bearing mounted on the eccentrics and are connected to the first screen box via flexible couplings, which make it swing. The first frame is set in motion by the dynamic action of the eccentric shaft thereon. The first oscillating system sets the second screen box and the second frame into motion via clutch links 10 and 11. Stroke of the screen boxes is determined by pre-compressing the rubber ring assemblies and selecting the radius of the eccentrics.

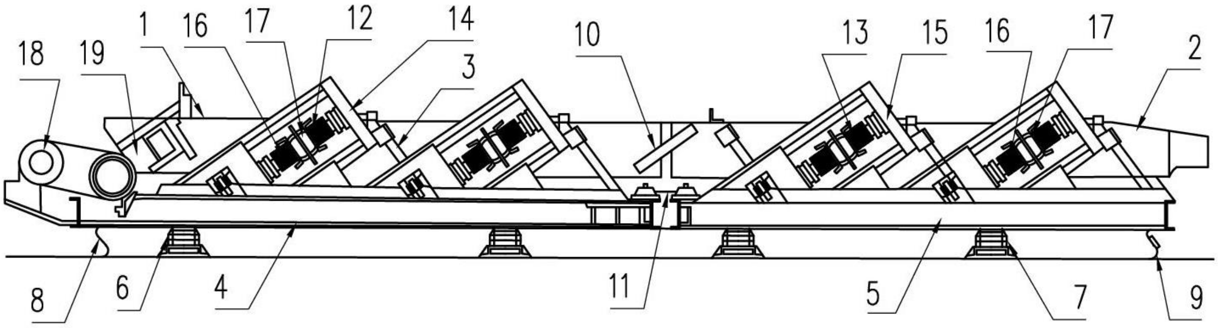

Fig. 3. ZDR resonance screen

ZDR screens are designed in two different sizes, with a screen box width of 1800 and 2000 mm, and with a screen working surface of 17 and 21 m^2. They have a capacity of 300 and 350 t/h. The screen boxes vibrate at a frequency of 800 cycles per minute with an amplitude of 16 mm. The screens are powered by motors with a power of 13 and 17 kW [5].

2.3. GRO-1 triple-mass resonance screen

The group of resonant screens also includes a box resonance screen in a triple-mass system, shown in Fig. 4.

The screen boxes 1 and 2 are positioned horizontally on the swing rods 3 on a joint frame 4, which is equivalent to the mass of both screen boxes. The frame is set on a foundation on elastic rubber cushions 5, enabling the frame to vibrate in resonance with the screen boxes.

In the trestles 6 fixed to the frame, groups of rubber rings 7 are mounted, resting on the support 8 fixed to the screen box. Beneath both sets of rubber rings, rubber buffers 9 are fixed, limiting the stroke of the screen box. The motor drives the eccentric shaft 11 through a belt transmission. The eccentrics bear the drive connectors 12, connected to the screen box with a double-sided set of rubber rings 13. Drive connectors 12, connected to the screen box by a double-sided set of rubber rings 13, are fixed on the eccentrics.

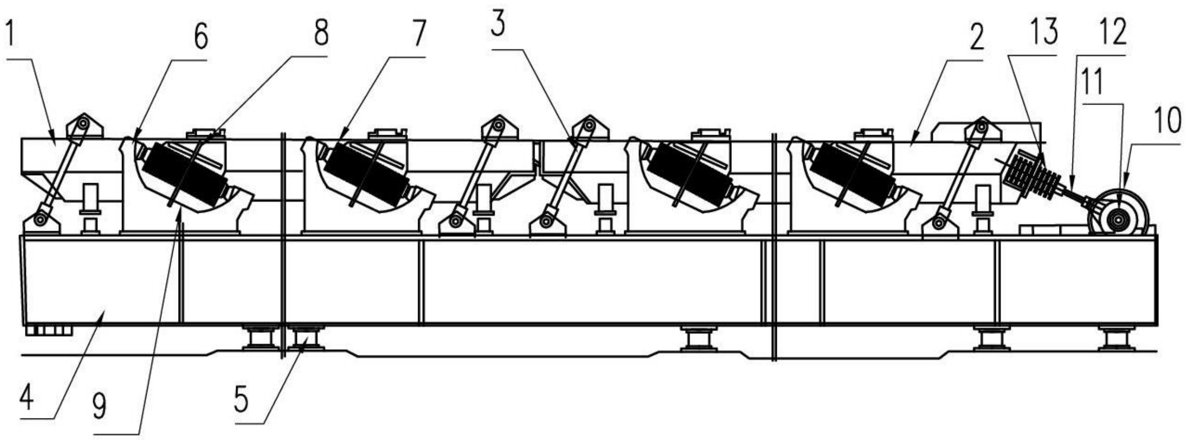

Fig. 4. GRO-1 triple-mass resonance screen

This screen is intended mainly for coal dewatering with a maximum grain size of 0 to 25 mm and for mud dewatering. Working width of GRO-1 screen is 2000 mm with a total length of 8000 mm and an active area of 15 m^2. The screen boxes vibrate at a frequency of 700 to 800 cycles per minute with an amplitude of 6 to 8 mm. Capacity of the screen used for coal dewatering is 100 t/h, and for mud dewatering it is up to 40 t/h. For drainage, wedge wire screens with a slot width of 0.25 to 1.0 mm are used [4].

2.4. EGK-2 two-mass resonance screen

The resonance screen shown in Fig. 5, equipped with an inertial drive, forcing the elliptical movement of the vibrating masses is another considered solution. Screen box 1 is fixed on the sets of helical springs 2, mounted on the supporting frame 3 of the screen. On both sides of the screen box there are counterweights 4, creating a system that vibrates with the screen box called the drive yokes. These counterweights are suspended by the levers 5 on the supports 6 of the screen box. Between the supports 6 and the handles 7 of the counterweights, elastic sets of rubber rings 8 are inserted perpendicular to the lever 5. These sets accumulate kinetic energy of the vibrating masses and transfer it to the vibrating system at the turning points. The drive shaft 9 is mounted in counterweights and a weight 10 is wedged on its external pivot, creating the inertial drive of the screen. Drive system of the screen consists of a motor, a belt transmission with V-belts and an intermediate shaft connected with a clutch to the drive shaft 10.

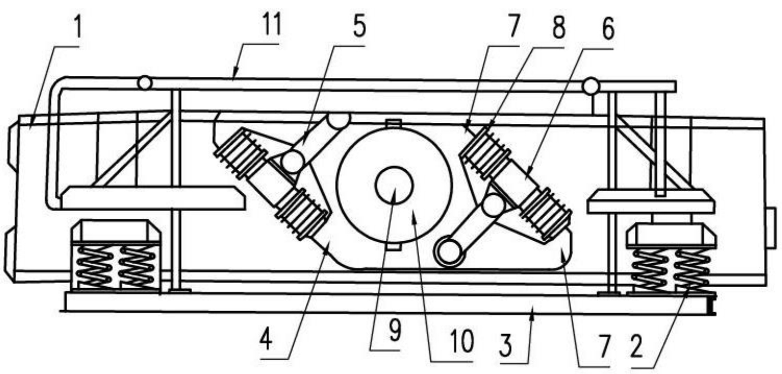

Fig. 5. EGK-2 resonance screen

Pipeline system 11 supplies water to showers used for product desludging.

This typical two-mass system vibrates in a scope close to resonance. The elliptical vibrations have a large axis of the ellipse directed in the axis of elastic rubber rings, while the small axis is directed in the direction of lever 5, and the system of resonant vibrations is in the direction of the large axis of the ellipse (the ellipse axis size ratio is 3:1).

Resonance screens of this type are built in four versions intended for screening fine-grained material (EFK), medium-grained (EGK), coarse-grained (EGS) and as heavy ESL-type screens. The vibration amplitude in these screens is 4 to 5, 5 to 7.5 and 7.5 to 10 mm, respectively, at a frequency of 1030, 850 and 730 vibrations per minute. These screens are designed with a sieve working width from 1000 to 2500 mm and its length from 2000 to 6000 mm. The drive is powered by motors of a power from 3 to 22 kW [4].

2.5. CDR-43 two-mass resonance screen

The resonance screen with one on top of the other arrangement of screen boxes directed at inclination of screens in the opposite directions, shown in Fig. 6, can also be included to the analysed screens.

Screen boxes 1 and 2 are suspended on sets of inclined elastic slats placed on the supporting structure 3 of the screen. Each screen box is equipped with two pairs of flexible sets 4. Swinging motion of the screen boxes is generated by shaft 5 through two-armed levers 6 and flexible couplings 7. The shaft 5 is driven by a motor and gears, not shown in the drawing.

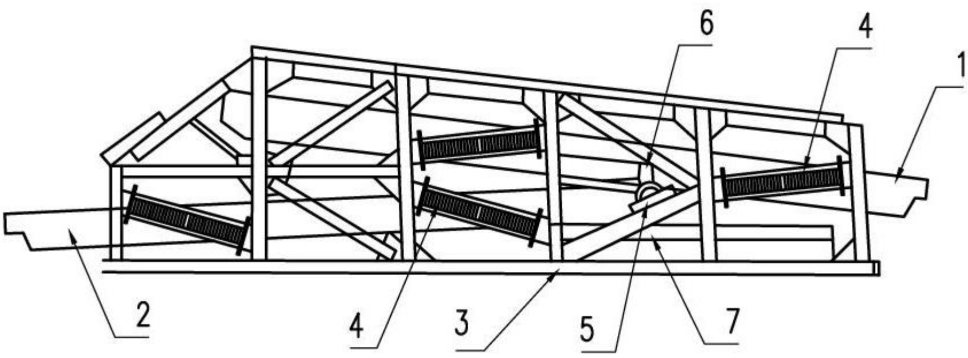

Fig. 6. CDR-43 resonance screen

Working width of the screen box is 1800 mm with an active screen area of 20.2 m^2. The nominal capacity of the screen for coal is 160 t/h with a maximum capacity of up to 200 t/h. An 18.5 kW motor is used to drive the screen. Stroke of the screen boxes is from 38 to 42 mm at a frequency of 400 cycles per minute. The permissible feed water content is 6% [4].

2.6. CDR-8 resonance screen

The last presented solution (Fig. 7) is a screen with the screen boxes 1 and 2 arranged in one after the other position. These boxes are suspended on the structure 3 placed on a system of elastic slats.

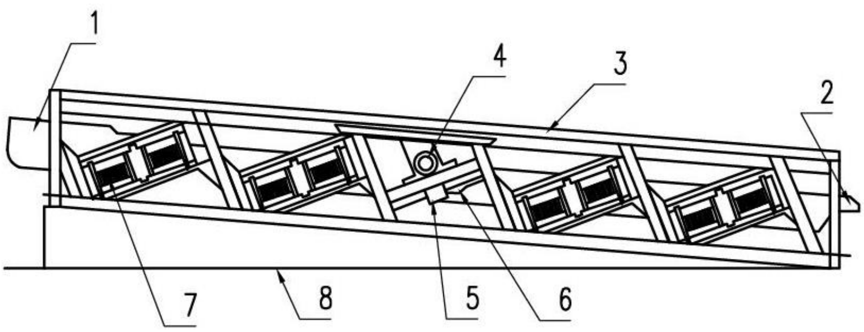

Fig. 7. CDR-8 resonance screen

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The drive shaft 4 is installed in the middle of the screen length, driving the end section of the first screen and the initial section of the second screen box with the levers 5 and a flexible coupling 6. Each box is equipped with two pairs of elastic assemblies 7 arranged perpendicular to the direction of the elastic slats. Screen boxes are driven by a motor and gearbox. A screen of this type requires an additional wedge-shaped structure 8. Table 1 shows the currently used variants of CDR-8 screeners.

These screens are manufactured in four sizes with the working width of the screen box from 1600 to 2200 mm and with the working area of the screens from 14 to 19.5 m^2. Nominal and maximum capacities (for coal) are from 145 (180) to 330 (390) t/h. The screens are powered by motors with the power of 15, 18.5 and 22 kW. Screen boxes vibrate at a frequency of 400 cycles per minute with a pitch of 38 to 42 mm [6].

2.7. Strengths and weaknesses of the analyzed solutions of resonance screens

The strengths are as follows. The existing solutions of resonance screens are highly efficient. Moreover, the screening process is of high accuracy. The screens have a low power demand needed to generate the working movement of the riddle.

Weaknesses of the screens are that they emit noise during their operation and require very careful and systematic control and adjustment, especially the flexible assemblies. Flexible assemblies require a very even initial stress of both their halves, because this determines the identical amount of kinetic energy transferred in both directions of the screen box movement and the transition of the entire system to work in resonance. It can be troublesome to systematically control the wear of all elastic components (aging of rubber rings and buffers), correct cooling of rubber elastic assemblies, selection of lubricants, etc. The problem may arise during the repairs, when it is necessary to pay special attention to keep the masses of the screen boxes and vibrating frames in multi-mass screens unchanged [19, 20].

3. Results

Resonance screens used in industry still have many disadvantages and do not always meet the users requirements. Due to the interest of the mining and metallurgy industry in resonance screens for coke classification and lack of such design solutions, research work was undertaken at KOMAG to develop a new design of CDR-85K (K – coke) resonance screen.

3.1. Design assumptions

The CDR-85K resonance screen is intended for the initial as well as final classification of each assortment of coal and coke. This version is designed for coke classification in the metallurgical industry. The only difference is a modification of the height of the side panels and the upper and lower riddle. The necessary modification results from the coke weight density (twice as low as that of coal), which translates into efficiency of the device.

The CDR-85K screen, depending on the screens used, in terms of material (rubber or steel screens) and screen mesh, can be successfully used for material classification in the range of 120-0 mm. The classification process can be dry or wet with a spraying system which prevents clogging of the screen mesh.

The use of successive riddles, combined with the possibility of setting the screen at a selected angle (horizontally - 0°, inclined to - 5°), enables the selection of the assumed capacity of the device.

Technical parameters of the designed CDR-85K resonance screen are presented in Table 1.

Table 1. Technical characteristics of CDR-85K screen [21]

Specification	Unit	Value
Output	t/h	300
Working area of metal screen	m^2	18,6
Number of strokes in the riddle	min^{-1}	400
Pitch of riddle	mm	40
Inclination angle	°	5
Total weight	kg	14437

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The assumed characteristic was developed on the basis of a literature analysis and guidelines for a metallurgical plant. The screen is used to separate coke of a grain size 80-0 mm into an upper product (80-30 mm) and a bottom product (30-0 mm), with a output of 300 t/h [21].

3.2. Design and operation of CDR-85K resonance screen

The design of CDR-85K resonance screen includes the following assemblies:
- upper riddle,
- lower riddle,
- screen frame,
- pendulum gear,
- tension frame,
- pendulum lever,
- rubber band assembly,
- drive frame,
- drive.

The main components of the CDR-85K resonance screen (Fig. 8) are the upper riddle 1 and the bottom riddle 2, fixed to the screen frame by rubber springs 18, 19, 20. A pendulum reducer 5 and an electric motor N=22kW, 6 are fixed on the drive frame 4. The electric motor drives the shaft 2200/20 12 through a flexible coupling 9, a pendulum reducer and a fixed coupling 10, setting it in a swinging motion together with the pendulum levers 13 located on both sides and the elastic couplings of rubber bands fixed in them 16. At equal distance from the centre of each lever arm 13 a set of rubber bands 16 is fixed, elastically coupling the riddle 1, 2 with the drive. The pendulum levers 13 are rigidly fixed on the main shaft 12 at a distance slightly greater than the width of the riddle. The pendulum reducer 5 is used to convert the rotational movement of the motor into the swinging movement of the shaft 12. In the CDR-85K screen, the main shaft 12 is supported on one side by a roller bearing 11 placed on the machine frame. Tensioning frame 14 and flat hanger 15 tension and fix the rubber springs 18, 19, 20. The tensioning frame consists of two tensioning bolts connected by plates to which one side of the spring set is screwed, and the other side is fixed in the spring foot of the riddle. Each tensioning frame includes two spring sets. For one riddle 1 and 2 there are 4 tension frames 14 – two on each side of the riddle.

The principle of operation of the screen is based on appropriate tension and swinging of the set of rubber belts 16 drive both riddles 1 and 2, which, thanks to the elastic suspension on leaf rockers, make a reciprocating oscillating motion with a stroke limited by four sets of rubber springs suitably tightened and fixed to the machinery frame. Screening takes place on a metal screen s=30 mm 21, which is fixed on the upper riddle 1 and on the lower riddle 2.

The basic flexible components of the CDR-85K resonance screen are:
- flexible couplings of rubber bands 16 connecting the riddle with the drive,
- elastic, resilient components, installed between the screen boxes and the screen supporting structure, limiting the stroke of the screen boxes 18, 19, 20.

