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Mechanization of cleaning the area of operating belt conveyor system

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Abstract:

Cleaning the belt conveyor system components is one of the greatest challenges when it comes to operational reliability and fire safety.

Machines and equipment used abroad for cleaning the conveyor belt and removing dirt accumulating under and next to the conveyor are discussed. The importance of cleaning the conveyor's surroundings with respect to reliability of the belt operation and fire hazard, is emphasized. Design of the boom to clean the floor under and next to the conveyor belt, is presented in detail. The boom is equipped with a jaw bucket that allows for pushing, scooping, and moving (hauling away) the run-of-mine. It was installed on an adapted existing caterpillar chassis powered by an electro-hydraulic unit.

The kinematics of boom operation in a confined workspace is analysed. The 3D visualization and a description of the boom design with a preliminary FEM analysis of the boom's arm is presented.

The design and range of the boom's operation allow cleaning backfilled and hard-to-reach spaces under the working conveyor.

Keywords: small mechanization, power industry, conveyor transport, boom

1. Introduction

Belt conveyors transport thousands of tons of aggregate, what requires ongoing monitoring of their condition, service and maintenance to ensure their uninterrupted operation. Conveyor belts are widely used to convey and transport different types of materials.

Improper operation of belt conveyors poses a serious risk of exogenous fire. A number of mathematical models are being developed to enable predicting the basic physical parameters indicating for fire of conveyor belts to improve work safety in mines. Mathematical models of a belt fire, based on belt fire observations and analyzes are developed [1].

Ignition of the run-of-mine gauge on the conveyor belt and/or the run-of-mine falling on the floor through leaks along the conveyor route may be one of the fire sources [2].

Many innovations were introduced in development of new solutions of cleaning devices for belt conveyor systems to obtain optimal cleaning effectiveness depending on the type of transported material and the ambient temperature. The design of the cleaning equipment can be adopted to different types of belts: plastic, vacuum type and high temperature belts, designed for a specific purposes. Conveyor belt cleaners are designed to clean by scraping the hardened materials sticking to the surface of the conveyor belt. There are basic (e.g. scrapers) and secondary (e.g. washers, rotating brushes) belt cleaners that are designed to solve cleaning and maintenance problems where it is necessary to transport materials that are exposed to wet, dirt and corrosive environment [3]. Swinderman [4] patented the adjustable conveyor belt cleaner that is capable of gradually adjusting the blade angle to the belt, with the ability to go from negative to positive angle depending on circumstances and environmental conditions. There are several other designs of primary and secondary cleaners on the market, adapted to different factors such as the type of material being conveyed, type of a belt, and speed of the belt movement.

Scrapers or other methods of cleaning the belt surface do not eliminate completely dirt from the belt conveyor system, as during its operation unpredicted disturbances such as belt cut or belt overload may occur. This causes spill out of the load and dirt covers the space under the conveyor belt. If there is no reaction from the conveyor's operator, excessive accumulation of the flammable material becomes dangerous causing a fire hazard or blocking the conveyor or breaking the belt [5].

In the Polish coal mining industry, roadheading machines are often used to clean the space under the conveyor route. The machines are of big size, so their maneuverability in mine workings is limited. They are not suitable to be used in this type of operations. Their possibilities of cleaning are only partial and they require a significant lifting of the lower belt, and the machine itself can only be set at a slight angle to the longitudinal axis of the conveyor.

However, very often cleaning the space under the conveyor route is manual, and to a small extent as the access to the space under the lower conveyor belt is limited. This is due to the low height of installed conveyor and the large depth of this space, defined by the width of the conveyor and a distance of the service route from the side wall.

Direct involvement of people in this activity is a laborious and dangerous task. Thus, it is reasonable to mechanise this operation, where the role of man is limited only to operating the equipment (as operator).

The analysis of existing technical solutions [6,7] indicates that self-propelled machines have become more and more common. These machines have a specific functional range allowing them to be used for collecting the material located in places that are difficult to access, e.g. to clean the space under conveyor belts in mines, in underground tunnels, box culverts and drainage systems, pumping stations, irrigation systems and others.

The DOUGLESS 900 mini loader (Fig. 1), which is an automated device capable of moving under a running conveyor belt, is known. Its height is 560 mm, length 2254 mm, width 1050 mm and weight about 900 kg. It is driven by a 12 kW diesel engine and can move at speed 3.5 km/h on rubber tracks. Bucket capacity is 0.13 m^3. The control of the machine is wireless. What is surprising, this machine, in an iron ore mine was able to recover 300 tonnes of material from under the haulage system in 12 hours.

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Fig. 1. Mini loader DUGLESS 900 made by MINPROVISE [8,9]

The HMS 200 mini-loader (Fig. 2), a remote-controlled, diesel-powered device, capable of cleaning the space under an operating belt conveyor is another solution. Its height is 650 mm, width is 1322 mm, and length is 2720 mm. The engine power is 16 kW and the bucket capacity is 200 kg.

Fig. 2. The HMS 200 mini-loader by HMS Group [10]

The devices presented above enable cleaning the space under the belt conveyor route are widely used in Australia, Canada and South Africa. Despite a tight construction, they certainly cannot be used in hard coal mine conditions due to lack of adaptation to the dust and methane hazards. Good maneuverability within the operational space such as the roadways, due to their dimensions, is an unquestionable advantage of these solutions.

However, the small dimensions have one major disadvantage, which is the low lifting height of the bucket. This does not allow in any way to return the recovered material directly to the belt of a conveyor.

2. Materials and Methods

2.1. Design of the boom

When designing the boom [11], the attention was primarily paid to the aspect of operational self-sufficiency, enabling the removal of material located under the belt conveyor. This means the boom should pick up material from the cleared space under the conveyor and put it directly on the belt.

The boom can be adapted to cooperate with a loader on wheels and on trucks (Fig. 3).

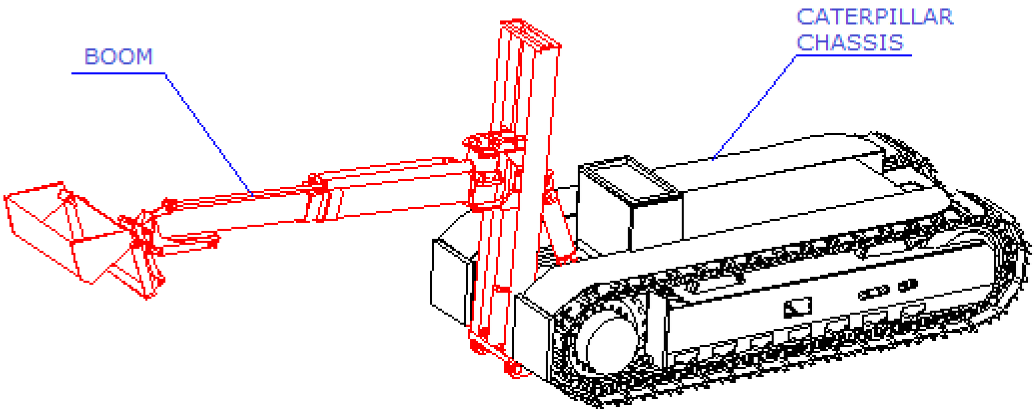

Fig. 3. The concept of a boom to be installed on a caterpillar chassis

The boom (Fig. 4) has three main components, connected to each other by sliding and articulating joints. In a result, its movement in three planes are possible. It is equipped with a multi-purpose bucket, mounted on a telescopic extending arm cooperating with the arm lifting the mast.