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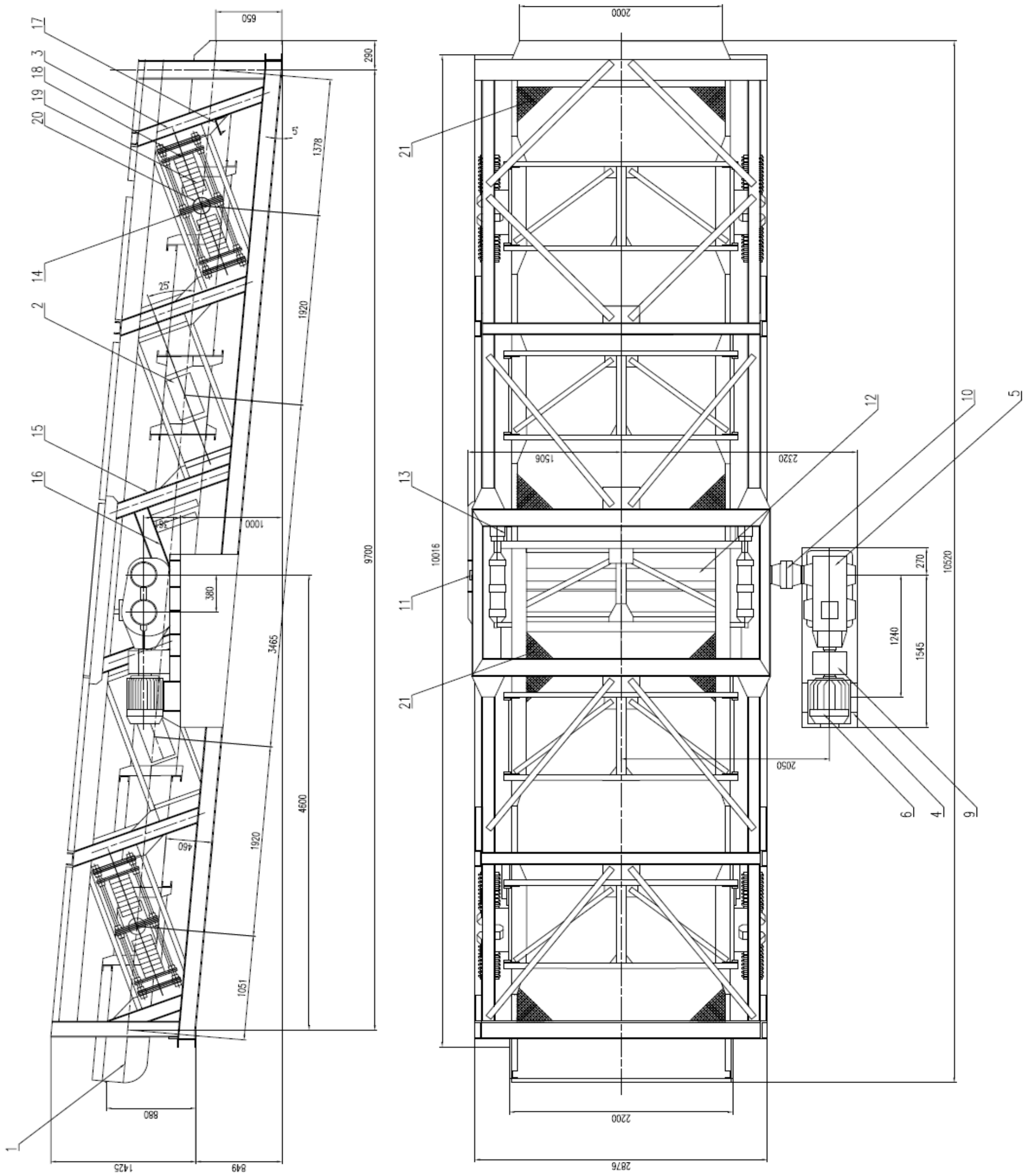

Fig. 8. Preliminary design of the 85K resonance screen [21]

3.3. Innovative design

A number of new and innovative solutions will be used in the developed solution listed below:

- drive system of the resonance screen for the use of a state-of-the-art pendulum reducer with an electric motor N=22 kW is provided. This solution will reduce electricity consumption and increase the durability of the drive compared to the old reducer. It will also allow to replace HK400/22 part-turn gearboxes manufacture of which has been discontinued. The designed system will be replaceable with the existing solutions and possible to use in operating screens,
- new rubber springs for the screen suspension were developed,
- in order to increase the screening capacity, larger clearances were applied and the sides of the screen were raised,
- screen decks are made of a material that has a tendency to self-cleaning, which will allow for higher system efficiency,
- anti-corrosive coatings are applied to screen components,
- the screen riddle is equipped with abrasion-resistant materials.

The design of the device has now been completed. Subsequently, it is planned to develop the technical documentation of the screen and make a prototype.

4. Conclusion

Due to the unavailability of CDR resonance screens on the market and the interest of the mining and metallurgy industry in modernization of classifying nodes based on this type of screen, KOMAG has developed a design of a new CDR-85K resonant screen.

The applied design solution of the CDR-85K resonant screen will provide a very high screening accuracy and such a characteristic of the vibrating motion of the screen box that will enable screening of difficult to screen material, which may have a large amount of the finest grains, at the same time having a high content of surface moisture.

Moreover, in order to ensure a constant and high screening efficiency, the screens with ability to self-clean from the grains adhered to them, were used.

The developed innovative solution in relation to the existing designs of this type will allow to increase the functionality and durability of the design.

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Application of composite materials in underground mining industry – fore-shaft closing platform

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Abstract:

According to Polish law regulations, fore-shaft in underground mines in process of its liquidation must be either filled with bulk material or closed with double-deck platform on its top. As liquidation by closing is cheaper and easier than filling, steel closing platforms are typically used for this purpose. However, steel price fluctuations due to COVID-19 pandemic together with rapid development of composite materials, make application of composite structure a tempting direction. The article presents a design of composite double-deck closing platform for fore-shaft liquidation in one of the collieries located in the eastern area of Silesian Coal Basin. Presented solution was thoroughly calculated and tested and then assembled in the mine. The aim of the research was to prove applicability of composite structures in underground mines with maintaining proper level of safety.

Keywords: composite materials, fore-shaft liquidation, shaft platform, mine liquidation

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1. Introduction

Safety of vertical mine workings – shafts and fore-shafts – in underground mines is a key issue during their whole lifecycle – from sinking, through their operation, to liquidation. Every mine working may be a threat for work and public safety, even after its liquidation. Thus, the issue of mine workings liquidation process itself is a subject for strict law regulations and numerous research and articles, concerning liquidation planning and monitoring of the process, as well as effects of the liquidation [1-6]. The most frequently studied threats and issues connected with shaft and mine liquidation are -geological and hydrogeological [7-12], economic and social [13-16], environmental [17-20] and technological issues [4, 21-23].

Shaft liquidation, similarly to its sinking and maintenance, is extremely expensive, thus such decision is always thoroughly analyzed and process itself is meticulously planned. Similar case is a liquidation of fore-shafts, vertical mine workings of different functions, usually transport and ventilation, having no connection to the surface. However, due to smaller lengths and cross-section dimensions, scale effect occurs.

Law regulations in mining in Poland precisely regulate rules of shaft and fore-shaft liquidation. According to Geological and Mining Law Regulation, shaft or fore-shaft has to be filled with material suited for geological and hydrogeological conditions and natural hazards occurrence [1]. Ventilation type of the shaft has to be taken into consideration as well, such as its equipment and connections with other mine workings.

Due to character of fore-shafts, the Regulation provides different liquidation ways of these vertical workings. It allows for a closure of a fore-shaft using a two-deck platform on its top level together with its isolation from other existing mine workings. Isolation is realized using durable barriers constructed of non-combustible materials in mine workings connected with the fore-shaft on each level. However, such a method of fore-shaft liquidation requires expert's positive opinion.

Fore-shaft liquidation using closing platform is particularly common in operating underground mines, where only the area of the fore-shaft is closed, due to different reasons. The main reason of fore-shaft liquidation is its functionality loss. It might be also caused by significant damages of the fore-shaft lining to an extent that makes it uneconomical to repair. Shaft liquidation by its closure is, for obvious reasons, significantly cheaper than "traditional" solution, i.e. filling fore-shaft. It requires less material for platform and barrier construction instead of filling, and less man-hours for the process to be conducted. Closing platforms are usually made of steel, which is generally the most popular material in Polish mining industry, due to numerous advantages. However, steel does have some disadvantages.

The greatest disadvantage of steel, in terms of mining industry, is its significant weight and susceptibility to corrosion. Especially in the case of constructions or support in workings designed for a long period of time. Whereas its high weight might be a difficulty in case of transport to remote and inaccessible areas and workings, where ability to use suspended or floor railway is limited or even impossible. In such cases, even manual transport might be a problem, especially if transported elements are of significant sizes. It has to be considered an issue in terms of fore-shaft closing platforms, as liquidated fore-shafts are usually located in old and abandoned areas of the mine, where dimensions of workings' cross-sections are usually reduced. Thus, transport of platform's element and their assembling in conditions of limited space are usually the greatest problem in the process of fore-shaft liquidation [24].

A method for overcoming these problems includes composite materials. In recent years they are gaining popularity in almost every branch of engineering, such as civil engineering, mining, mechanics, aeronautics and so on [24, 25]. Composite materials can be made, using different methods and technics, from different components. Their strength parameters are similar to steel, with significantly lower weight. The process of composite elements allows for a great flexibility both in terms of composite strength parameters and in shape and dimensions of elements produced, since composite elements can be formed into almost any shape. Also, their treatment is easier than in the case of steel elements. The main disadvantage of composite materials is their price. However, in a long time period, application of composites instead of steel might become profitable. Moreover, high steel prices and their large fluctuations due to COVID-19 pandemic make composite materials more tempting for mines and other potential buyers [24, 26-29].

It should be also noted, that composite materials are already in common use in underground mines. However, they are rarely spotted as construction elements. Composite materials are usually used for mesh-wire lagging protecting roofs and sidewalls and in bolts [24, 26, 28, 29].

The article presents an example of composite materials application for construction of fore-shaft closing platform. This construction was designed for conditions of underground coal mine located in the Silesian Coal Basin.

2. Geological and mining conditions in the vicinity of the inter-level fore-shaft

2.1. Fore-shaft parameters

The inter-level ventilation shaft is located in the north-eastern part of the Mysłowice-Wesoła colliery, located in the east of the Silesian Coal Basin. The fore-shaft was sunk in 1990s using traditional drill and blast mining method. It connects levels 465 and 665 m and its total length is 202.15 m. Parameters of the fore-shaft are presented in Table 1.

Table 1. Inter-level fore-shaft parameters

Parameter	Value
Top level depth	182.50 m below sea level
Bottom level depth	384.65 m below sea level
Total length	202.15 m
Diameter	4.5 m
Function	Ventilation - upcast
Equipment	Ladder compartment Compressed-air pipeline ϕ150 mm Downcast water pipeline ϕ150 mm Goaf reconsolidation medium pipeline ϕ185 mm Methane pipeline ϕ325 mm

The fore-shaft has following connections with mine workings:

- at the level 465 m (depth: 492.1 m) – double-sided inlet directed south and north,
- at the level 664 m (depth: 699.2 m) – single inlet directed west.

The fore-shaft is protected with single-layer lining of variable thickness, made of concrete blocks. According to the original project of the lining BSz1 concrete blocks of class [30-31] and M12 class mortar. The fore-shaft lining is presented in Fig. 1. Its parameters are as follows:

- 492.1 ÷ 496.6 m – concrete blocks lining with thickness of 0.58 m (two blocks thick),
- 496.6 ÷ 699.2 m – concrete blocks lining with thickness of 0.44 m (1.5 blocks thick),
- in the sections located in coal seams the thickness of the lining equals 0.74 m (2.5 blocks thick).

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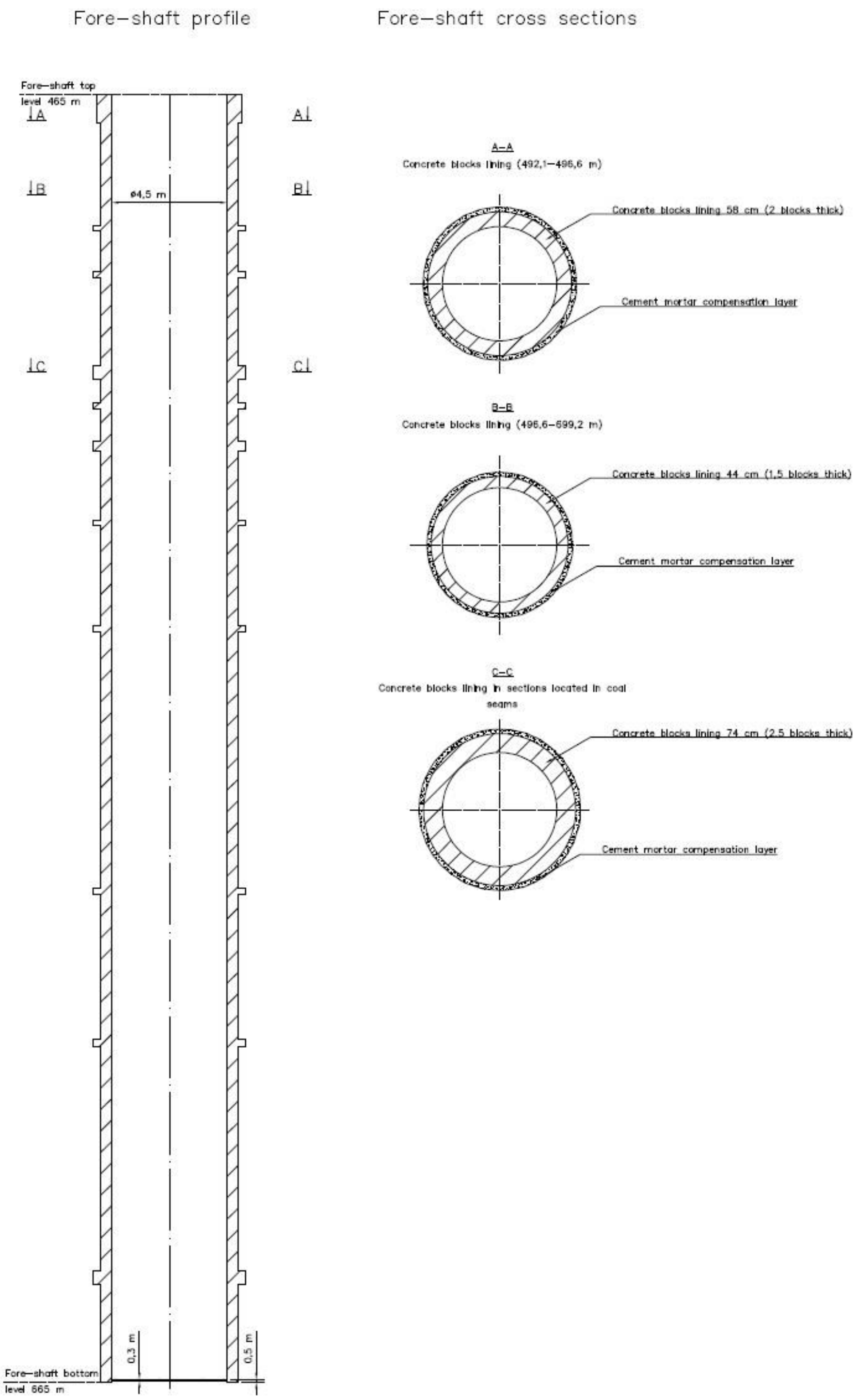

Fig. 1. Inter-level ventilation fore-shaft lining

Due to significant fore-shaft lining damages in the vicinity of the inlet at the level 465 m, the following repair work was carried out in 2007:

– fore-shaft lining replacement on the length of 6 m below the level of 465 m,
– replacement of steel protections in the inlet at the level of 465 m,
– reconstruction of the lining above the fore-shaft collar,
– reconstruction of the drift at the level of 465 m.

Before the reconstruction of the drift, floor heave reaching 1.0÷1.5 m occurred in this area. According to the data gathered by the mine staff, similar phenomenon can be spotted in the drift currently.

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2.2. Geological and hydrogeological conditions in the vicinity of the inter-level fore-shaft

Vicinity of the fore-shaft comprises basically two formations:

- mudstone formation – between the depth of 0 and 72 m; comprising layers of shale, mudstone, coal seams and sandstone;
- sandstone formation – between the depth of 72 and 202 m; comprising layers of sandstone, sandy shale and coal seams.

In the vicinity of the level 665 m layers of shale, coal and sandstone occur.

In the upper part of geological profile (in the vicinity of the level 465 m) numerous coal seams occur, however their thickness rarely exceeds 1 m. Only exceptions are seams 405/1 at the depth of 42.8 m with thickness of 1.8 m and 416 at the depth of 171 m and thickness of 2.0 m. No tectonic faults were found in the profile of the fore-shaft, however rock layers located between the depth of 117 and 143 m are fractured.

Rock mass in the area of the fore-shaft is dewatered by roadways located at the levels 465 and 665 m. The only water and gas horizons occur at the depth interval of 120÷143 m. Thus, water and gas inflows into the fore-shaft are connected with fractured rock layers. There is no water inflow at the bottom level of the fore-shaft. However, it should be noted that local water inflows from behind the shaft lining occur in the fore-shaft.

Intense longwall exploitation of seams 349, 401, 405/1, 405/2 and 510 was carried out in the vicinity of the inter-level ventilation shaft, both before and after it was sunk. Coal seams 349, 401, 405/1 and 405/2 were exploited using longwall caving. Thickness of mined seams varies between 1.2 and 2.6 m. Minimal horizontal distance between the fore-shaft and longwall was 130 m east and 40 m west, both in the seam 349, exploited between 1974 and 1978, located about 150 m above the fore-shaft top level.

Exploitation of the seam 510 is worth noting. It was carried out between 1999 and 2011 using longwall caving. The seam 510 is located from 15 to 30 m below the fore-shaft bottom level and the closest longwall was located in the distance of 110 m from the fore-shaft. Thickness of the seam 510 is 2.2÷3.5 m.

It can be assumed, that coal mining in the vicinity of the inter-level ventilation fore-shaft, especially exploitation of the seam 510 negatively affected lining of the fore-shaft. Effects of this influence were reconstructions of the shaft and neighbouring workings.

3. Composite closing platform

Composite closing platform was designed for liquidation of inter-level ventilation fore-shaft by closing its top at the level of 465 m. The other elements of the fore-shaft closure are explosion-proof barriers made of fast-curing binder. Due to high convergence of workings of the level of 465 m transport of the platform is impossible. Thus, the platform was designed as a bolted joint construction. It can be assembled in any chosen place and it was designed to be transported through the fore-shaft using a winder installed above the fore-shaft top.

3.1. Platform characteristics

Designed platform consists of two decks. The first one of them is located directly on the top of the fore-shaft, fully covering it. The other deck is situated 500 mm above the lower deck to which it is assembled. Both decks form bolt-connected and compact space frame.

The platform consists of the following elements:

- supporting structure,
- locks,
- cover,
- mountings and joints.

The supporting structure is entirely made of C-shape composite profiles NKG2006010. Profiles were connected using angle mountings and bolts. The locks are also made of NKG2006010 C-shape profile. They are designed to prevent movements of the platform, placed on the fore-shaft top. They

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are inserted into slots made in the fore-shaft lining and assembled to it at the distance of 200 mm. Cover is made of composite open grille (NKG type) with eyelet of 30 x 30 cm and thickness of 38 mm. Anti-slip grilles are assembled to both platform decks.

The only non-composite elements of the platform are steel mountings and joints. The mountings are used to connect the cover with supporting structure and connect elements to each other. Mountings and joints are made of S235JR type steel. All steel elements were galvanized. A diagram of the platform is shown in Fig. 2.

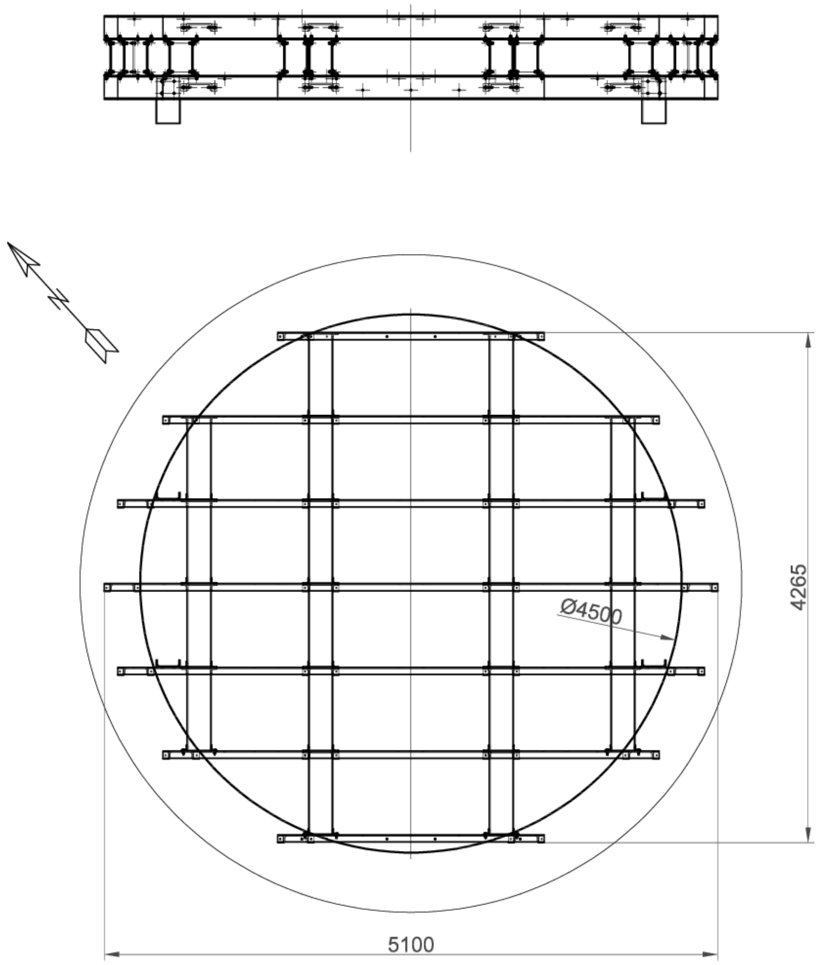

Fig. 2. A diagram of the platform construction

3.2. Calculations

The decks of the platform were designed for maximum load of 250 kg/m^2. Calculation tests of the platform were conducted with factor of safety n ≥ 6. Stress limit for composite elements, made of NKG material with tensile strength R_m = 340 MPa, was assumed as:

$$k = \frac{Rm}{n} = \frac{340}{6} = 56.6\ MPa \quad (1)$$

Static analysis was conducted using Autodesk Robot Structural Analysis Professional (RSAPRO) 2018 software. A general scheme of the platform is presented in Fig. 3. It was assumed that supporting structure is made of C-shape profiles C200 NKG C2006010 (Fig. 4). Technical characteristics of the profile is presented in Table 2. Table 3 presents strength and material parameters of the NKG material.

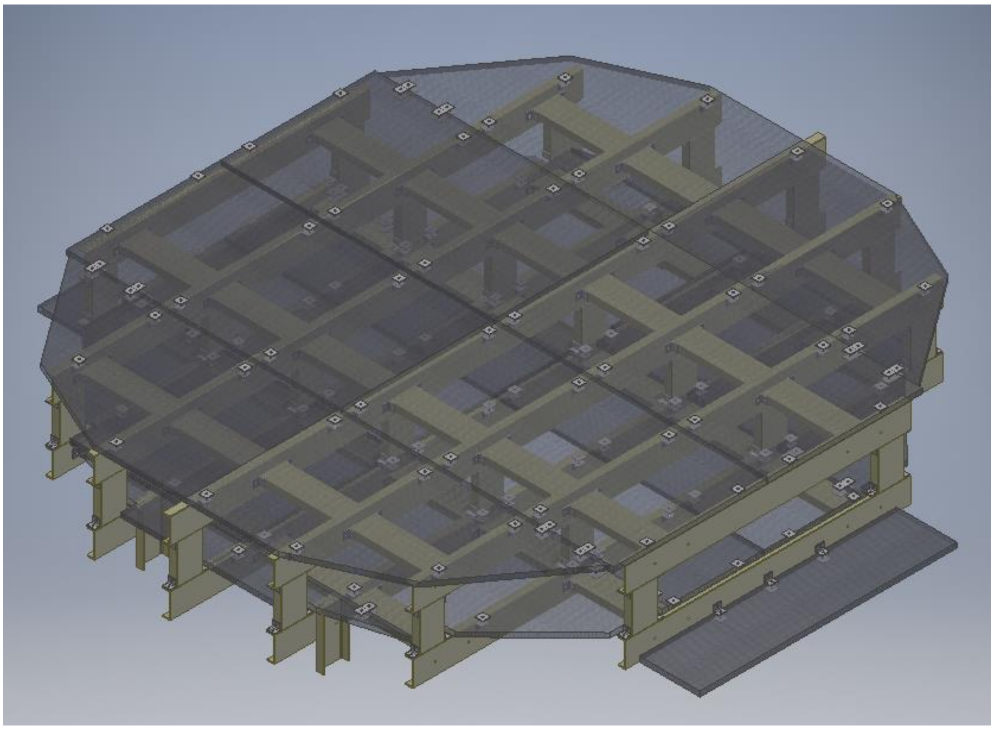

Fig. 3. A general scheme of the fore-shaft closing platform

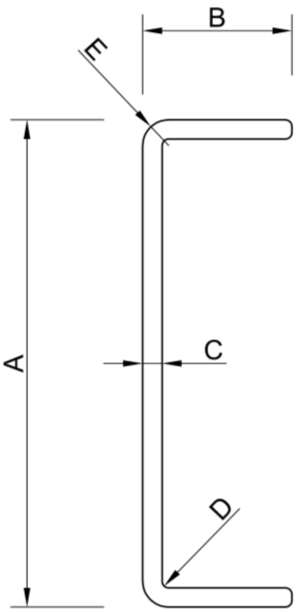

Fig. 4. Composite C-shape profile

Table 2. Technical characteristics of composite C-shape profile (supplier's data, according to [32])

Mark	A, mm	B, mm	C, mm	D, mm	E, mm	Weight, kg/m
NKG C60505	60	50	5	2	7	0.85
NKG C100405	100	40	5	6	8	1.8
NKG C150506	100	50	6	8	2	1.9
NKG C2006010	200	60	10	10	4	3.6
NKG C2508015	250	80	15	15	2	8.0
NKG C3009020	300	90	20	20	1	9.5
NKG C35010025	350	100	25	25	1	11.0
NKG C38012530	380	125	30	30	1	12.4

Table 3. Parameters of the NKG composite material (supplier's data)

Property	Test method	Value	Unit
Specific weight	ISO 1183/ASTM D 792	1.75 – 1.90	g/cm^3
Tensile strength	EN ISO 527-4	340 – 500	MPa
Compressive strength	EN ISO 14126	350 – 400	MPa
Shear strength	EN ISO 14130	25 – 30	MPa
Flexural strength	EN ISO 14125	500 – 550	MPa
Flexural modulus	EN ISO 14125	20 – 25	GPa

A truss model of the platform was developed and maximum stress was checked for the typical load for platforms in underground mines, which is equal P = 2.5 kN/m^2 and deadweight, including covers, which is equal Qp = 1 kN/m^2. All the loads act on the top deck of the platform. A truss model of the platform is presented in Fig. 5. It comprises a lattice, which is a combination of two platform decks, connected with C-profiles. Forces Pz, acting on the construction, are P = 2.5 kN/m^2 and Qp = 1 kN/m^2 and area of the platform's cross section is 15.9 m^2. The forces acting on the platform's construction are shown in Fig. 6.

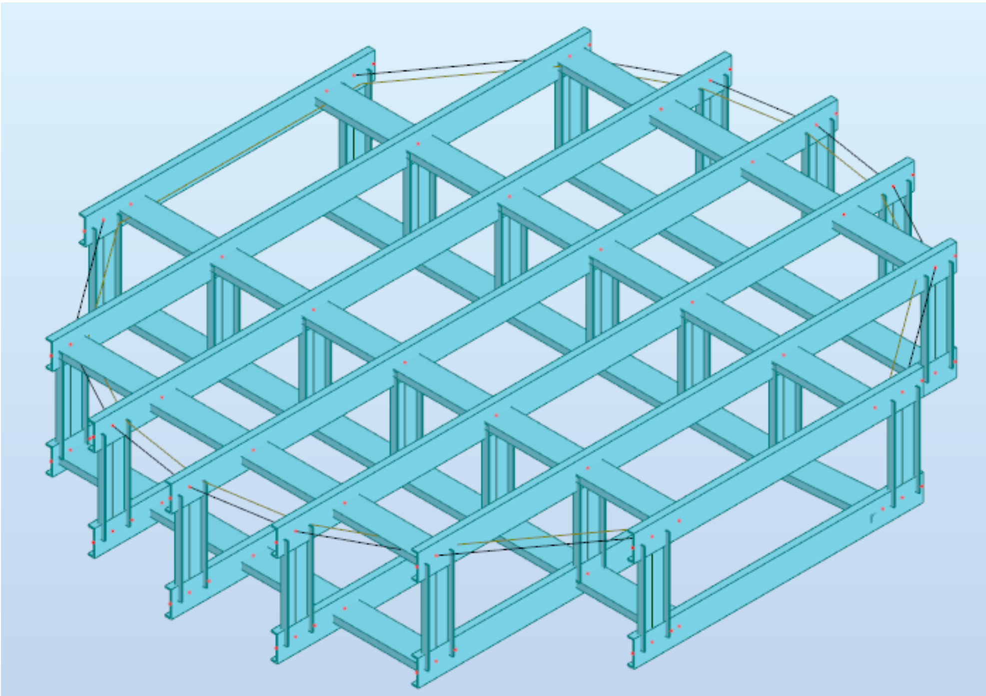

Fig. 5. Truss model of the fore-shaft closing platform developed in ROBOT software

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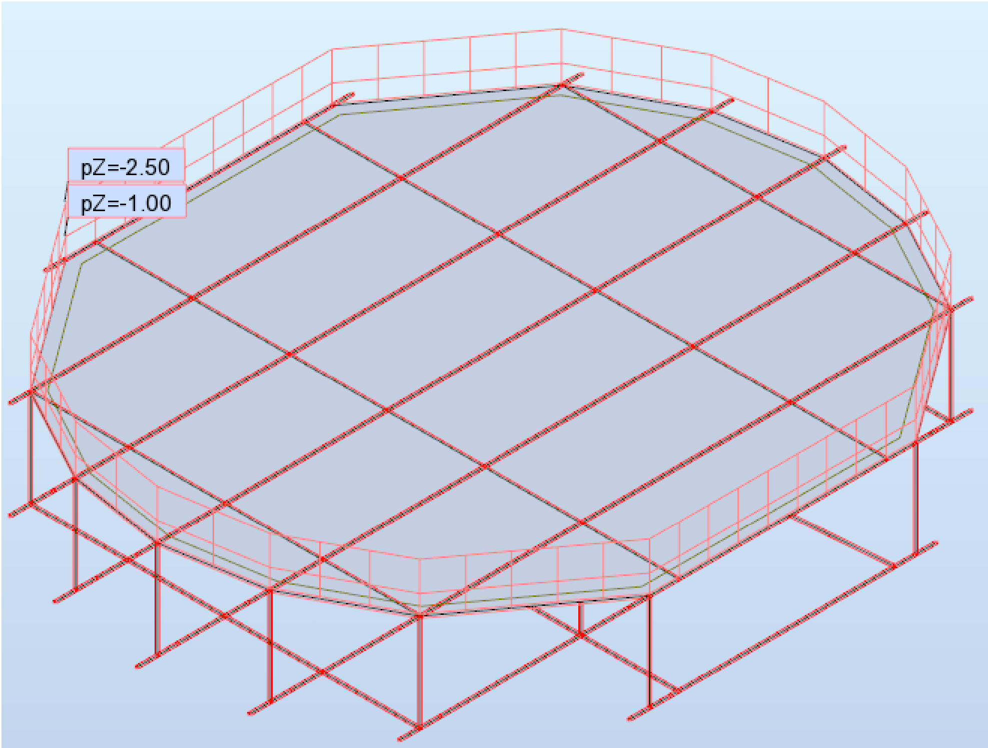

Fig. 6. Forces acting on the model (units: kN/m^2)

Stress in construction's elements was calculated basing on acting forces, comprising the deadweight multiplied by confidence factor kc = 1.3. Results revealed that maximum stress value is 18.41 MPa (Fig. 7). Moreover, stress in construction's fulcrums is between 12 and 14 MPa. Other stress values do not exceed 4 MPa.

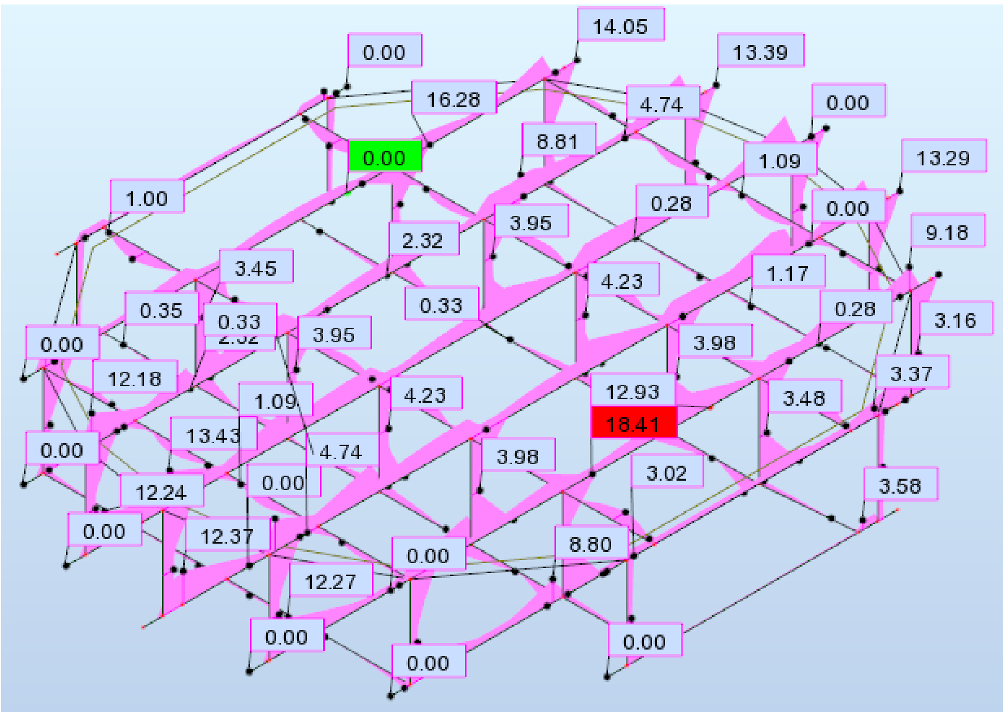

Fig. 7. Values of stress calculated (units: MPa)

Analysis of obtained results reveals that values of construction's stress are significantly smaller than the stress limit value, equal to 56.6. MPa. Values of support reactions are presented in Fig. 8 and in Table 4. Maximum value of support reaction is equal to 6.2 kN, with almost no bending moments.