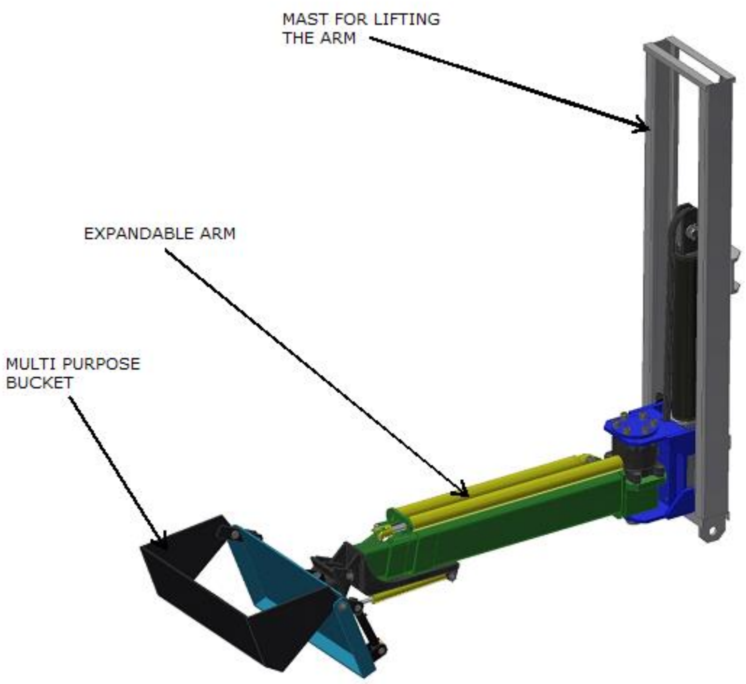

Fig. 4. 3D visualization of the boom

The multi-purpose bucket can rotate and twist in two planes (XY and YZ). The boom extension has the ability to move and swivel also in two planes (XZ and XZ). The boom lifting mast can also move and turn in two planes (YZ and XY).

The boom lifting mast (Fig. 5) is a welded frame. The side components of the frame are made of steel profiles open on one side. Their internal surfaces are the driving routes for a carriage with rollers. At the bottom of the carriage there is a chain lock that moves the carriage. On the opposite side there are holes to which a hydraulic turntable is bolted. At the bottom, in the turntable axis, there is a sliding bearing for the pin. The upper and lower parts of the mast frame are connected by transverse profiles. In addition, the lower part has mounting eyes, connected with the frame of the caterpillar chassis with bolts. In the central part of the frame there is a transverse profile, which is as an attachment point for the chain, and a single cylinder eye of articulated mast is welded to it. The base of the cylinder, on which the lifting cylinder rests, is welded to the frame bottom. The cylinder lifts the carriage, to which the boom with the multi-purpose bucket is attached. Chain mechanism was used to convert the sliding movement of the cylinder piston rod into the carriage lifting movement. Its double gear ratio allows the carriage to advance along the entire length of the mast. The gear ratio is achieved by immobilising one end of the chain attached to the mast frame while the other end was attached to the bottom of the carriage. The chain runs through a sprocket attached to the piston rod of the lifting cylinder. Extending the piston by a given stroke, the cylinder shortens the chain length twice, causing the carriage to move by twice the cylinder stroke. The stroke of the carriage is 1200 mm.

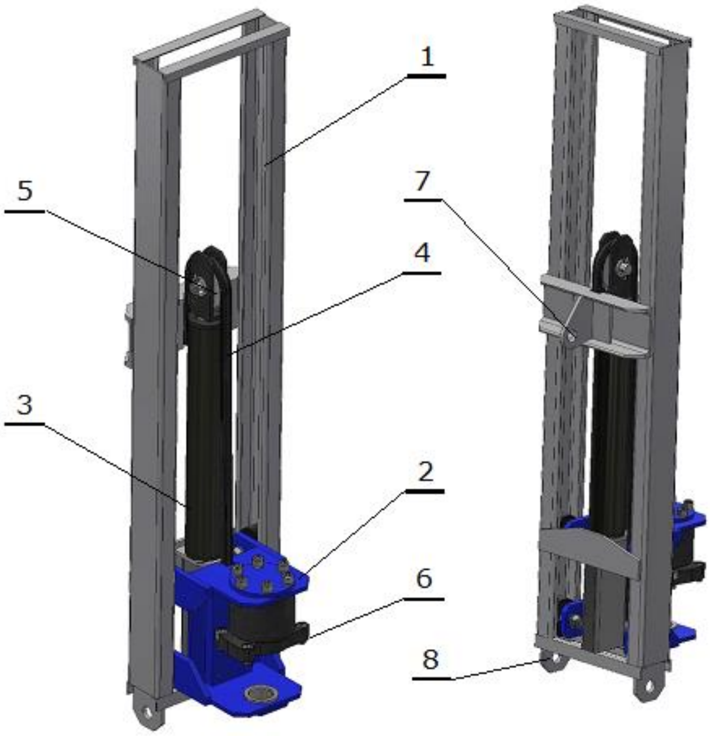

Fig. 5. Mast for lifting the arm
(1 – mast frame, 2 – carriage, 3 – lifting cylinder, 4 – chain, 5 – chain wheel,
6 – hydraulic swivel, 7 – eye of mast articulation cylinder, 8 – mast assembling eyes)

The extendable arm (Fig. 6) consists of three segments that slide into each other. The segments are made of bent sheets with a closed cross-section. The arms are reinforced with a metal sheet at their ends. The extension cylinders are attached to the middle arm. Attachment lugs of the multi-purpose bucket and the bucket tilt cylinder are at the end of the extendable arm. On the other side the arm has a socket for mounting in a turntable with a pin.

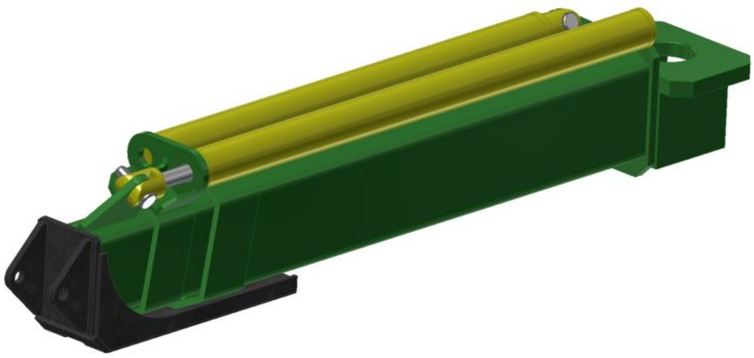

Fig. 6. Extendable arm

Multi-purpose bucket (Fig. 7) consists of the following two subassemblies:

- a bucket with a possibility of opening – for scrapping with the bottom edge,
- articulating joint – which enables movement in two planes: horizontal with inclination ±30° and vertical with inclination from -45° to +35°.

Hydraulic cylinders are used to open and control the bucket movement in horizontal and vertical planes.

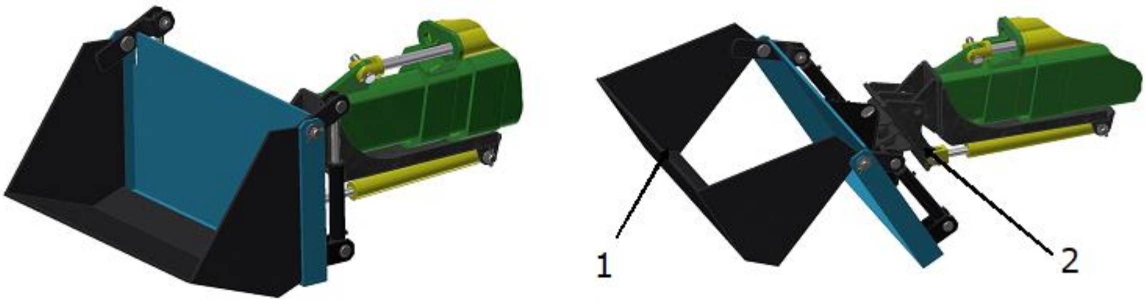

Fig.7. Multi-purpose bucket – general view
1 – bucket, 2 – articulating joint

2.2. Strength analysis of the arm

The boom has to work in a confined space, therefore it should be as small as possible. In addition, the boom should have flexible manoeuvrability allowing easy access to the required area to be cleaned, and its structure should carry the expected range of loads. Autodesk Inventor was used for the initial static analysis.