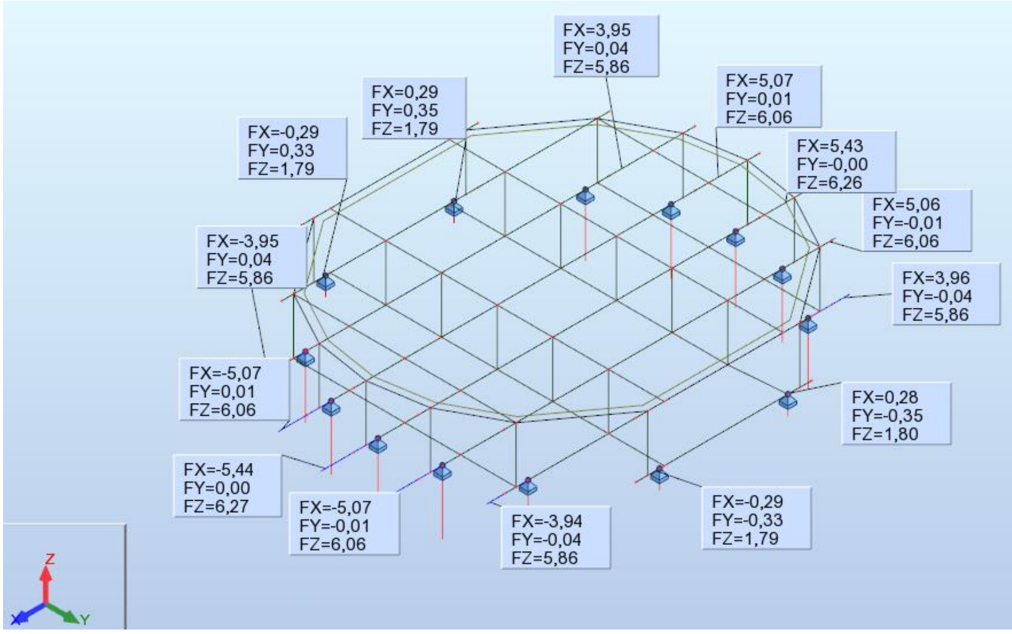

Fig. 8. Values of support reactions (units: kN)

Table 4. Values of support reactions

Node/case	FX, kN	FY, kN	FZ, kN	MX, kNm	MY, kNm	MZ, kNm
133/3 (K)	-3.95	0.04	5.86	0.00	0.00	0.00
134/3 (K)	-0.29	0.33	1.79	0.00	0.00	0.00
135/3 (K)	-5.07	0.01	6.06	0.00	0.00	0.00
136/3 (K)	-5.44	0.00	6.27	0.00	0.00	0.00
137/3 (K)	-5.07	-0.01	6.06	0.00	0.00	0.00
138/3 (K)	-3.94	-0.04	5.86	0.00	0.00	0.00
139/3 (K)	-0.29	-0.33	1.79	0.00	0.00	0.00
140/3 (K)	0.28	-0.35	1.80	0.00	0.00	0.00
141/3 (K)	3.96	-0.04	5.86	0.00	0.00	0.00
142/3 (K)	5.06	-0.01	6.06	0.00	0.00	0.00
143/3 (K)	5.43	-0.00	6.26	0.00	0.00	0.00
144/3 (K)	5.07	0.01	6.06	0.00	0.00	0.00
145/3 (K)	3.95	0.04	5.86	0.00	0.00	0.00
146/3 (K)	0.29	0.35	1.79	0.00	0.00	0.00

Then it can be concluded that the designed supporting structure is able to bear acting loads with maintaining the factor of safety $n \geq 6$.

4. Conclusions

The presented composite platform, designed and constructed for interlevel ventilation fore-shaft liquidation, meets safety requirements, in terms of material requirements (composite materials comply with legal safety requirements) and construction, which is confirmed by calculations presented in the previous section. It is absolutely crucial, as safety requirements must be fulfilled, to positively evaluate designed solution of fore-shaft liquidation, both during the process of liquidation itself and after it is finished.

An application of composite materials for a construction of the presented solution generates additional benefits, comparing to traditional steel platforms. Primarily, composites are resistant to aggressive atmosphere, contrary to steel. Estimated lifetime of composite platform greatly exceeds lifetime of steel constructions. In the presented case, it was significant to facilitate transport of the platform's elements and their assembly. Another important factor was lower weight of the composite material. It was caused by significant degradation of neighbouring mine workings, causing in their cross-sections' dimensions limitation. It should be noted, that it is a common problem in liquidated underground mine areas and workings.

The greatest disadvantage of composite materials is their high price. However, it should be taken into consideration that purchase price of the material is not tantamount to overall cost of production and maintenance of construction for underground mining, such as numerous types of platforms, including closing platforms for fore-shaft liquidation. In times of COVID-19 pandemic it is extremely hard to perform precise comparative analysis of steel and composite construction production costs, due to high and unstable steel prices. Moreover, the comparison of these costs should take into consideration not only costs of the material, but also transport costs, including both transport from the producer or supplier to the mine and underground transport or anti-corrosion protection costs, which is not necessary in the case of composite constructions. In the case of fore-shaft closing platforms maintenance costs are negligible, but they should be taken into account in the case of other structures. For now, it is difficult to conduct a fully reliable comparison due to lack of composite constructions in underground mines. However, comparing steel and composite elements that are already in use in mines (such as mesh-wire lagging and bolts), maintenance costs of composite structures are expected to be lower than in the case of steel constructions.

Other disadvantages of composite materials include problems concerning connecting elements with bolts and lack of experience in underground composite applications. Such a situation might cause resistance of miners or management of underground mines, however this attitude has changed recently.

Comparing pros and cons of composite materials in structures for underground mining and observing the market of composite materials, a number of composite constructions in the mining industry is expected to increase. It should be considered the right direction of development, especially due to practical and financial factors.

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Dilemmas of the energy transformation in Poland 2021/2022

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Abstract:

The subject of the article is an analysis of the energy transformation in Poland against the background of the changes taking place in the environment. Authors study key issues related to the energy transformation to analyze the dynamics of the Polish energy transformation as well as the possible directions. In the end they discuss the three possible scenarios for Poland which could transform the country's energy system from coal to zero emission. The discussion is up-to-date according to the European and world directions of industrial transition into green energy and Poland has got huge challenges ahead while the time to take steps is passing.

Keywords: just transition, energy system, renewables, energy transformation

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1. Introduction

The turn of the year 21/22 showed the challenges faced by the domestic energy sector in Poland. The high share of coal in electricity generation resulted in an increase in electricity bills. It was overlapped by turbulences on the gas market, which the domestic gas operator could not handle, which resulted in a surge in gas prices on the domestic market. The subject of the article is an analysis of the energy transformation in Poland against the background of the changes taking place in the environment, which are gaining momentum. We will conduct a literature review of key issues related to the energy transformation to analyze the dynamics of the Polish energy transformation. We will analyze program concepts aimed at overcoming the delays of the domestic energy sector. The aim of the article is to show the complexity of the energy transformation process on the example of Poland. The working hypothesis about the strong resistance of incumbent energy operators who have taken over the main decision-making centers of the state by creating a false coal energy security doctrine with the weaknesses of the organizational structures supporting the energy transformation will be verified. We will apply a process approach to the analysis of the accompanying social and economic phenomena. The literature review will be supported by own observations from the position of the ZKlaster association operating in the field of energy transformation.

2. Materials and Methods

2.1. Key issues of the energy transformation

The literature review allowed for the construction of bundles of issues that are used to describe the current situation in the field of energy transformation in the technological, social, economic and political environment and to identify the premises for the formulation of energy transformation scenarios.

Just Transition

The Paris Agreement signed in December 2015 under the United Nations Convention on Climate Change (UNFCCC) is an extremely important and ground-breaking agreement that applies to almost all emissions in the world. As agreed, the EU target (in the context of the necessary reductions by developed countries as a group) is to reduce greenhouse gas emissions by 80-95% by 2050 compared to 1990. This requires a deep, rapid transformation of the energy system and an assessment of the role of policy instruments such as pricing in transition carbon. The challenge of decarbonization is also posed in the context of a limited carbon budget and the concept of "non-combustible coal", which has implications not only for Europe, but also for the whole world [1].

In Poland, the solidarity aspect of the energy transformation process is exposed. However in political activities, this translates into delaying the process of energy transformation in the interests of incumbent energy operators and demanding increased funds from the EU to protect large professional groups related to the energy sector and counteracting energy exclusion of wide social classes. The transition from high-carbon to low-carbon energy systems raises serious concerns in regions whose economies are heavily dependent on coal-fired power. Concepts of a comprehensive just transition framework, based on a multi-level perspective of socio-technical change, appear in the literature. They have the character of system innovations, proposing mapping of a just transformation in three dimensions: 1) spatial scale (regional, national, international); 2) time horizon (currently experienced and anticipated injustices); 3) connection with the dynamics of change (injustices related to the optimization of the currently dominant system, destabilization of the incumbent system, acceleration of alternative solutions in niches). This framework is used to analyze the ongoing energy transition in Estonia, for example, including the interactions between the incumbent oil shale regime and wind, solar, nuclear and bioenergy as new niche challenges. Based on the analysis of the content of media information, Estonian scientists have compiled a list of 214 separate cases of deviations from the just transformation in 21 different categories. It was discovered that strong actors push energy solutions and influence current political elections in violation of the principles of just transition. From the perspective of the general public, ethical dilemmas arise related to the costs of destabilizing the regime of old operators and accelerating the construction of new energy [2].

Building a false awareness of the energy transformation in Poland is related with fear of losing jobs by large professional groups. Meanwhile, many countries around the world are prioritizing cheap renewable energy sources for recovery from a global pandemic and long-term economic growth. Climate change mitigation goals set choices for a rapid move away from coal and other fossil fuels. Sustainable technologies bring wider socio-economic benefits, as shown by the example of countries that previously restructured their energy sectors and increased the share of RES. The energy transition has generated an interest in employment changes linked to concerns about job losses in conventional energy sectors. A better understanding of the direct employment impact of the energy transition is crucial for policy making by politicians. Research by scientists focusing on the effects of accelerated use of renewable energy, assuming that the world will obtain 100% of its energy from renewable sources by 2050, shows that direct jobs related to energy, heating, transport will increase significantly from around 57 million in 2020 to nearly 134 million by 2050. The conclusions of extensive research support the thesis that value chains for renewable energy and sustainable technologies are more labor-intensive than fossil extractive fuels. This means that the global energy transition will have a positive impact on future stability and economic growth worldwide [3].

Energy transformation scenarios

The adoption of the European Green Deal strategy was received without enthusiasm by government centers in Poland, as achieving the target of 100% reduction in greenhouse gas emissions by 2050 was very abstract. Only the adoption of the climate target to reduce greenhouse gases by 55% for 2030 caused a shock. The Fit for 55 package proposals launched aggressive government propaganda against the rapid decarbonisation of the energy system in Poland. Renewable energy interest groups and climate activists have been pushed on the defensive under the pressure of the doctrine of independence and energy security based on coal. Large interest groups of the old energy operators have gained an advantage in the political narrative in Poland.

At the same time, a determination has emerged on the part of the European Commission, driven by a combination of factors and synergies between technological development, political activities and public attitudes, to strengthen cooperation within the EU to achieve climate goals. EU support programs have been launched to increase social commitment and stimulate technological innovations that may become the basis for an effective energy transformation in Europe. Concepts of transformation pathways have emerged, shaped by the intersection of policy, technology and society development. Analyzes indicate that achieving rapid decarbonisation inevitably involves the implementation of new technologies, accompanied by the ruthless enforcement of decarbonisation policies in the short term to accelerate the energy transition. A review of Europe's energy transition scenarios leads to findings leading to the identification of consolidated and robust recommendations to policymakers and politicians for the effective achievement of the EU's Green Deal [4].

Many countries in Europe have opted for a gradual transition to 100% green energy generation. However, uncertainty has arisen over the economic and social consequences of such a transformation based on wind and solar technologies. Concerns have arisen about rising electricity prices due to a mismatch between supply and demand. In Switzerland, studies were carried out using the theory of dynamical systems to analyze the process of gradual transition from nuclear power generation to solar and hydro power generation. Various transformation scenarios were developed to test the cost-effectiveness of a water pump energy storage system to address the problem of the time difference between supply and demand. Research shows that leaving the system on the free market may entail energy shortages in the transition period and a doubling of the electricity price. To mitigate this effect, a capacity auction mechanism has been proposed, which will facilitate the transition to renewable energy. In addition, subsidizing photovoltaics indirectly encourages storage, thus eliminating shortages and mitigating the increase in electricity prices during the transition period (Fig. 1) [5].

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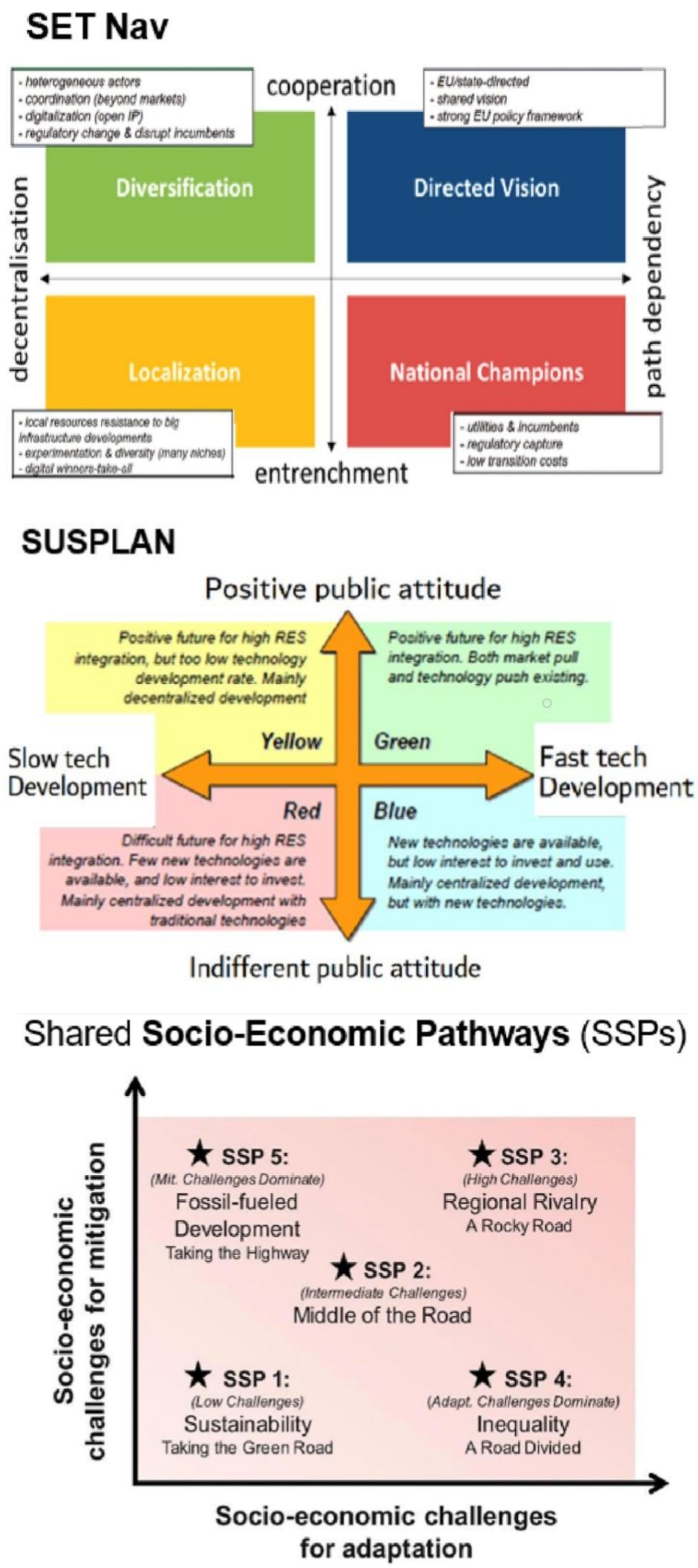

Fig. 1. Examples of widely-used 2 × 2 scenario typology to combine two main dimensions of uncertainty into four storylines spanning a wide possibility space [5]

In recent decades, global trends have seen a sustained and rapid growth in RES and an unprecedented pace of learning by organizations in generating electricity from solar and wind photovoltaics. Thanks to new technologies, which are now available at lower costs than those used by fossil fuel operators, the continued high growth rate of RES is certain. Verification of the hypothesis about achieving the dominance of photovoltaics and wind in global primary energy supplies by 2050 by applying "top-down" extrapolation of global trends gives positive results. Simulations of solar and wind energy deployment using a logistic substitution model containing a number of potentially fundamental limitations to further growth lead to the conclusion that there are no insurmountable constraints in terms of physical and raw material requirements, production capacity, energy balance, system integration and macroeconomic conditions. In addition, there is synergy with the direct capture and storage of carbon dioxide in the air that would achieve global zero CO_2 emissions by the middle of the century. However, achieving such an outcome would require a large-scale reconfiguration of the architecture of global and regional energy systems (Fig. 2). Cheap renewable primary electricity is likely to be an important factor driving the energy transformation. However, obstacles will remain, the overcoming of which will require foresight and strategic, coordinated actions due to the depth and dynamics of the transformation [6].