The arm was subjected to action of force 19.5 kN, causing the arm to bend. It is equal to half the nominal force of the cylinder tensioning the chain lifting the arm. Since one end of the chain is fixed the other end causes the trolley to move with the arm, the speed of the carriage is twice as high as the speed of the cylinder extension. Additionally, the arm was loaded with M1 and M2 torques. The torque M1 results from the articulating mechanism of the trolley guides, while the torque M2 comes from the operation of a hydraulic swivel powered by a working fluid under a pressure of 10 MPa.

The metal plate, to which the hydraulic swivel was attached, was loaded with the arm bending force of F1 = 19.5 kN, the same place was also loaded with the M1 and M2 torques. Fixation of the arm was simulated rigidly by fixing the distinguished nodes and removing the axial displacement of the pivot nodes in axial direction. (Fig. 8 and 9).

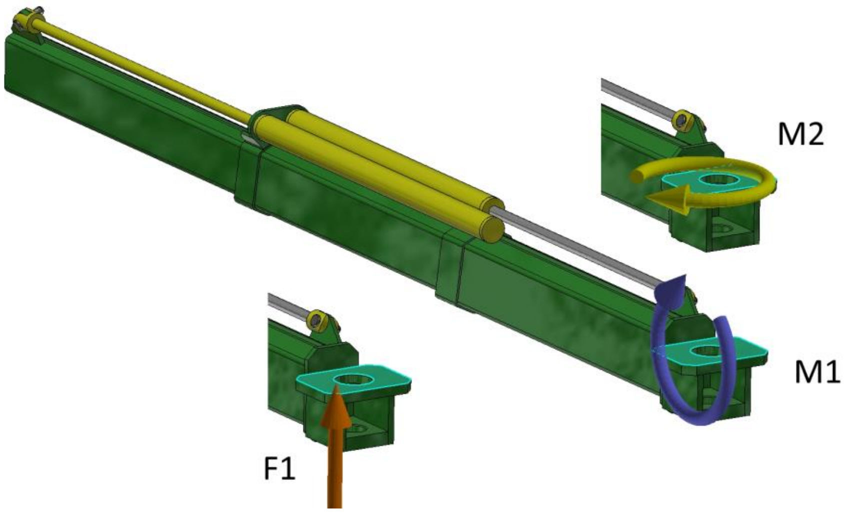

Fig. 8. Scheme of load to the arm model
(Assumed: concentrated force F1 = 19.5 kN, torque M1 = 11.5 kNm, torque M2 = 300 Nm)

The removed model degrees of freedom are presented in Fig. 9.

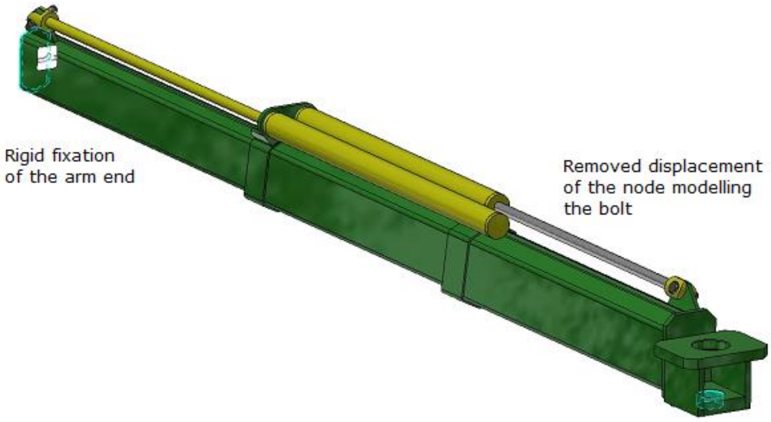

Fig. 9. Assumed boundary conditions

In Fig. 10 the arm model, created by the Finite Elements Method consisting of 4022 tetra finite elements is presented.

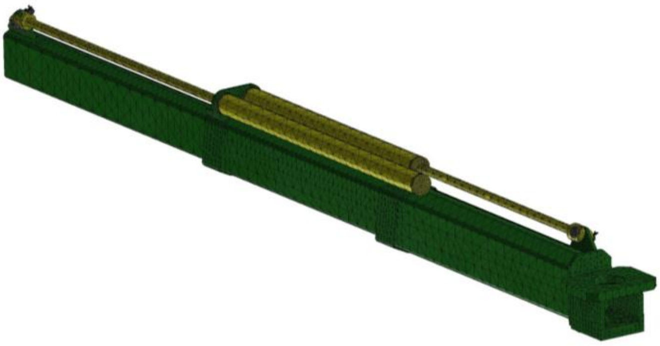

Fig. 10. Model FEM of the arm

Adequate material parameters were assigned to each metal sheet. S690Q steel was assumed.

The results of the arm calculations are presented in the form of contour maps. Fig. 11 shows displacement maps with a maximum displacement of 26.03 mm.

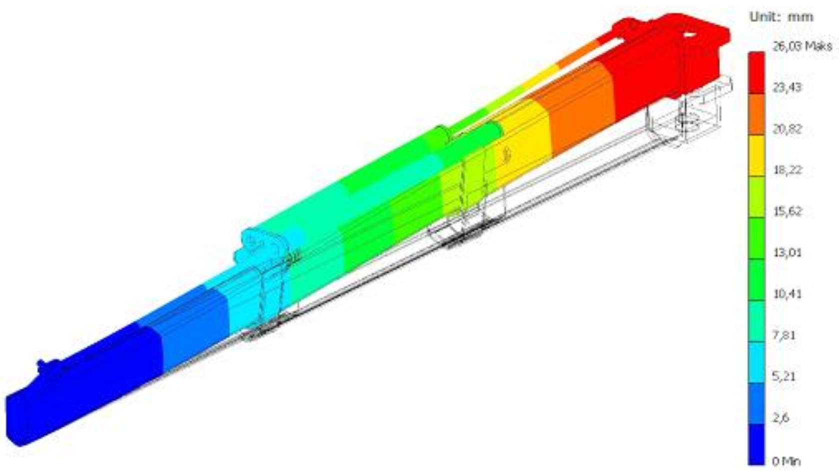

Fig. 11. Displacement maps

Fig. 12 shows the results of the numerical simulation of the arm model in the form of reduced stresses maps. The maximum stress was found in the place of mounting the cylinders and was 708 MPa, while the greatest reduced stress in the remaining arm modelling elements was not greater than 400 MPa.

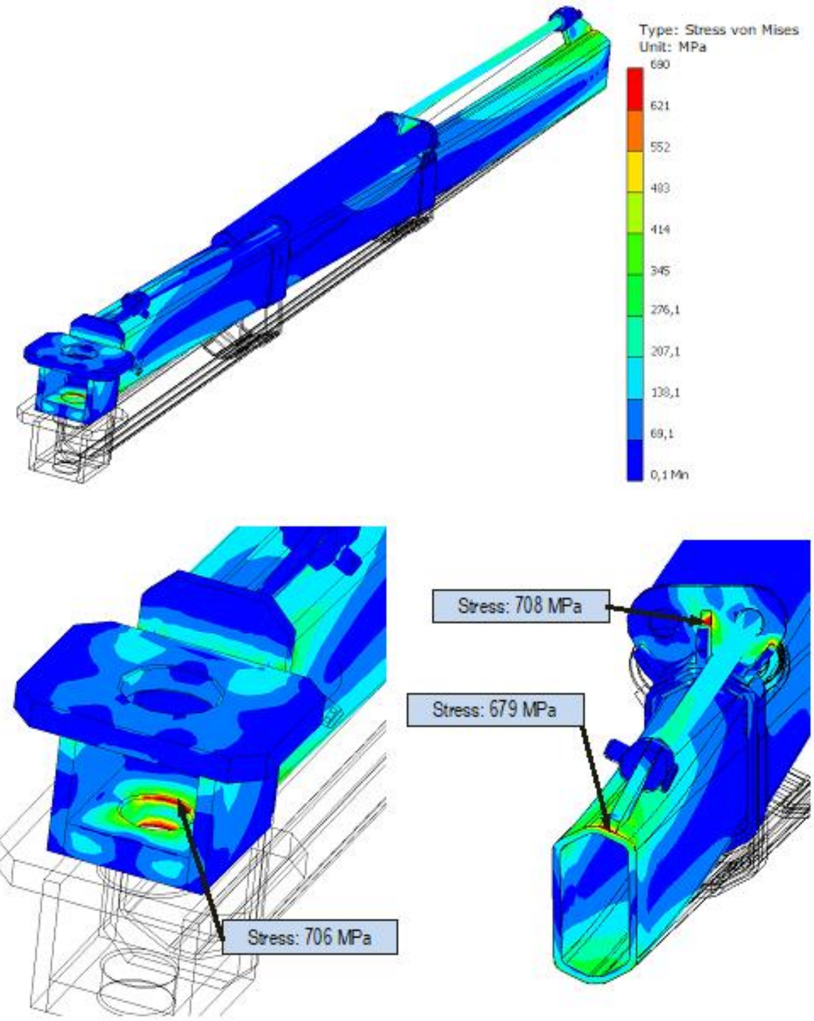

Fig. 12. Maps of reduced stresses

To summarize the strength analysis, it should be stated that the reduced stress in the arm components reaches the value of about 400 MPa, thus lower than the yield point for the adopted arm material (Re = 690 MPa). In the bolt opening and in the place where the boom extension cylinders are installed, the reduced stress locally amounts to more than 700 MPa (see Fig. 12).

The presented contour maps show that the stress zone greater than 700 MPa covers a small area lying on the model surface. Probably a more detailed analysis of the FEM model would show that the extreme values of the reduced stress are the result of extrapolation of the stress fields in the finite elements modelling the boom plate. Therefore, it can be assumed that for the assumed boundary conditions, the structure of the arm and the thickness of the metal sheets are appropriate.

3. Results - technical parameters of the boom

Fig. 13 shows the range of operation of the boom installed on a sample caterpillar chassis.

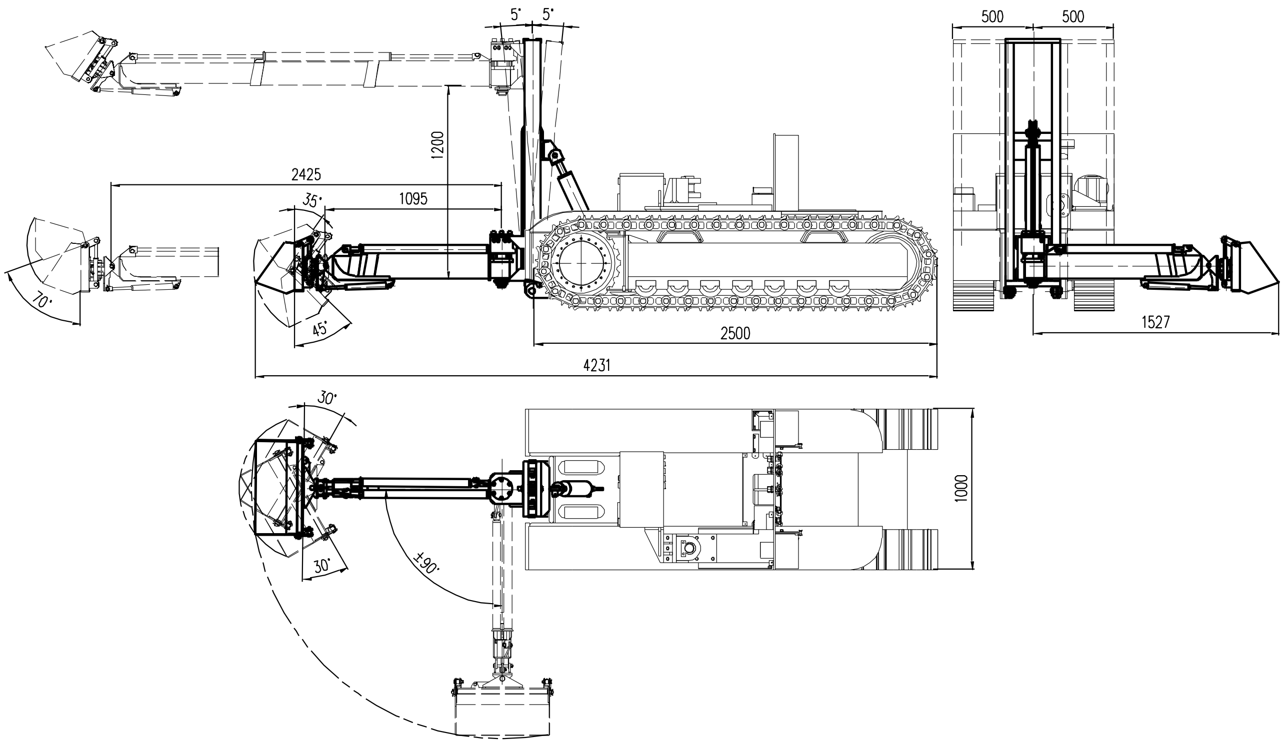

Fig. 13. Range of the boom operation

Technical parameters of the boom are given in Table 1.

Table 1. Technical parameters of the boom

Parameter	Unit	Amount
Height of the bucket lifting	mm	1200
Arm load-bearing capacity	kg	1500
Arm stroke	mm	1330
Bucket capacity	dm^3	20
Horizontal tilt of the bucket	-	±30°
Vertical tilt of the bucket	-	-45°÷+35°
Bucket opening angle	-	70°
Working pressure	MPa	10

Fig. 14. shows the machine equipped with the boom operating in a roadway with ŁP-10 support.

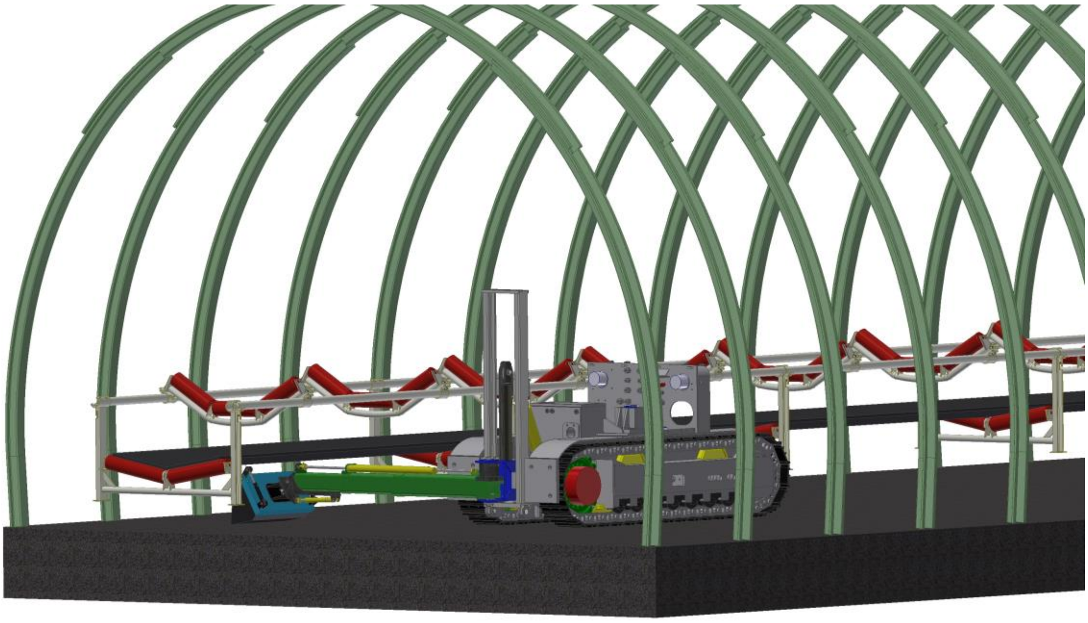

Fig. 14. 3D visualization of cleaning the floor under the belt conveyor system

4. Conclusions

The concept of a machine equipped with a multifunctional boom, which limits human presence in a high-risk work environment, such as confined spaces and hard-to-reach areas, and allows working at a safe distance with a drastic reduction in working time in this space was the research project main objective. The boom allows cleaning almost the entire floor under the conveyor, access to which is dangerous as well as loading the scraped material directly onto the conveyor.