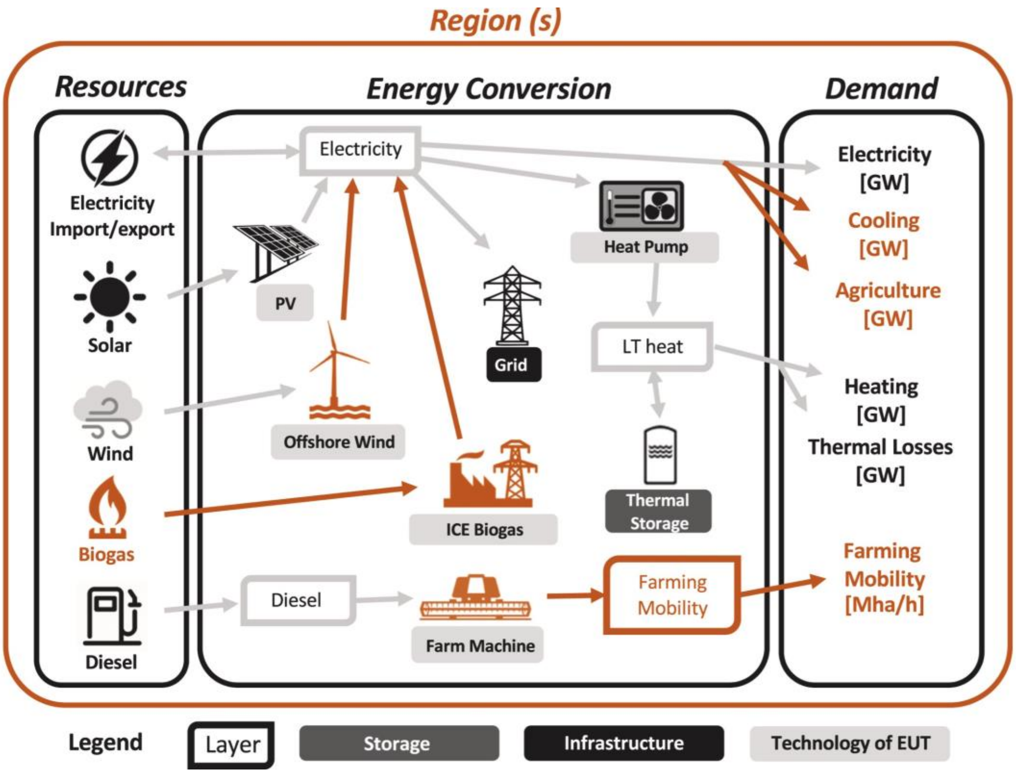

Fig. 2. Conceptual representation of a regionally-characterised national energy system: resources are converted by technologies to supply end-use demand in the different sectors (electricity, mobility, heating). Layers – such as electricity and LT heat – are defined as all the vectors in the system that need to be balanced in each period. The novel features of the regionalised EnergyScope version are highlighted in orange. Abbreviations: natural gas (NG), Internal Combustion Engine (ICE), photovoltaic (PV), low temperature (LT), end-use type (EUT) [6]

Deep decarbonization, meaning a transition to net-zero emissions energy systems, is made possible by modeling renewable energy technologies, storage and sector coupling. For example, you can use an extended and regionalized version of the EnergyScope software to be able to analyze the increasing complexity of energy systems and facilitate the selection process among the various possible transformation scenarios. The first Italian decarbonisation strategy feasibility model developed with regard to the uncertainty in the implementation of carbon capture and storage and renewable technologies shows that emissions can be [6] thanks to radical electrification of the energy system

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combined with a broad the use of renewable energy sources and efficient energy conversion technologies. An analysis of the synergies, advantages and disadvantages of the proposed approach with regard to alternative modeling approaches, used in recent deep decarbonisation research, shows that modeling the energy transition, using high computing efficiency programming tools and a snapshot approach, can justify transition scenarios by optimizing the energy transition path renewable [7].

The transformation to climate neutral energy systems is becoming a global challenge. In Poland, attempts are being made to improve planning capacity by combining generation expansion and short-term planning models into a single modeling system. An example is the combination of two models: TIMES-PL and MEDUSA, to design the road to carbon neutrality in the Polish power system. Three energy scenarios have been developed which show that by 2050 it is possible to reduce carbon dioxide emissions by 95% from the public electricity and heating sector. Detailed simulations of the power system operation have shown that load balancing is possible after installing 15-20 GW of electric power by 2050 in disposable energy technologies, next to energy storage and CHP plants [8].

Hydrogen is gaining in importance in the current global energy transition. There is growing enthusiasm and widespread enthusiasm for the hydrogen economy, as shown by economic and policy strategies currently under development that support carbon neutrality by 2030 and a swift clean energy transition. According to experts, green hydrogen has the potential to create a favorable cycle for future energy networks based on renewable energy sources. Hydrogen can provide much-needed flexibility to energy systems by acting as a buffer for non-dispatch renewable generation. The excess energy stored in hydrogen can be used to produce electricity (fuel cells or power systems), heat (combustion) or both (cogeneration), drastically reducing greenhouse gas emissions.

In the hydrogen scenario, it is important to plan the transformation of various sectors of the economy (transport, industry and energy) in order to achieve scale and synergy. The conducted analyzes indicate that hydrogen can effectively contribute to the achievement of the goal of carbon neutrality and, in the area of mobility, it can compete with lithium-ion batteries. The analyzes also show short-term solutions to reduce the carbon footprint of energy production. An example is the blending of fossil fuels with hydrogen where a combined cycle gas turbine power plant can achieve a significant reduction (0.28) using a 70% and 30% blend [9].

Problem sectors: gas, construction and transport

In Poland, the doctrine of gas diversification was adopted in the consensus of all political forces in the geopolitical context of rapid independence from gas supplies from Russia. It was concluded that the economic risks are weighed down in relation to the risk of cutting off supplies from the main direction. However, the objective function constructed in this way was severely tested when spot gas prices broke records at the turn of 21/22, which the Polish operator began to translate into the accounts of retail customers. This did not result in a revision of government centers in their approach to optimizing gas supplies and building a long-term strategy to decommission fossil fuels, but rather burdensome propaganda and conflicts in centers of political disposition. This leads to questions about the mechanisms leading to the hardening of the adopted doctrine of gas diversification.

The ongoing research into the interests of natural gas in the context of climate action in the European Union provides interesting insights. Initially, it was difficult to determine whether climate policy would reduce or increase the role of natural gas in the energy system. It is widely accepted that gas is a transition fuel during decarbonisation, meaning that it can briefly replace the more emissive fossil fuels such as coal. This narrative perpetuated the forms of power of incumbent natural gas operators, including control of resources, infrastructure and involvement in the policy-making process. Gas operators assumed that they were able to apply adaptive strategies for the transition to a low-emission energy system. However, the EU tightened its climate targets, which forced incumbent gas operators to modify the political discourse in the changing context of the fuel market. Research shows how incumbent operators use their material, organizational and discursive power to expand the status quo and adapt to pressures to introduce far-reaching changes to transformation scenarios. The process, known as "trasformismo" (Gramsci), is the natural gas industry's response to climate action that determines the political discourse shaping the trajectory of the gas energy transition [10].

The construction sector is a huge challenge, as it plays a key role in the energy transition and the reduction of carbon dioxide emissions. Capturing the dynamic CO_2 emission characteristics of building materials is a great problem during the entire life cycle of a building. In the Netherlands, research was carried out on the basis of a dynamic building stock model that combines dynamic material flow analysis with energy modeling of buildings. The environmental impact of material and energy requirements has been assessed taking into account the future electricity mix in the path towards climate neutral and energy supply of residential buildings in the Netherlands by 2050. The research results are very optimistic and show that the demand for space heating is declining by around 2 / 3 by 2050 and 80% of the electricity from the public grid for appliances and lighting could potentially be replaced if rooftop PV systems are installed on 50% of refurbished buildings and all new buildings. Greenhouse gas (GHG) emissions from operating energy will be reduced by 60-90%, depending on the adopted energy mix [11].

In the light of the Paris Agreement, road transport from issue is a segment of human activity that is extremely difficult to transform. Achieving ambitious emission reduction targets in the European transport sector requires a rapid transition to carbon-free technologies. Relative cost competitiveness analyzes of commercial vehicles constructed with different alternative propulsion technologies through the Total Cost of Ownership (TCO) assessment are needed to assist policymakers in accelerating the carbon-free transition to road transport. The research carried out in this area allowed for the identification of key parameters which, after appropriate targeting, enabled the use of more sustainable niche technologies. The assessment was based on a newly developed database of cost parameters that were triangulated during expert interviews. Scientific research shows that the cost competitiveness of low-emission or zero-emission niche technologies in some application segments in European countries is already visible today. In particular, battery electric vehicles were found to be very promising in the light and medium truck segment, but also in the heavy long-distance segments in countries that have introduced targeted support measures. Three TCO parameters drive this competitiveness of low-emission mobility: tolls, fuel costs and CAPEX subsidies. Following the analyzes, recommendations were made to make policy makers more focused on the OPEX parameter than on the CAPEX parameter, and use a combination of different state support instruments to ensure greater coverage, increased policy efficiency and flexibility [12].

Impact of the COVID-19 pandemic on the energy transition

The COVID-19 pandemic has raised important questions about energy. The pandemic shock initially led to emissions reductions in line with the rate of decline required to achieve the goals of the Paris Agreement. These unforeseen drastic emission reductions proved temporary as they did not involve major structural changes. However, the subsequent consequences of COVID-19 and the political response had an impact on the global economy. In the EU, recovery plans have provided an opportunity to deepen the path towards a low-carbon economy, while seeking to improve employment, health and equity and enhancing the role of modeling tools. Long-term adaptation to the low-carbon path and the development of a pandemic resilient transition to renewables has put in place policy mechanisms to help energy-intensive sectors such as transport, tourism and the automotive industry reduce CO_2 emissions. Despite the risk of an increase in emissions following a pandemic, current energy-socio-economic-environmental modeling tools allow for broadening the scope and tackling these complex issues of the energy transition. The research community is now able to assess distinct and unusual scenarios such as sector and country lockouts, drastic changes in consumption patterns, significant investments in renewables and breakthrough technologies, and conduct an uncertainty analysis. All of these instruments are capable of assessing the cost-effectiveness of decarbonisation options and the potential consequences for employment and income distribution [13].

The COVID-19 pandemic has highlighted the challenges awaiting the energy transition, but also the opportunities for its development. The main obstacles to the pandemic's impact on renewable energy transformation are the lack of investment and weak market demand. First, renewable energy projects suffer from high start-up costs and technical investment as a result of significant reductions in government subsidies. Second, the lower price of fossil fuels further increases the difficulty of selling fossil fuels. Third, the reduction of industrial activity leads to a decrease in the demand for renewable energy equipment, slowing down the growth of renewable energy production capacity. Fourth, the

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global renewable energy supply chain has been disrupted by mandatory trade restrictions, making it difficult to implement new projects. Finally, during a pandemic, energy poverty is more pressing than ever, making the transition to renewable energy more difficult. The COVID-19 pandemic has also created a unique opportunity to switch to renewable energy. First, the risk of investing in fossil fuels has increased dramatically as global demand for fossil fuels has plummeted. Second, governments have unprecedented implementation capacity to implement energy reform policies and legislation during an economic recovery. Third, the unique benefits of renewable energy enabling remote operation and digital intelligence provide an excellent opportunity to replace fossil fuels with renewable energy during a pandemic [14].

The coronavirus pandemic has further led to an increased use of online tools across society, both in business, education and in everyday life. This shift to an online society has prompted researchers to reflect on the extent of public control and surveillance and the forms of enforcing compliance with official ways of thinking, attitudes and behaviors through online activities. On the other hand, the process of spreading smart energy systems around the world has started with the increased use of smart meters in energy systems. Research on intelligent energy systems and current trends in energy policy allowed for the formulation of recommendations regarding the development of energy democracy and democratic legitimacy in the context of the possible impact of intelligent technologies on Community energy systems [15].

In Poland there is a meaningful increase of RES in the system despite the pandemic situation. The increase is also visible among microinstallations in households of which there were about 350,000 in Poland at the end of 2020. It brings the phenomenon called ”duck curve”, consisting in low energy consumption from the power grid (correlated with the simultaneous delivery of the produced PV energy to the grid) during the day and relatively high energy consumption in the evening which is the next challenge for transformation [16].

2.2. Program initiatives

Popczyk's concept

Jan Popczyk proposed a coherent concept for the transformation of the entire energy sector based on fossil fuels towards electroprosumerism (an economy without fossil fuels, also without nuclear energy) before 2050. The concept is universal, but clearly focused specifically on Poland. According to Professor Popczyk, the energy transformation in the breakthrough (innovative) mode should be based on scientific foundations, defined by the paradigmatic three: (1) the eclectic electro-consumerist paradigm and two hard paradigms, i.e. (2) exergy and (3) virtualization. The concept also has three broad dimensions: economic, social and environmental (nature and climate). The concept consists of 51 program postulates that can be creatively confronted with the EU energy transformation plans and in the global context (American in the Euro-Atlantic zone and Chinese in the socialist market economy) [17].

10 steps of the Energy Forum

Forum Energii is an independent Think Tank, the purpose of which is to support the transformation of the Polish energy sector. As a result of many years of work, 10 steps to overcome the crisis have been presented, each of the proposed points has its justification in in-depth analyzes. According to the authors, a plan based on the presented steps can be prepared in two years. Forum Energii invites further groups of experts, politicians and non-governmental organizations to discuss and wants to build a broad consensus around the energy sector [18].

Instrat Foundation

The independent foundation dealing with energy issues believes that the share of renewable energy in Poland in the electricity sector may be increased to 61% in 2030, in heating and cooling from up to 32.5%, and in transport from 14% up to 15%. This requires regulatory changes, especially those specifying support for PV, the abolition of the 10H rule on wind energy and timely actions related to the construction of offshore wind turbines [19].

Jagiellonian Institute

The institute, which is an independent analytical center, a center for the exchange of views and strategy building, recommends a thorough restructuring of the energy sector, pointing to imperfections causing overstated costs of the current energy sector, e.g. excessive employment, low efficiency and inadequate qualifications, maintaining redundant or multiplied organizational units, improper purchasing policy, pathology - e.g. in fuel supply, scrap management, management of coal combustion by-products, maintenance of the network or just simple theft, inadequate internal communication and politics social dialogue, the tendency to defend "possessions" by various interest groups [20].

Five ZKlaster's strategic initiatives

During the ZKlaster analytical workshop on 17/01/2022, five initiatives were formulated that should receive funding from the KPO. These are:

1) Support for the development of energy communities (microgrids).
2) Development of independent energy distributors equipped with energy storage.
3) Strategic management of hydrogen projects with experimental clauses.
4) Financing systemic energy storage services.
5) Development of green heating with the circular CO_2 cycle.

3. Discussion of the directions of transformation

When analyzing the possible directions of transformation, several scenarios appear for Poland. When we talk about the energy transformation, three positions are clear. The first of them talks about the immediate need to develop nuclear-based energy, and about renewable energy sources as supplementary sources. This direction seems difficult for several reasons. Western European countries have started the process of abandoning this type of energy, and their negative approach to creating new nuclear power plants may effectively block this process in Poland. In addition, the construction of such power plants is very time-consuming and expensive, and observing the construction of recently launched nuclear units in European countries, each time it takes longer than planned, multiplying the costs at the same time. This may result in a reduction of investments in renewable energy sources with the simultaneous risk that the power plant will not be put into operation on time, and therefore it will expose Poland to loss of energy security and collapse of the stability of supplies. The last important aspect of nuclear power plants is the storage of radioactive waste, which poses a real threat to people and the environment.

The second position, strongly advocated by politicians, tries to base the transformation on small, prosumer energy sources. This doctrine wants to prove that the energy security of the society and green energy transformation can be based on renewable sources installed at each house or on the roofs of multi-family blocks, thermal modernization of buildings and small energy storage facilities. This solution does not take into account the fluctuating energy demand of residential buildings, a poorly developed power network that is not able to operate effectively in two directions (receiving and delivering energy) and the constant, large needs of industry and services for electricity. This is also the worst option for cost reasons. Here we can compare the costs of an industrial photovoltaic installation with a capacity of 1 MW and a total of prosumer installations with a capacity of 1 MW. According to data from Zklaster, 1 MW of an industrial installation currently costs PLN 2.4 million (about 0.6 million EUR), compared to a photovoltaic prosumer installation where 10 kW is a cost of PLN 40,000 (about 9,000 EUR) upwards, which means a minimum of PLN 4 million per 1 MW (about 900,000 EUR) [21]. This means that with significant shortages of RES energy, investing in smaller sources, apart from educational and political activities, is unjustified and may lead to further increases in electricity prices for the general public, mainly for industry and services, which will directly translate into their prices. To sum up, if we continue to invest domestic money in prosumer energy instead of large sources, we will not cause a significant increase in the amount of green energy in the national energy mix, for which end consumers will pay in the prices of products and services anyway.

The third direction is to create a hybrid solution based solely on renewable energy sources and energy storage systems, assuming that energy will be sent from the recipient as short as possible. This

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requires the creation of regions for distributed production of renewable energy that will strive for maximum self-balancing. In this case, the emphasis is on the largest possible renewable energy sources combined with all possible energy storage systems. We are talking here about technologies that use water, wind and sun, as well as hydrogen to generate and make the best use of electricity and heat in the emerging microgrids. Such a system would meet the requirements of EU directives and seem to have the lowest risk. Moreover, it is possible to find potential domestic and foreign investors to finance investments.

An important aspect for the discussion is the transformation of society, including the current employees related to the coal economy. In this case, maintaining unprofitable jobs, instead of preparing them for a smooth transition to modern technology sectors, may cause a significant crisis on the labor market. If you take into account modern sectors and Industry 4.0, they require highly qualified human resources, providing well-paid jobs in return.

4. Conclusions

The global direction resulting from the care for the natural environment and the prevention of natural disasters occurring due to the significant emission of CO_2 into the atmosphere by humanity has already been given. We are talking not only about Europe, but also China, the Arab Emirates and the USA. More countries are joining efforts to reduce CO_2 emissions, the largest producer of which is industry, including coal-fired power plants. Despite the considerable resistance of the incumbent operators, who are afraid of changes, which is completely natural, there is currently no possibility for Poland to deviate from the goals set by the European community in the collection of documents under the collective name of Fit for 55. The only unknown is the moment when very rapid changes begin, because due to many years of shortcomings in preparing for transformation, Poland no longer has time to slowly enter the situation of change.