It has been assumed that the minimum clearance under the conveyor belt should be 500 mm.

The benefits of using a machine equipped with a boom for cleaning the space under the belt conveyor are as follows:

- easy access to the conveyor of low clearance,
- does not require stopping the conveyor while it operates,
- eliminates physical effort of the personnel responsible for cleaning the dirty surfaces,
- increases safety of the personnel working in dangerous and confined spaces or in areas of high risk,
- reduces rate of incidents as well as fire hazard,
- increases effectiveness of cleaning the dirty surfaces under the conveyor,
- reduces the failure rate of the belt conveyor operation.

The above-mentioned advantages of the presented solution justify the necessity of further tests to implement the discussed boom on an industrial scale.

The scope of application of the discussed boom goes far beyond the hard coal mining industry, because use of any belt conveyor requires removal of the transported material that pollutes its surroundings.

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Dispersed, self-organizing sensory networks supporting the technological processes

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Abstract:

Examples of automation of technological processes for mineral extraction are presented. Aspects related to the diagnostics of machines and devices during operation processes are discussed. Applying the distributed sensor networks to enable designing and manufacturing the machines and devices operated in accordance with the idea of Industry 4.0, the Internet of Things, M2M communication and autonomous behaviour was proposed. The paper presents impact of applying the distributed sensor networks on increasing work safety (multi-redundant communication) and reducing the employment in hazardous areas is presented. Implementation of algorithms based on swarm intelligence to control the routing processes of distributed sensor networks was suggested. Areas of application of distributed sensor networks based on swarm intelligence in other industries (renewable energy sources) are also outlined.

Keywords: sensor networks, swarm intelligence, routing, intrinsic safety

1. Introduction

Currently, managing the manufacturing process is possible due to information transmitted to supervisors in a real time. This is possible because a network of sensors continuously monitors the condition of machines and equipment involved in the production process. Every smallest part of the process is in the network (Fig. 1) (IIoT Industrial Internet of Things). Information received from the network of sensors enables making decisions affecting the technological process. With the same information, it is possible to immediately observe the effects of the decisions made. This manufacturing process is known as Industry 4.0 (Fig.1)

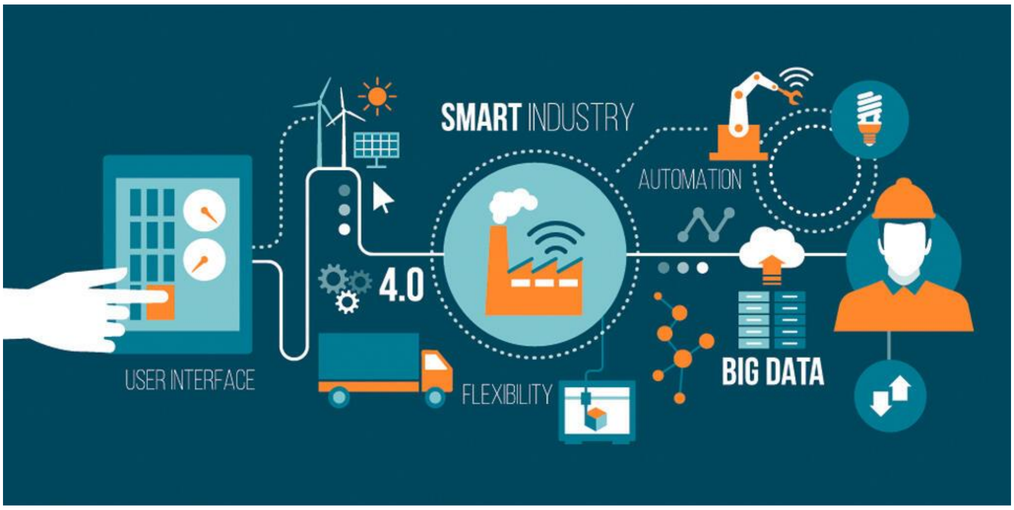

Fig. 1. Industrial Inthernet of Things (IIoT) [1]

The world economy entered the so-called "The fourth industrial revolution" [2]. Digitization of production (Industry 4.0) is one of the processes describing the changes. The concept of Industry 4.0 was introduced in 2011 by professor of physics Henning Kagermann and later transformed into a strategy for the development of the German industry [3]. The idea was to improve the efficiency of manufacturing processes through automation and real-time data exchange [4].

Analyses of the World Economic Forum in cooperation with McKinsey & Company [5] indicate the areas of production processes that changed after the implementation of Industry 4.0 solutions (Fig. 2).

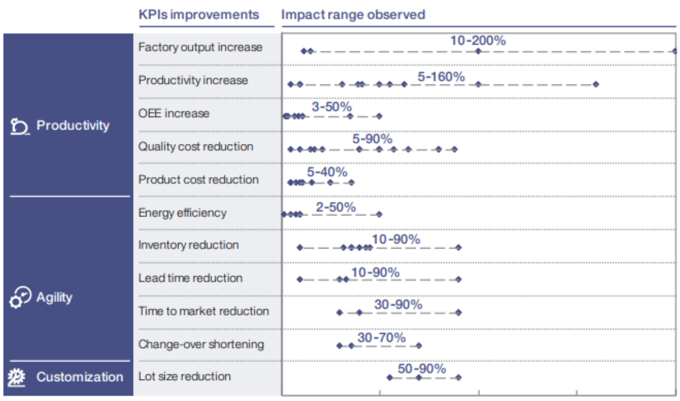

Fig. 2. Impact of Fourth Industrial Revolution use-cases on select KPIs(operational and financial key performance indicators) in lighthouse factories [5]

The analyses indicated 16 production plants in the world that moved from the level of pilot implementations to full integration of technology and implementation of the Industry 4.0 concept. Some plants, due to the application of the Fourth Industrial Revolution, doubled their efficiency, and are able to invest the funds in new technologies and implement solutions of the fourth industrial revolution [5].

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We are at the beginning of implementing Industry 4.0 solutions on the Polish market. The report (Fig. 3) prepared by Computerworld together with ABB shows that only 14% of enterprises have a strategic transformation plan developed. 48% of respondents declared partial implementation of Industry 4.0 solutions. Enterprises that do not intend to introduce any changes related to Industry 4.0 are accounted for as much as 27% of the respondents [6].

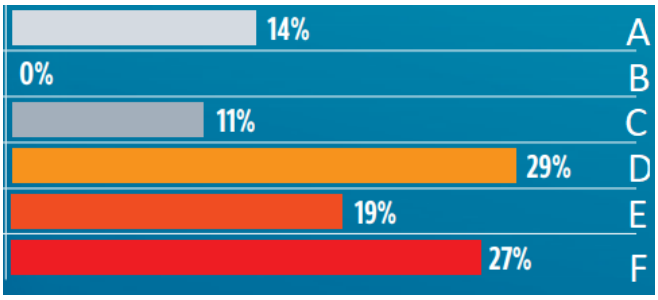

Fig. 3. Research report on the implementation of Industry 4.0 solutions on the Polish market [6]

The appropriate use of technical solutions to improve specific areas of production processes is the challenge for enterprises implementing Industry 4.0 solutions. The further part of the article indicates the areas of hard coal production processes in which it is possible to implement the idea of Industry 4.0.

2. Materials and methods

In today's mining industry, each manufacturing process is digitized. Fig.4 presents the control room of Tauron Mining Group. The control room monitors the status of each mining process, starting from the condition of shearer and powered roof support, through the condition of belt conveyors and ending with the condition of hoist shaft. This information helps in making decisions necessary for the proper functioning of the mining process.

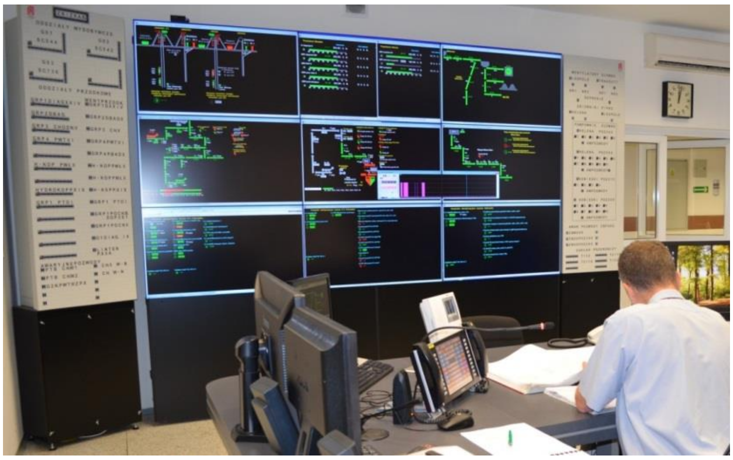

Fig. 4. Tauron's control room [7]

Data for supervisory systems are sent from a network of measuring sensors analyzing the condition of each machine and device as well as the atmosphere at risk of methane and/or coal dust explosion. Sensor networks operate usually in separate diagnostic or automation subsystems of mining processes. Several of the subsystems, in which a network of wireless diagnostic sensors works or it is possible to implement such a network are presented in the article.

The Shield Support Monitoring System (SSMS) is the first of the subsystems presented. The most innovative functions of the SSMS (Fig. 5) include the width measurement of the bridgehead and the monitoring of the powered supports geometry. The most innovative functions of the SSMS (Fig. 5) include the width measurement of the face road and the monitoring of geometry of the powered roof support. These parameters are important for ensuring the stability of the longwall panel and the correct conditions of cooperation between the roof support and the rock mass, and in certain conditions, may affect the possibility to damage certain components of the powered roof support.[8] The system consists of the SSMS-S face road measurement module, SSMS-I inclinometers and the SSMS-C central unit (Fig.5). The system components are wired together within one powered roof support. The SSMS-C central unit receives data from the SSSM-I inclinometers and the SSMS-S module via the modbus, and then wirelessly sends the data to a supervisory network with a "mesh" type topology [9].

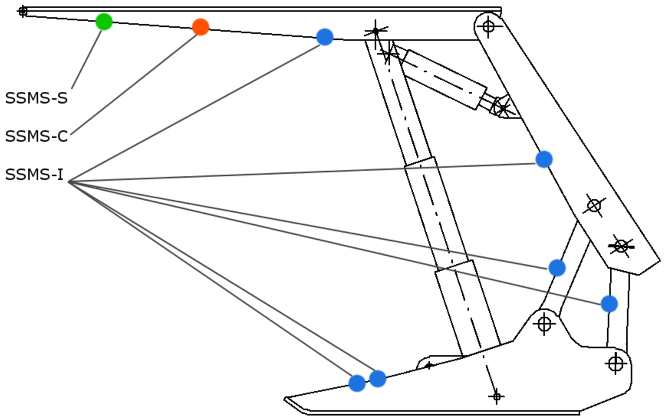

Fig. 5. SSMS elements on the powered roof support. [8]

The system should be fully equipped with wireless communication of the entire sensor network. The routing algorithm for this network, due to its expansion by a large number of nodes, is suggested to be implemented on the basis of an intelligent routing algorithm, which should enable obtaining a stable data throughput despite the increase in the number of network nodes to over a thousand. The expansion of the SSMS sensor network may contribute to the remote operation of the longwall mining process.

The roadheader position measuring system [10], responsible for autonomous roadways development, is another of the presented subsystems. The solution is based on an innovative method using the wave propagation in the roadway. The concept is modelled on the GPS, where 24 satellites located in geostationary orbits are the reference points. In the case of a solution implemented in underground mining plants, the active electronic systems installed on the components of the roadway support will play a role of satellites (Fig. 6). The systems will communicate directly with the transmitting and receiving system installed on the machine’s body. The positioning system not only increases safety, but ultimately enables the automation of the drilling process, significantly increasing the efficiency and safety of mining [11]. Expansion of the system with an intelligent sensor network will provide real-time information on the roadheader condition (diagnostics subsystem), and will also provide control over the remote mining process.

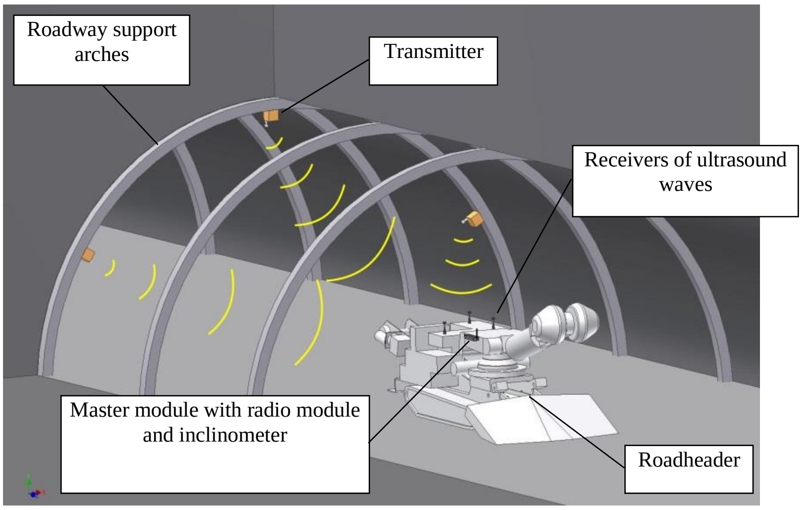

Fig. 6. Roadheader navigation system [11]

In addition to the data on the position and parameters of the roadheader, the sensory networks can also transmit information on condition of the arch support frame (Fig. 7), and more precisely on their load. As part of the international INESI project, the stress in the arch support was measured using draw-wire sensors. Information about the stress can then be transmitted to a sensor network. The applied solution would provide information on condition of the frame of arch support along the entire length of the workings (the length of mine roadways ranges from several hundred meters to several kilometers).