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SOK Research Project – Bw-1n gallery drilling test using Bolter Miner and exclusive bolting in Polish conditions

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Abstract:

The article presents the SOK Research Project idea, course and final results. The project was oriented onto an implementation of exclusive bolting in one of the Polish underground coal mines, realized with use of a multifunction Bolter Miner. Until starting that project the Jastrzębska Spółka Węglowa S.A. (Jastrzębska Coal Company J.S.C.) has been using different types of other supports (steel arches as gallery / roadway supports). Previous trials of implementing exclusive bolting in the Polish coal mines in the nineties of the XX century were not successful due to different reasons. In the case of the SOK Research Project, after having conducted detailed geological and mining analyses, a part of the Seam 401 in the Budryk Mine was chosen for tests of exclusive bolting with use of JOY 12CM30 Bolter Miner in the gallery drilling operations. Due to previous experience, gained in the process of exclusive bolting in the Upper Silesian Coal Basin conditions, special attention was paid to bolting designing as well as an installation and monitoring. As the SOK Research Project was the first trial in Poland of gallery drilling using exclusive bolting and Bolter Miner, so it was difficult to predict exact costs and final efficiency results. For all the project participants, i.e. the mining crew, engineers, managers and researchers it was an on-job training in the scope of new technology. The SOK Research Project enabled to gain a lot of new experience and knowledge, leading to guidelines and conclusions which can be useful in the following exclusive bolting implementations with Bolter Miner technology.

Keywords: bolting support, Bolter Miner, test gallery, research project, mining-and-geological conditions, monitoring, advance

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1. Introduction - project assumptions and scope

The SOK Research Project, realized by the Jastrzębska Spółka Węglowa S.A. (Jastrzębska Coal Company), over the years 2017-2020, was oriented onto an assessment of possibilities in the scope of adapting best available techniques and technologies, used in the world mining industry, to increase efficiency of a production cycle. It included a technical dialogue aimed at on identification of the best technical and technological solutions as regards mining operations, haulage of the run-of-mine as well as monitoring of the rock mass [1-8]. Such an approach to the research programme enabled to reach the project objective of implementing exclusive bolting successfully. After having analyzed different mining and geological conditions the Bw-1n test gallery at the Budryk Mine was chosen for a realization of the SOK Research Project. The project itself, but in particular its results, achieved in difficult mining, geological and organizational conditions, turned out to be a technological break-through in the Polish mining industry. The research work within the project concentrated on implementing exclusive bolting in galleries of the Jastrzębska Spółka Węglowa S.A. and on an analysis of a full spectrum of possibilities enabling an application of this technology in the process of gallery drilling and also an extraction of residual parts of deposits. A detailed description of mining-and-geological conditions in the area of the gallery under development included roof, floor and hydrogeological conditions, tectonic faults and natural hazards. Special attention was paid to an installation of the bolting system and its monitoring. It should be highlighted that an implementation of exclusive bolting, realized with use of the Bolter Miner, was a real challenge for all the research project participants, representing leading suppliers of the state-of-the-art technological systems for the mining industry, researchers from the national and international scientific institutes and managers from the leading companies producing minerals in Poland. The project assumptions were based on knowledge and innovations and the final successful results confirmed the JSW'S policy based on a collaboration between science and industry.

After having transported the JOY 12CM30 machine components to the pre-prepared assembly chamber, on 10th October 2019 a realization of the SOK Research Project - Exclusive Bolting started.

The project was conducted in the Bw-1n test gallery, situated in the Seam 401 of the Budryk Mine, at the depth of about 900 metres. It showed that the technology of developing galleries in exclusive bolting systems was safe and that the working was stable. The operations, executed by the teams of miners, were less arduous than in the case of traditional support. The date: 9th November 2020 was the last day of the project duration, so the research project lasted 13 months, during which 1168 metres of the Bw-1n test gallery were drilled [9-12]. The fourth month of the project was particularly difficult due to the problems with an execution of Bend No. 1, changing the direction of drilling the working from the north-eastern to the eastern one. Between the fifth and ninth months of the project realization a straight section of the length of about 800 metres was developed. It should be mentioned that geological conditions deteriorated then. An increase of separations was observed in two measurement points, so a decision about changing the bolting network was taken. In the area of Bend No. 2 the roof conditions deteriorated significantly. Apart from that a local increase of rock layers inclination happened, so it was indispensable to change a location of the designed bend, changing the development direction from the eastern to south-eastern one. A stability of the Bw-1n test gallery was controlled by five stations of convergence monitoring and measurements stands of current control [13]. The conducted tests and monitoring of the rock confirmed a correctness and efficiency of applying exclusive bolting system. During the development period of nine months, the gallery was fully functional and stable. The problems connected with a dynamic increase of roof separations, detected during the sixth month, were solved quickly and efficiently. A change in the bolting network, which will be presented in detail in the following chapters of this article, enabled to continue mining operations without any negative impact on the personnel's safety level.

Down-times and failures, experienced in the development process, were caused by fluctuations of water pressure in the fire-extinguishing pipeline and down-time in the mine central haulage system. Apart from the problems of technical-and-organizational nature, the COVID-19 pandemic had a significant negative impact on the project realization [14].

In the sixth, seventh and ninth months of the project duration there were down-time periods connected with an introduction of the state of epidemic. In the result of such unexpected circumstances a decrease of daily advances was unavoidable and thus an increase in the project costs happened.

The research-and-development character of the project enabled to conduct series of analyses, an elaboration of best practices and to gain operational experience in the scope of optimum lay-out of machines and devices, designing exclusive bolting system and its installation in deep gassy mines as well as a selection of exploitational materials and monitoring of galleries developed with use of exclusive bolting [15].

2. Materials and Methods

Tasks of the SOK Research Project

The SOK Research Project was started in 2017 by signing the following agreements and contracts:

- 24th March 2017 – Agreement with Joy Global (Poland),
- 20th June 2017 – Agreement with the Główny Instytut Górnictwa (Central Mining Institute),
- 20th April 2018 – Consortium Agreement signed by the JSW Innowacje, JSW S.A., GIG, JOY Global.

A project organizational structure contained the Project Team and the Steering Committee.

Fig. 1 shows the companies taking part in the implementation project of exclusive bolting system and their collaborative links.

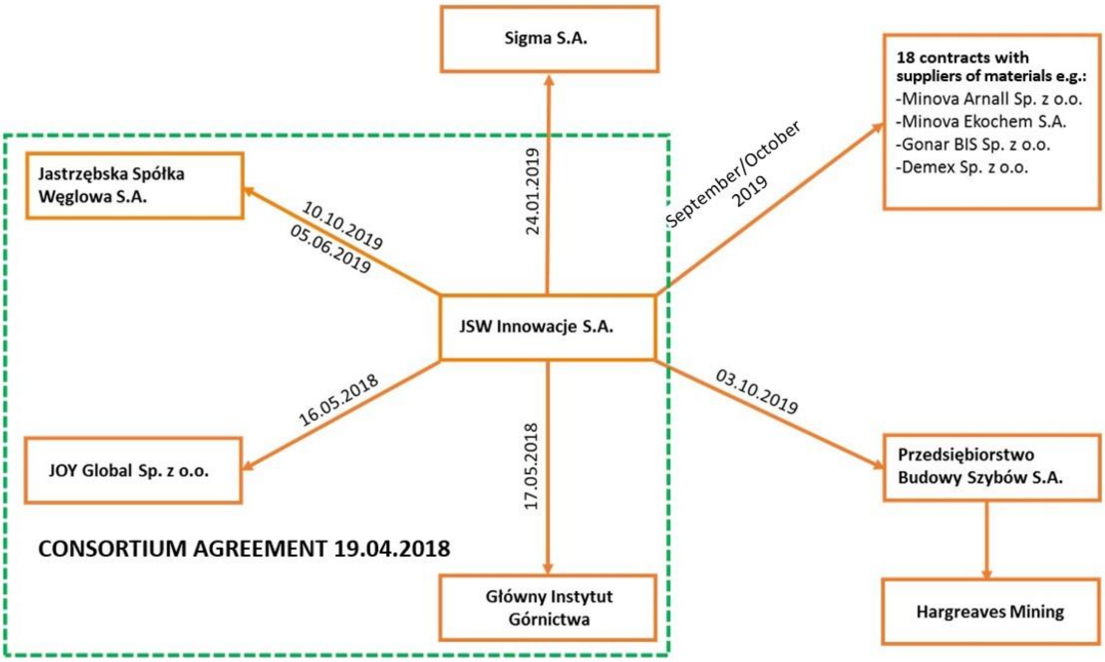

Fig. 1. Companies involved in a realization of the SOK Research Project [1]

The tasks were divided in the following manner:

- JSW Innowacje S.A. – project coordination, realization of scientific-and-research work, organization of the Bolter Miner delivery and other indispensable face equipment as well as organization of materials and measuring instruments deliveries,
- JSW S.A. (Board Office) – project supervision,
- PBSz S.A. – development operations,
- Hargreaves Mining – personnel/machinery operators' training,
- JOY Global – Bolter Miner manufacturer and BM technical service,
- SIGMA S.A. – auxiliary equipment (belt conveyors etc.) manufacturer,

– Główny Instytut Górnictwa – expert services and bolting research and designing.

Stages of the SOK Research Project

The SOK Research Project was divided into seven stages, including two stages of an assembly and disassembly of the test rig and five stages of the gallery development, in which three stages concerned a development of straight sections and two stages – a development of bends. The project research programme of developing the Bw-1n test gallery in exclusive bolting contained the following tasks:

Task 1: A construction of a test rig in the underground environment and operational conditions, including an assembly of the Joy 12M30 Bolter Miner, face devices and equipment for haulage of the run-of-mine together with an elaboration of reports.

Task 2: Development tests at the test rig in the underground environment and operational conditions during a development of the Bw-1n test gallery to Bend No. 1 together with a preparation of the report.

Task 3: A development of the Bend No. 1 together with driving 70 metres of the Bw-1n test gallery for an installation of the run-of-mine haulage devices according to the technical documentation of the SIGMA S.A., an installation of the run-of-mine haulage devices and a preparation of the report.

Task 4: A realization of planned tests at the test rig in the underground environment and conditions, taking into consideration the conclusions drawn from a development of the second segment of the Bw-1n test gallery and a preparation of the report.

Task 5: A specification of possibilities of the SOK technology at developing the Bend No. 2 together with a development of 70 metres of the Bw-1n test gallery for an installation of the run-of-mine haulage devices according to the SIGMA S.A. documentation, an installation of the run-of-mine haulage devices and a preparation of the report.

Task 6: Development tests conducted at the test rig in the underground environment and underground conditions enabling to demonstrate the technology at driving the third segment of the Bw-1n test gallery and a preparation of the report.

Task 7: An analysis of the current state of the SOK technology and an elaboration of methodology for a liquidation of the test rig in the underground environment and conditions, including a disassembly of the JOY12 CM30 machine, of the face devices and of the SIGMA S.A. run-of-mine haulage devices together with a preparation of the final report on the SOK Research Project.

The research-and-development project started with a selection of the most convenient venue for an assembly of the JOY12CM30 machine. The machine was assembled in the assembly chamber, prepared earlier in the Seam 401 of the Budryk Mine. An operational conformity of all the machine subassemblies was checked [16-17]. A development of the Bw-1n test gallery in the Seam 401 of the Budryk Mine was started in the second month of the project duration. The section of only 65.8 metres of the working was developed due to down-times caused by mechanical failures of the machine and belt conveyors as well as technological reasons such as a construction of a periodical control station.

The third month of the project realization ended at 200 rm of the Bw-1n gallery. It should be highlighted that development operations were sped up significantly and the number of down-time breaks was reduced. An advance of operations in the third month of the project "SOK Research Project" is shown in Fig. 2.

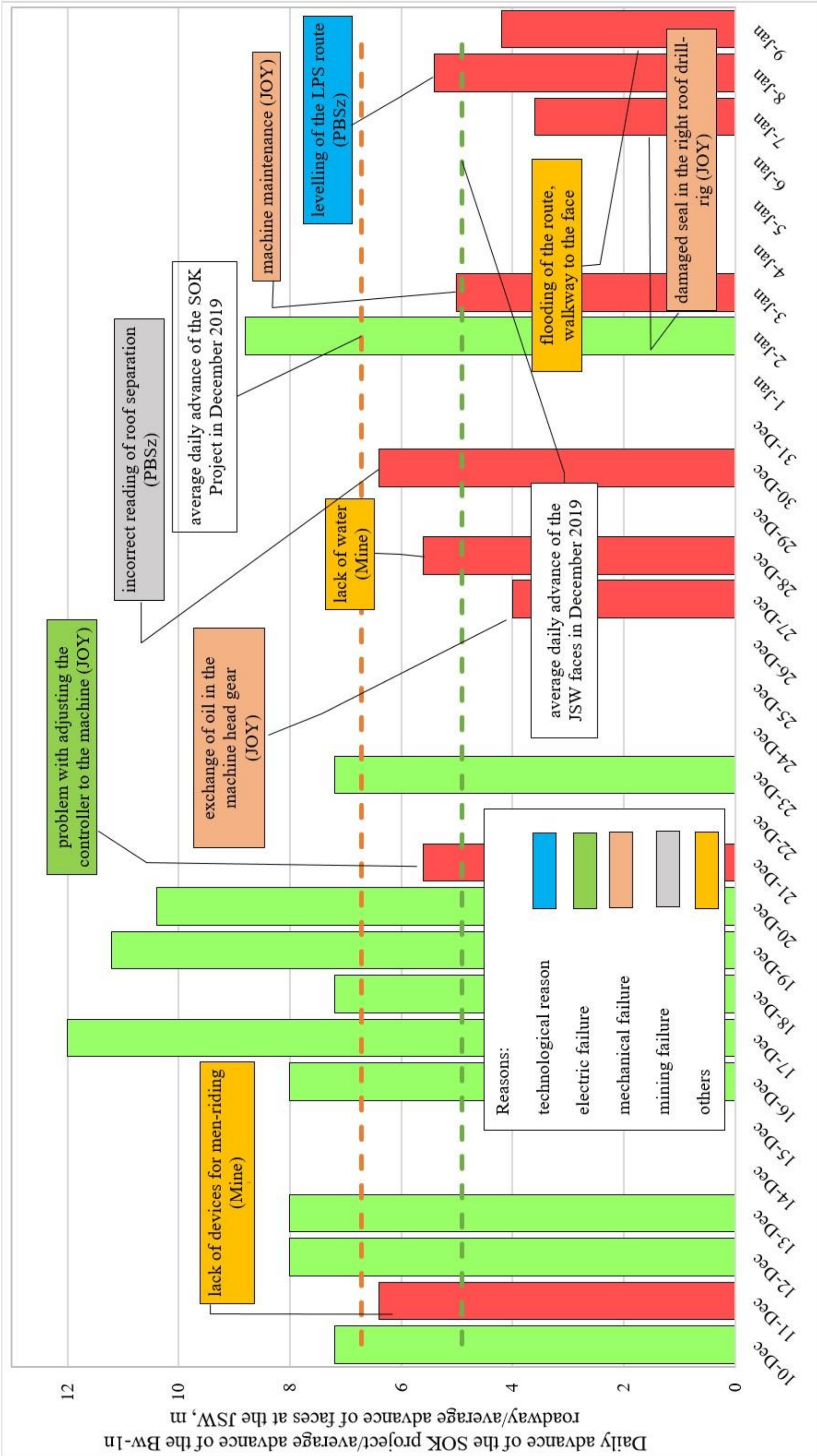

Fig. 2. Advance of operations in the third month of the SOK Research Project duration [5]

An execution of the bend was planned for the fourth month of the project realization. It required an increased amount of labour, especially for a reconstruction of the technical infrastructure and an installation of a bigger number of bolts, including rope bolts.

The fourth month was ended at 255.2 rm of the Bw-1n test gallery. The machine was withdrawn and an installation of chock supports was started to develop the bend at 210 rm. The working of 6.8 m x 4.2 m was developed until 5th February and then the basic dimensions 5.6 m x 4.2 m were continued, which enabled to increase the daily advance.

The daily advance of the working in the project fourth month is presented in Fig.3.