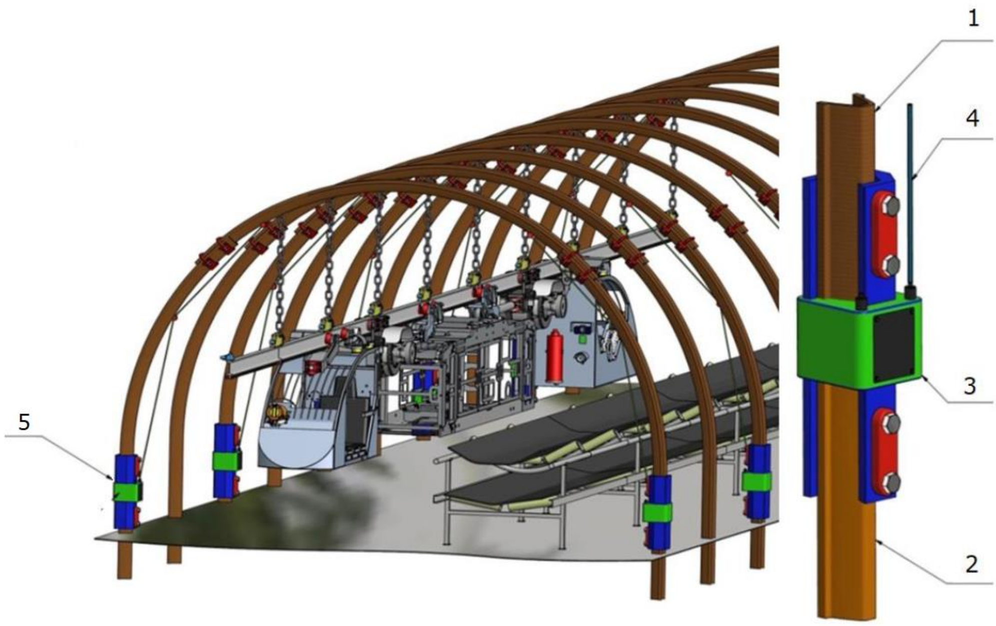

Fig. 7. INESI load monitoring system in arch support: 1 – upper part of wall-side segment; 2 – lower part of wall-side segment; 3 – data-processing module with sensors and data-transferring components; 4 – distance sensor cord; 5 – measuring module [12]

It is also important to monitor the condition of belt conveyors to eliminate the risks associated with their operation in mine workings. Belt conveyors are mainly used to transport the run-of-mine, however, after meeting the relevant regulations, it is also possible to move people. Therefore, it is necessary to ensure the safe operation of the belt conveyor. Sensor networks could transmit information on the temperature and rotational speed of the belt conveyor's supporting rollers. A proposal to implement such a subsystem is presented in Fig. 8.

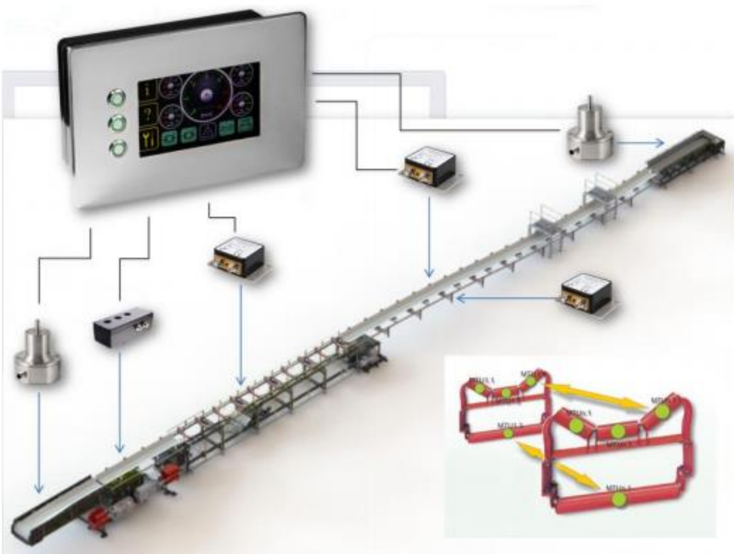

Fig. 8. Monitoring of belt conveyors [13]

The use of sensor networks with intelligent routing algorithms improves technological processes and allows industrial plants to implement the idea of Industry 4.0. Work realised since 2019 in the SUMAD project (whose aim is to analyze the future management of mine heaps, with particular emphasis on geotechnical, environmental, socio-economic challenges as well as sustainable development and long-term management) allowed to identify new fields for application of the intelligent sensor networks. Placement of photovoltaic panels [14] with inteligent control (the idea of the solution is to monitor the parameters of photovoltaic modules, such as: voltage and current intensity, module surface temperature, solar radiation intensity at the module and ambient temperature and humidity) is one of the elements of post-mining heaps management. (Fig. 9 and Fig. 10)

Intelligent controllers of each panel [15] should communicate with each other using radio waves. A grid of a mesh topology is planned. Due to the number of photovoltaic modules installed in power plants, the created wireless network will have a highly complex structure. There are more and more implementations of routing protocols based on artificial intelligence technology and methods in this type of networks [16].

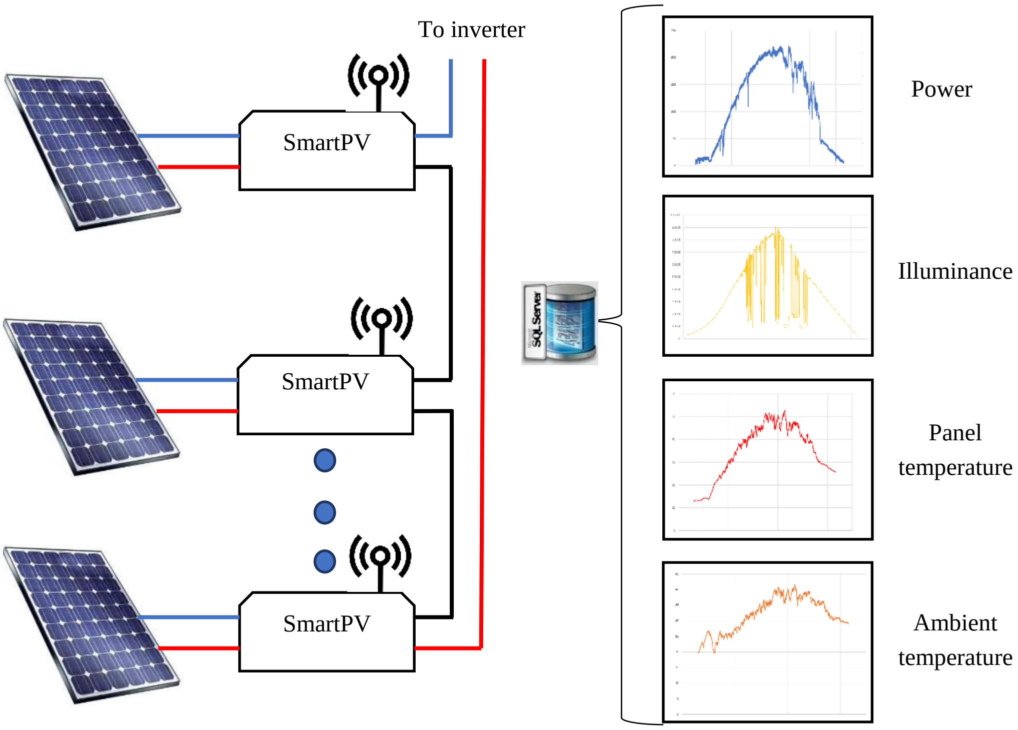

Fig. 9. Intelligent control module for photovoltaic panels [16]

Fig. 10. Intelligent control module for photovoltaic modules [17]

Only the selected subsystem with possibility to expand or implement the Industry 4.0 solutions in a form of intelligent sensor networks are presented. In such extensive networks it is necessary to properly organize information transmission to ensure operational reliability, flexible configuration and operational safety. It is particularly important to ensure the reliable operation of sensor networks operating in conditions of methane and/or coal dust explosion hazard. To meet these requirements, advanced transmission algorithms (routing algorithms) are implemented in sensor networks, making it possible to efficiently manage data flow in an extensive network infrastructure.