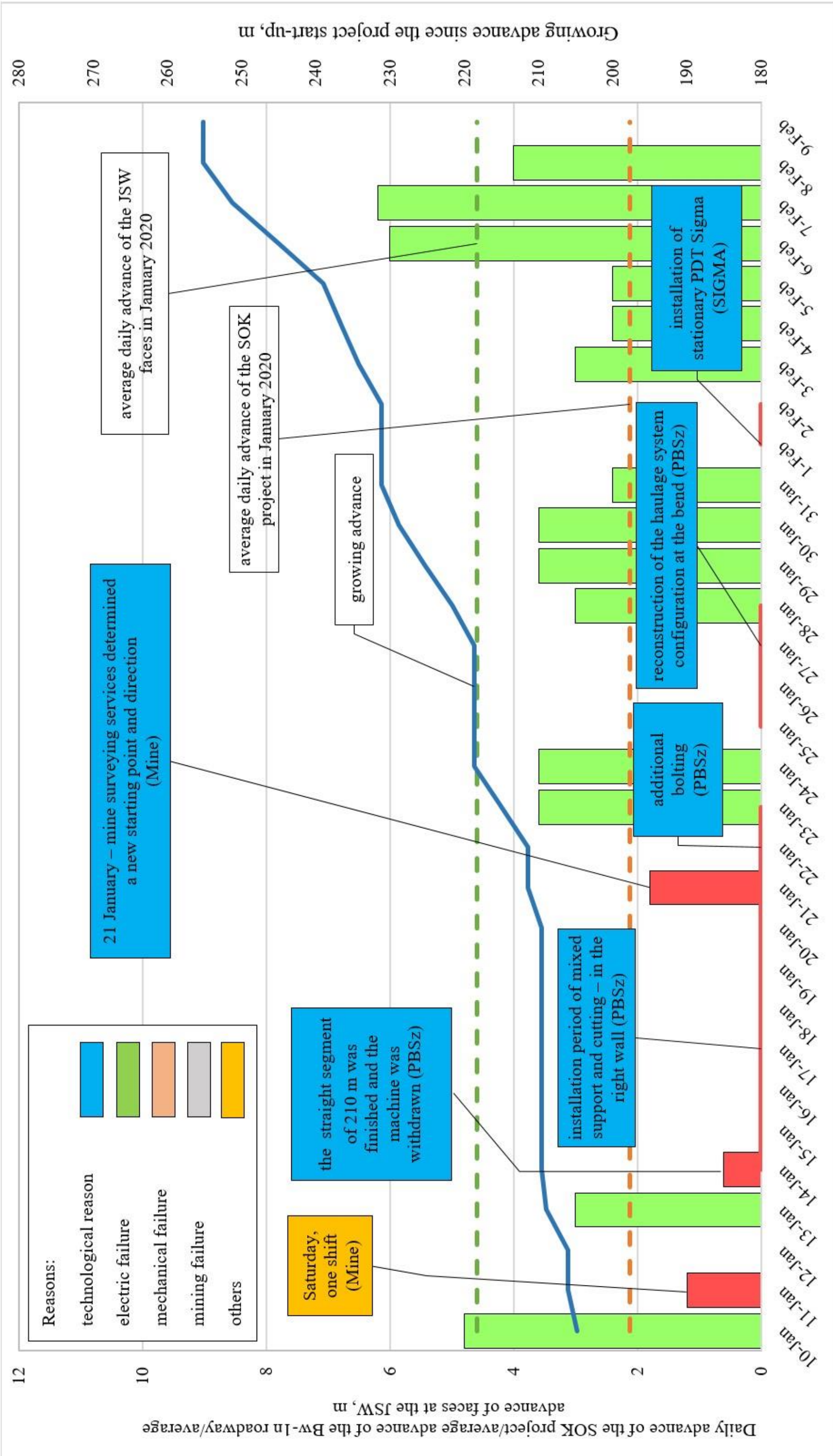

Fig. 3. Advance of operations in the fourth month of the SOK Research Project duration [5]

The fifth project month ended at 392 rm and the sixth project month - at 556.4 rm of the Bw-1n test gallery. Since 23rd March 2020 an organization of work has been changed due to an introduction of the COVID-19 epidemic state in Poland. The worktime was reduced to 3 working shifts every 24 hours, lasting 6 hours each. Then the daily advances dropped below the average.

Down-time was caused by failures of the main haulage system, a failure of the machine roof drill-rig, of its cutting head, a failure of the water flow in the machine and also lack of water and pressure jumps in the fire pipeline.

The seventh month of the project duration enabled to reach 689.2 rm of the Bw-1n test gallery. When the COVID-19 restrictions were annulled and four-shift system was returned a daily advance increased. The down-time was mainly caused by mechanical failures, an extension of the run-of-mine haulage route and the machine sinking in weak floor rocks.

The eighth month of the project duration ended at 903.2 rm of the Bw-1n test gallery. The average daily advance reached 9.70 metres, whereas in the case of other faces developed with use of conventional technology - 5.14 metres. It is worth highlighting that the concentrated bolting network was installed. It should be borne in mind that when better roof conditions occur, the daily advance can be even greater. The down-time was caused by failures of the main haulage system, of the SIGMA conveyor, a voltage decay in the grid, exceeded methane concentrations as well as lack of water in the fire pipeline.

The ninth month enabled to reach 1015.4 rm of the Bw-1n test gallery. The advance was extremely limited because of severe restrictions in the Upper Silesian Region due to a big number of the COVID-19 cases. The development operations were conducted during single shifts in June. However, at the beginning of July normal operation of the Budryk Mine started. The daily advance in June was 6.22 metres. Some mechanical failures were recorded but they were rare. Initially, it was planned to make the second bend, but due to delays it turned out impossible.

The tenth month of the SOK Research Project realization ended at 1059.4 rm of the Bw-1n test gallery. The advance was reduced due to a sudden change of mining-and-geological conditions, mainly due to an increase of the Seam 401 inclination angle to about 15^{o} which made a continuation of the development operations practically impossible, so the machine was withdrawn and installed in the new location of the bend. An average daily advance in July was only 3.49 metres. An average daily advance in the project accounting period was 2.01 metres [18-19].

In Fig. 4. A growing advance rate of the Bw-1n test gallery development, over the period of 10 months of the SOK Exclusive Bolting, is presented.

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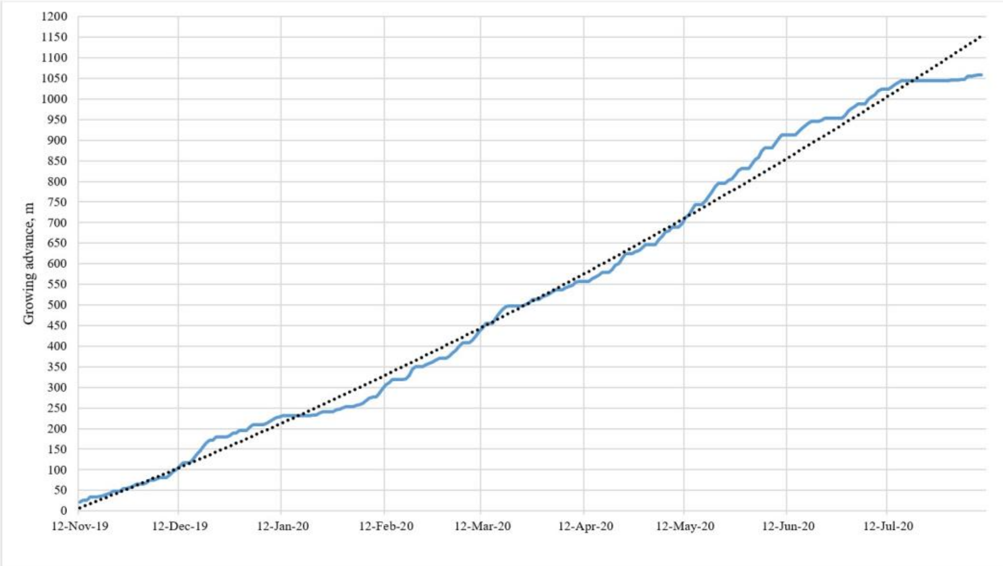

Fig. 4. Cumulative advance of the Bw-1n test gallery development over the period of ten months [5]

3. Assessments, comments, conclusions and recommendations

Having analyzed a series of machines of Bolter Miner type available on the market, including possibilities of their use in the mining-and-geological conditions of the JSW S.A. mines, the Bolter Miner of JOY12CM30 was chosen.

Its cutting weight was from 2.2 to 4.9 m, cutting width – from 4.6 to 5.4 m and its weight – 85000 kg. The minimal roof opening before the web was 2.0 (1.0) m.

Fig. 5 presents a view of the JOY12CM30 Bolter Miner implemented in the Budryk Mine.

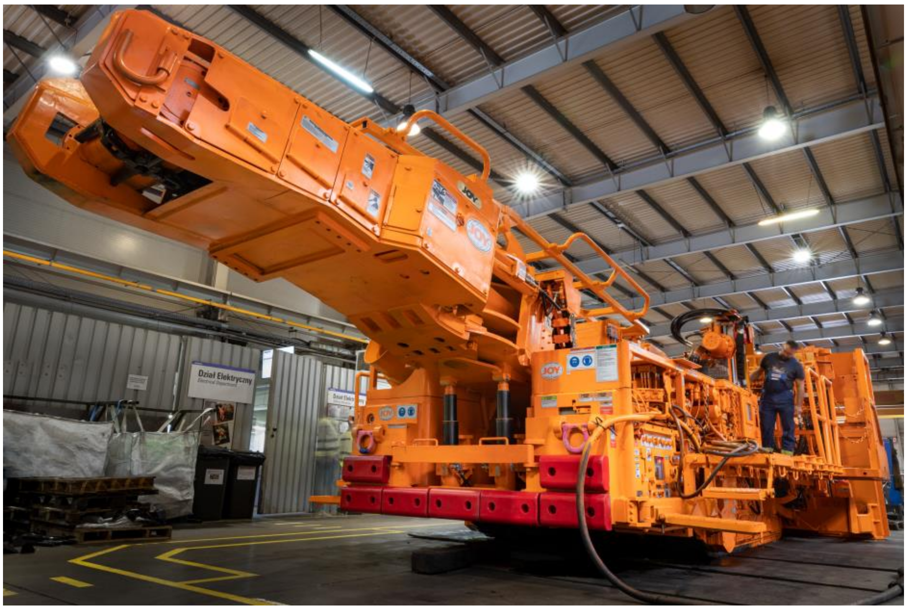

Fig. 5. A view of the JOY12CM30 Bolter Miner [16]

In the initial version 6 bolts in the roof and in the walls were accepted. In the case of the project basic variant of 14 bolts, the achieved advance varied from 15 to 30 rm (Fig. 6).

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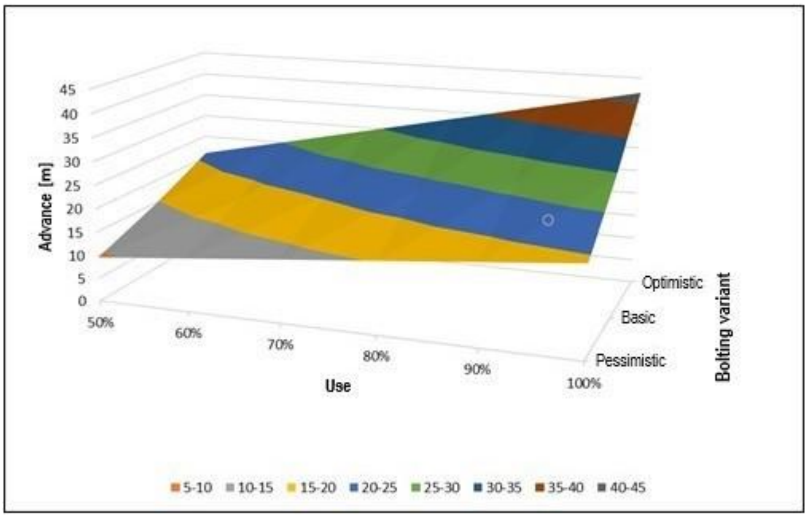

Fig. 6. Relationship between advance and bolting variant

The analysis concerned the cutting and bolting cycle in relation to the number of bolts and their spacing. A conservative approach was assumed as regards time consumption – on the level of 50%. From Fig. 7 it can be seen that in the case of increased number of bolts the SOK Research Project is efficient economically.

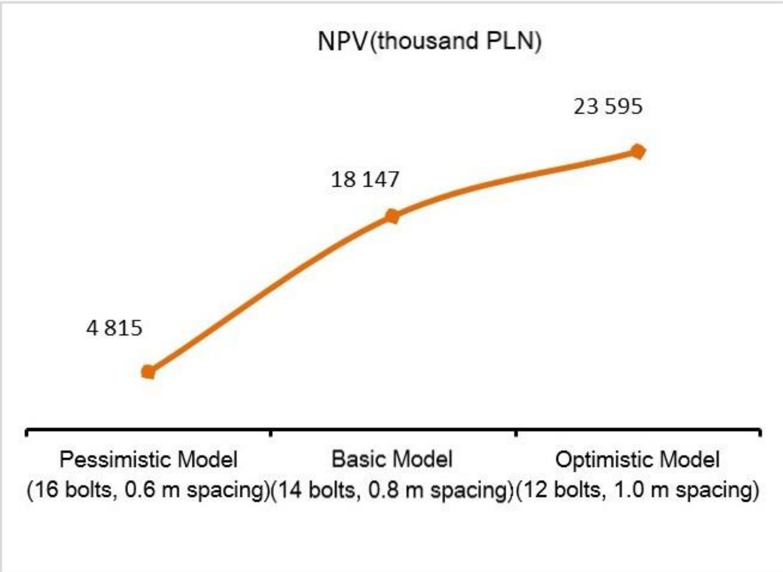

Fig. 7. Economic efficiency of the SOK Research Project

Even if the number of bolts is increased to 10 in the roof and 8 in the walls and the spacing is reduced to 0.6 m the economic efficiency is still positive.

It is worth bearing in mind that advances possible to be achieved, with use of the Bolter Miner, are greater than an average advance achieved with a use of a road-header and chock supports (6.0 m/day) already at 20% of the BM system available time (Fig. 8).

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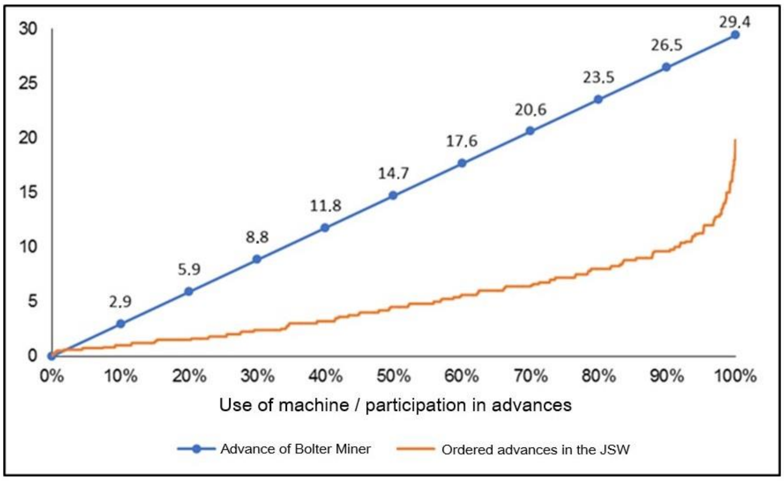

Fig. 8. Relationship between the working development advance and the degree of the 12CM30 Bolter Miner use in relation to advances achieved at JSW S.A. with use of conventional method of developing roadways with roadheaders

The SOK Research Project results confirmed a possibility of using exclusive bolting in the conditions of the test gallery developed with the Bolter Miner. Different, than initially forecasted, mining-and-geological conditions caused that it was indispensable to change the bolting system design project which had an impact on the number and length of the applied bolts and thus extended the time of bolting roof and walls in one working cycle. The mechanical strength of rocks was lower than that one predicted by geological-and-surveying staff of the Budryk Mine, so it was indispensable to change the bolting network.

A big disadvantage also concerned the Bolter Miner sinking in the floor. An occurrence of sphaerosiderite lenticles of the compressive strength reaching 85 MPa was a probable reason of a serious failure – a damage to the cutting head. The run-of-mine transport system, consisting of stationary belt conveyors (Bogda), belt conveyors (Boa) and Sigma belt feeder suspended to the machine, was unreliable operationally.

According to the operational manual, the 12CM30 machine is designed for cutting rock of the Rc which does not exceed 60 MPa [16]. An essential technical element of the system includes a sub-system for a transportation of personnel and materials to the face. It should also be mentioned that a peripheral location of the Bw-1n test gallery caused decays in electric energy supplies and pressure drops of technological water which caused breaks in cutting and/or bolting operations. Another crucial factor, having a direct impact on development results, included personnel's work time. In the case under consideration it was about 5 hours in the 4-shift system, whereas in Australia it varies from 10 to 12 hours, in China and Russia – 8 hours.

In the result of the SOK Research Project realization repeatable failures of the power hydraulic system were experienced e.g. damage to hydraulic hoses during drilling-and-bolting operations. There were leakages of oil due to damage of seals. In the water system mechanical failures of flowmeters occurred.

However, the final conclusions, which can be drawn on the basis of the SOK Research Project analysis, authorize to state that an application of the gallery development with use of the Bolter Miner, enabling an installation of exclusive bolting, gave positive results. This technology has a big potential in terms of efficiency improvement as well as in terms of development advance in relation to the results achieved in the Bw-1n test gallery, developed in the Seam 401 of the Budryk Mine.

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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:

$$N_{US} = N_Z \cdot \eta_S \quad (1)$$

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and:

$$N_{UP} = N_{US} \cdot \eta_P \quad (2)$$

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:

$$N_{losses} = N_Z - N_{UP} \quad (3)$$

therefore:

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

For two units:

$$N_{losses-2} = 2 \cdot N_{losses} \quad (4)$$

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:

$$T_W = T_{WATER} - T_{AMBIENT} \quad (5)$$

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Then:

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

Selection of coolers for the cooling system used in a conveyor operating in surface conditions.

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.

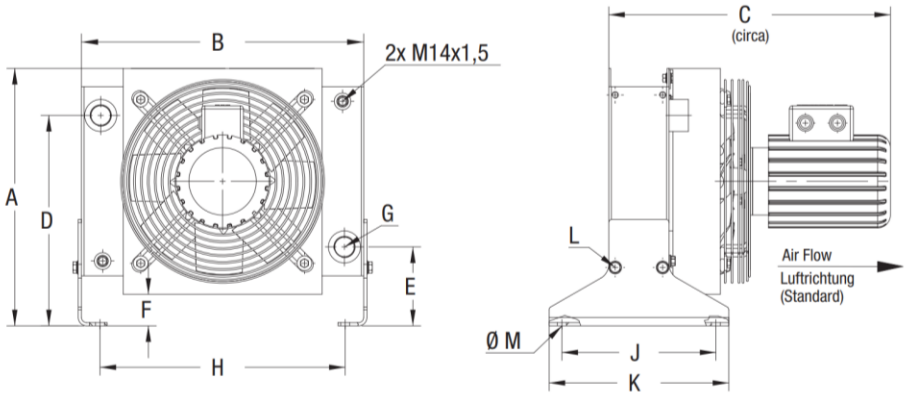

Fig. 1. View of A type cooler [15]

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.

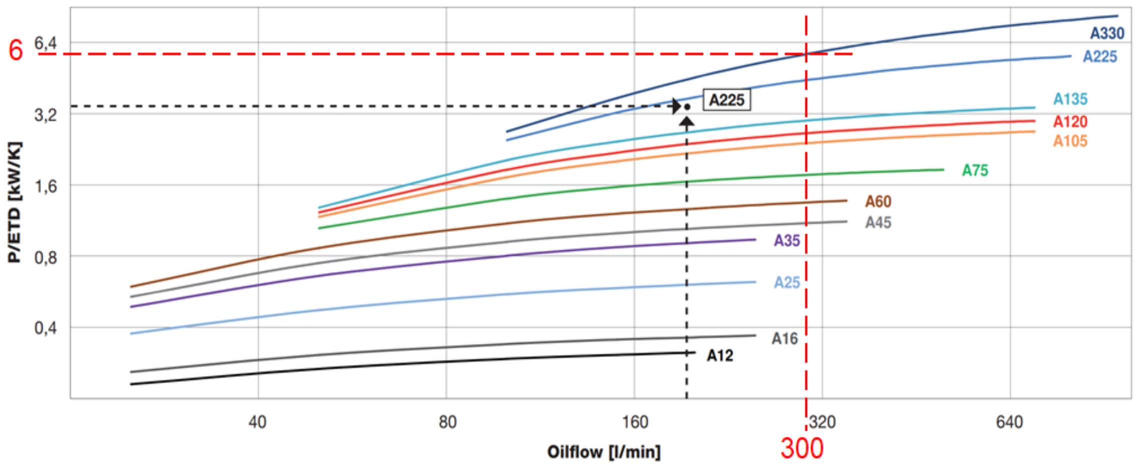

Fig. 2. Cooling power depending on the flowrate of the cooling liquid per 1 deg. of temperature difference [15]

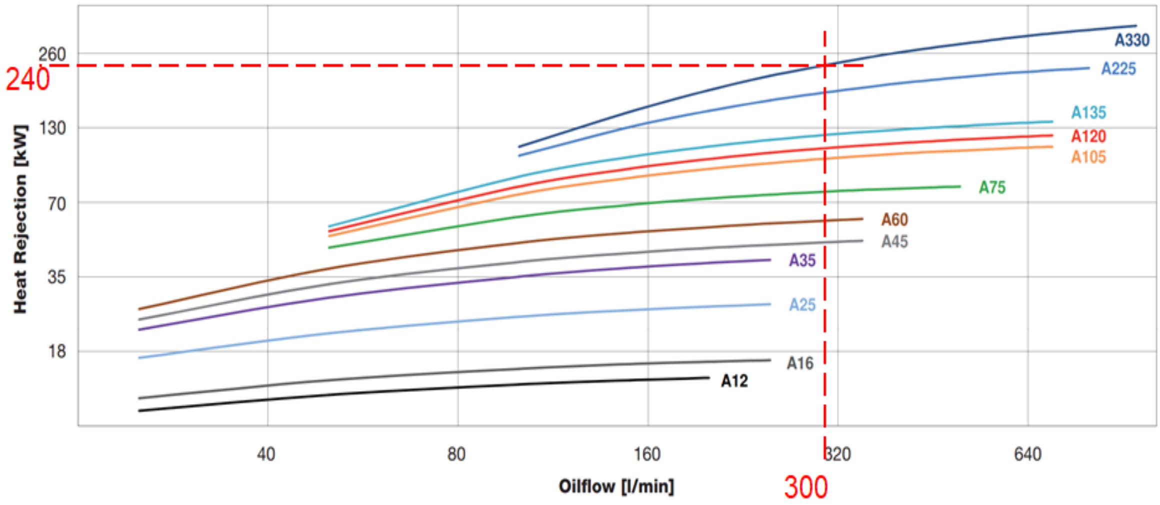

Fig. 3. Total cooling power depending on the coolant flowrate [15]

<u>Selection of coolers for the underground cooling system.</u>

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.

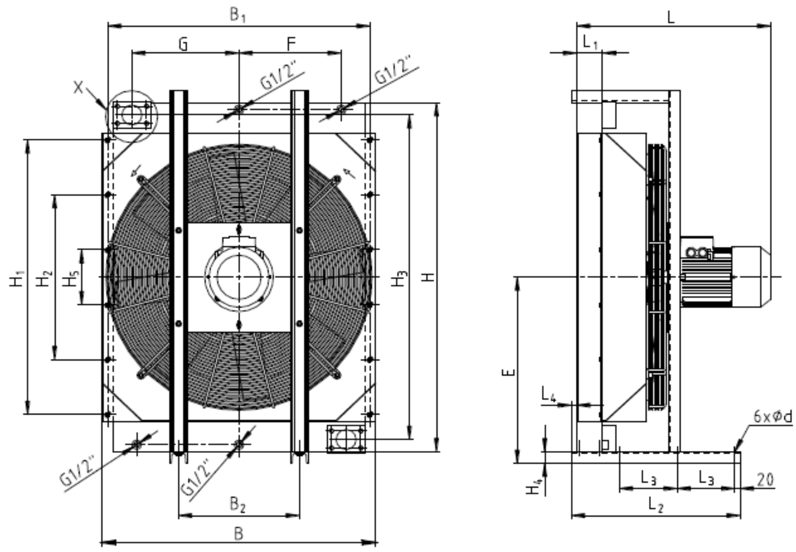

Fig. 4. View of the cooler for use in a potentially explosive atmosphere [16]

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.

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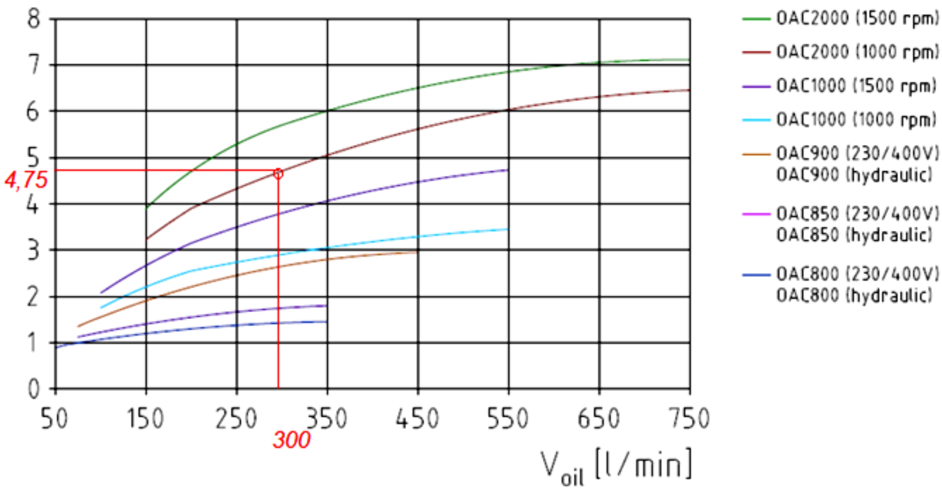

Fig. 5. Cooling power depending on the coolant flowrate for the sample coolers [16]

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.

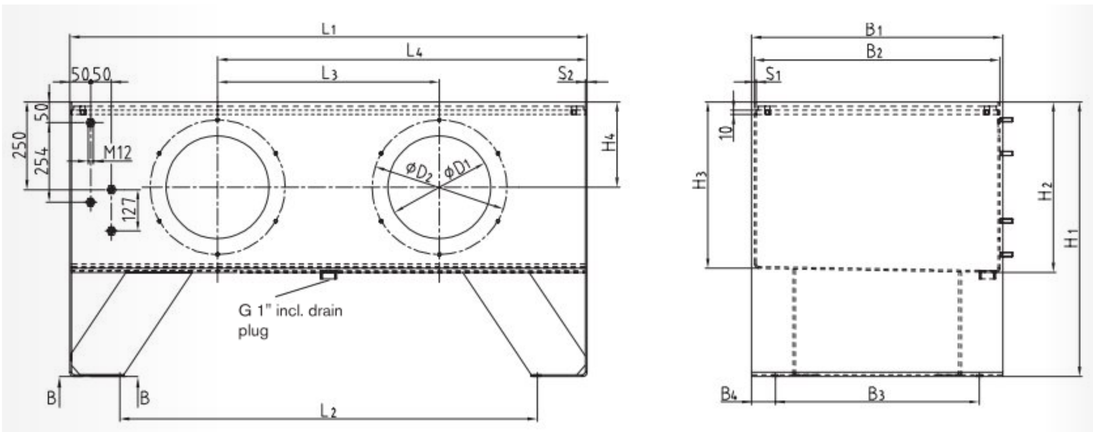

Fig. 6. Sample tank for a coolant [17]

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 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).

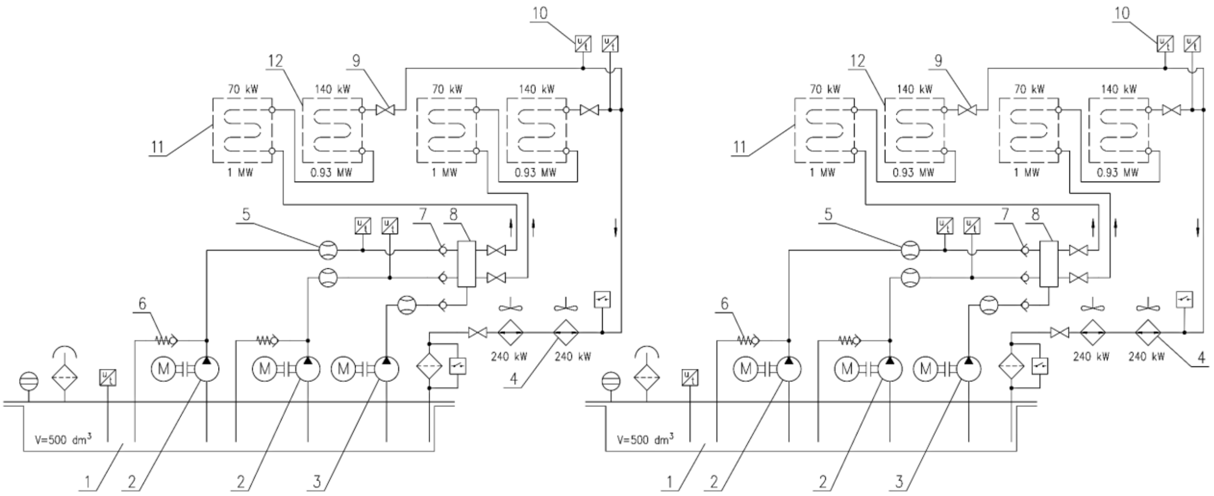

Fig. 7. Diagram of the surface cooling system of conveyor belt drives: 1 - tank, 2, 3 - pump units, 4 - air-water cooler, 5 - flow meter, 6, 7 - check valves, 8 - collector, 9 - cut-off valve, 10 - temperature sensor, 11 - electric motor flow system, 12 - gear flow system

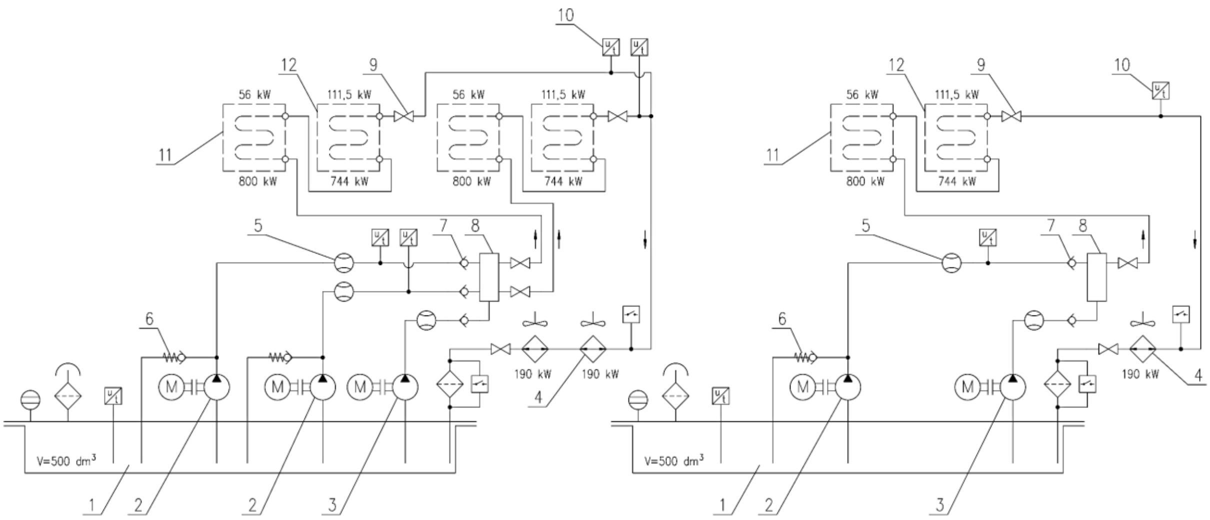

Fig. 8. Diagram of the underground cooling system of conveyor belt drives: 1 - tank, 2, 3 - pump units, 4 - air-water cooler, 5 - flow meter, 6, 7 - check valves, 8 - collector, 9 - cut-off valve, 10 - temperature sensor, 11 - electric motor flow system, 12 - gear flow system

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.

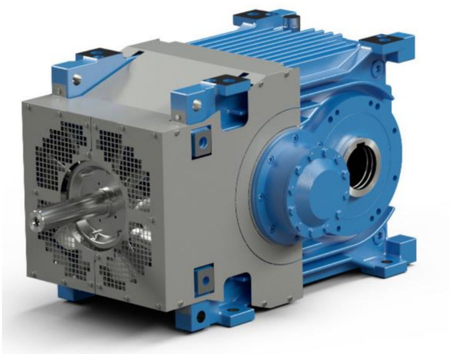

Fig. 9. Helical-bevel gear requiring no additional cooling [18]

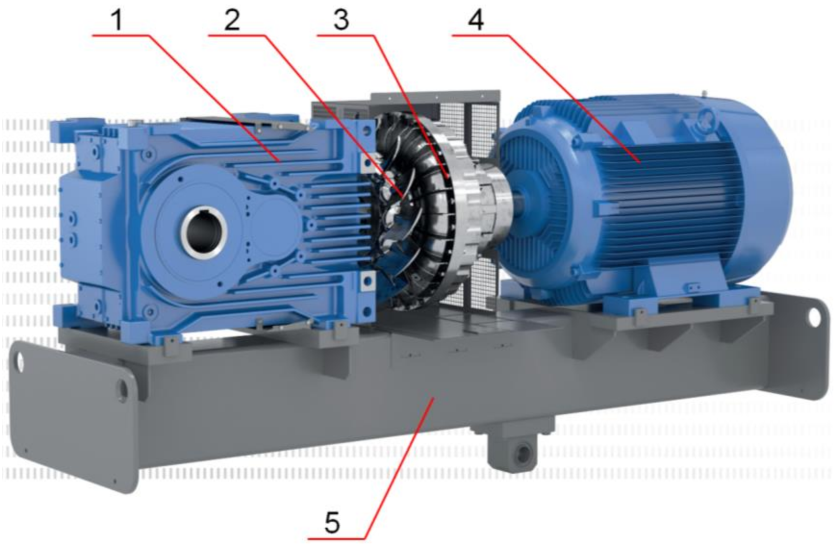

Fig. 10. Sample of Nord drive unit [18]
1 - gear, 2 - fan, 3 - hydrokinetic gear, 4 - electric motor, 5 - base

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.

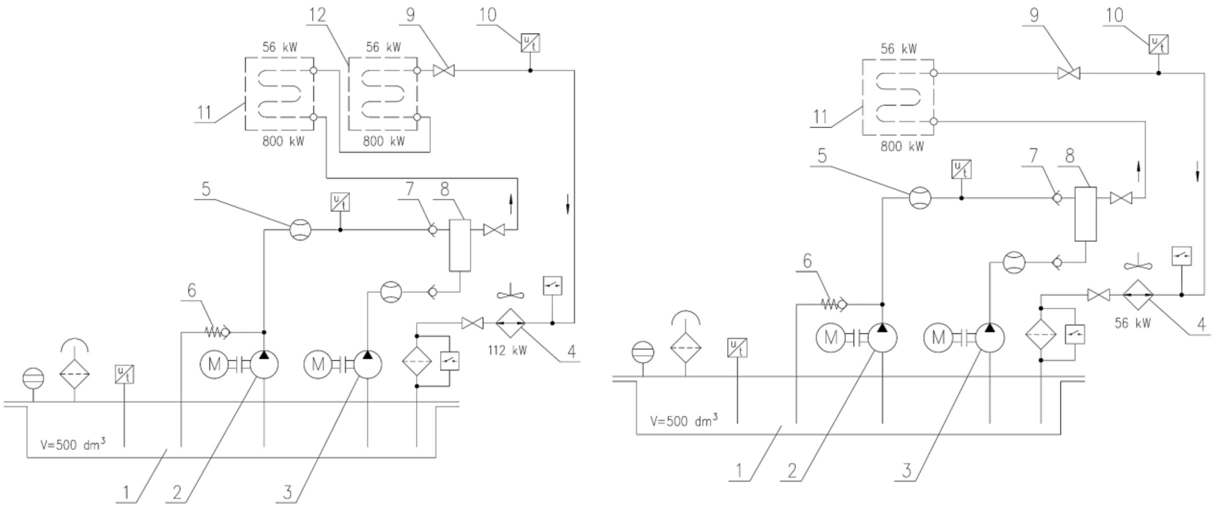

Fig. 11. Diagram of the cooling system of the underground drive with the use of a gear with higher efficiency: 1 - tank, 2, 3 - pump units, 4 - air-water cooler, 5-flow meter, 6, 7 - check valves, 8 - collector, 9 - cut-off valve, 10 - temperature sensor, 11 - electric motor flow system, 12 - gear flow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

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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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