3. Results and discussion

The use of sensor networks with intelligent routing algorithms improves technological processes and allows industrial plants to implement the idea of Industry 4.0. Work realised since 2019 in the SUMAD project (whose aim is to analyze the future management of mine heaps, with particular emphasis on geotechnical, environmental, socio-economic challenges as well as sustainable development and long-term management) allowed to identify new fields for application of the intelligent sensor networks. Placement of photovoltaic panels [14] with inteligent control (the idea of the solution is to monitor the parameters of photovoltaic modules, such as: voltage and current intensity, module surface temperature, solar radiation intensity at the module and ambient temperature and humidity) is one of the elements of post-mining heaps management. (Fig. 9 and Fig. 10)

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Routing algorithms in sensory networks are used to ensure optimal delivery of the data packet from the sender to the receiver. Packets can be delivered to the receiver in an optimal way depending on the set following criteria: the highest network capacity, energy savings, packet transmission time, etc.

Routing algorithms used in sensory networks are divided into proactive, reactive and hybrid. In proactive algorithms, the routes between each network node are saved in the so-called routing tables. On the other hand, the reactive algorithms are searching for a route, when it is necessary (at the moment of sending the data packet). This results in no need to occupy the memory of each network node for the routing tables. Unfortunately, longer time for delivery the package to the receiver is the consequence of using such a method. Hybrid algorithms are another types of algorithm used in the routing the sensory networks. In this type of algorithms, selected areas of the network work with the use of proactive algorithms, while their connections are made with the use of reactive algorithms.

Implementation of the presented algorithms to sensory network nodes, operating in the areas of methane and/or coal dust explosion hazard, is associated with meeting the several additional requirements due to the design of each network node. The hardware implementation of a single network node must meet the requirements of the ATEX directive (the power radiated from the transmitting/receiving antenna must be limited to the appropriate values) and the radio system should be of low-energy (nodes are battery-powered or supplied by "energy harvesting").

Taking into account the presented requirements, the selected routing algorithms were analysed. During the literature review, the projects in which simulation tests of reactive and proactive protocols as well as the algorithms working on the basis of swarm intelligence, were distinguished. Some of these projects, which took into account following criteria: packet transmission time, network capacity and energy savings are presented.

Fig. 11 shows the result of simulation tests with use of the reactive AODV protocol, the proactive DSR protocol and the protocol based on the intelligence of the SICROA swarm (the algorithm was

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prepared on the basis of the ACO ant algorithm). The tests verified the delays generated by each algorithm in relation to the number of network nodes. The test result indicated that the SICROA algorithm generated the smallest delays in transmission of data packets.

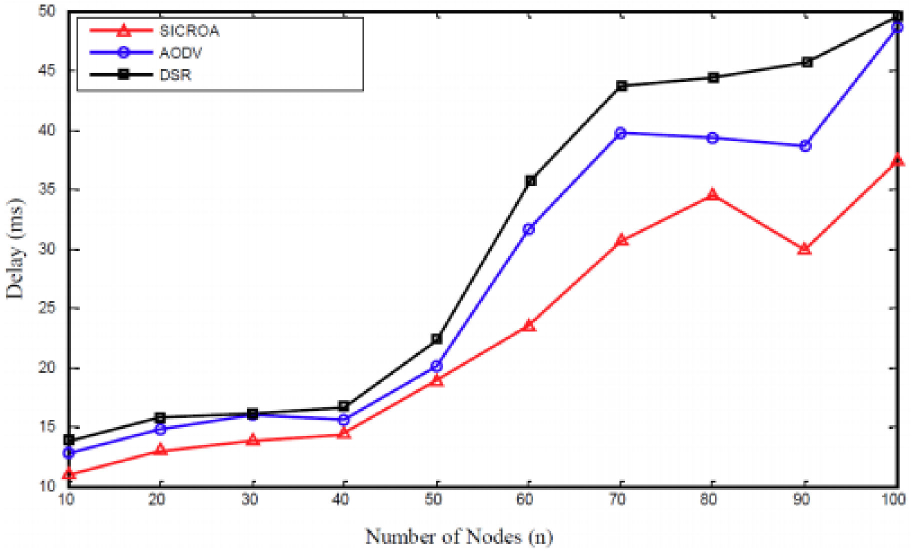

Fig. 11. Latency measurement with respect to node count [18]

Fig. 12 shows the result of simulation tests with use of the reactive AODV protocol and the SSKIR protocol, working on the basis of swarm intelligence (built on the basis of PSO). The tests show that the SSKIR protocol allows to maintain the channel capacity at a higher level than the reactive protocol. Network of a size 500 nodes was tested [18].

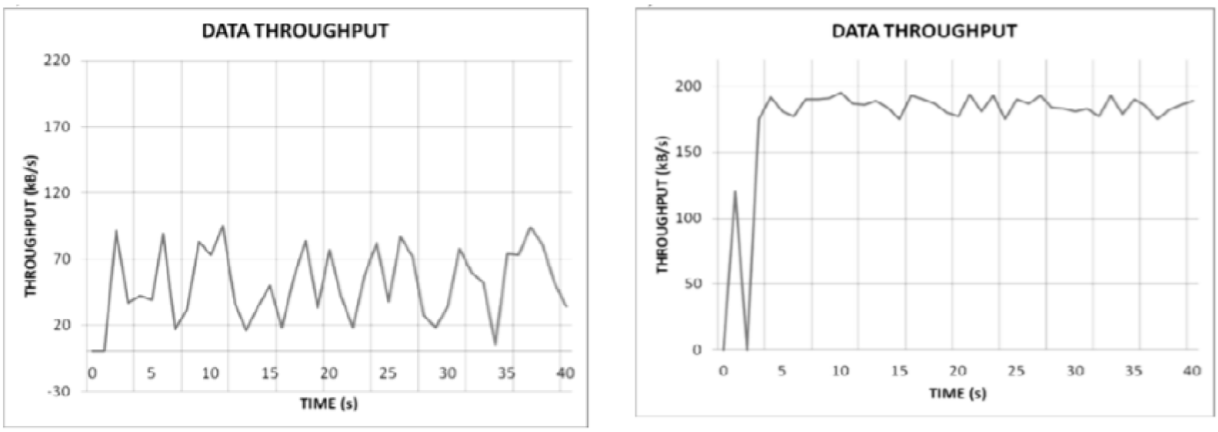

Fig. 12. AODV and SSKIR protocols [18]

Another of the simulation tests (Fig. 13) compared the reactive DSR, AODV algorithms, the proactive DSDV algorithm and the Beehive algorithm working on the basis of swarm intelligence (BI algorithm). The tests showed that the lowest energy consumption of each network node is during the use of the Beehive protocol.

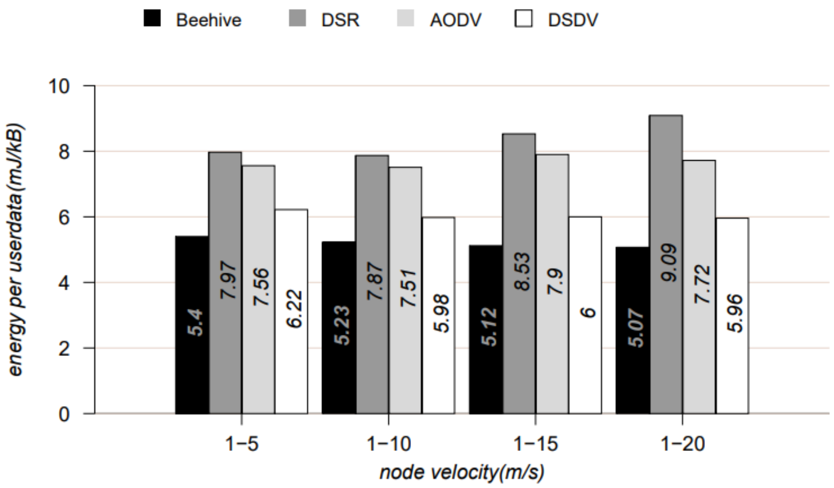

Fig. 13. Energy consumption – Beehive, DSR, AODV, DSDV algorithms [19]

Effective data transmission in sensory networks is very important, in addition, it is necessary to ensure the operational security of each network node (by ensuring the stability of routing protocols).

Algorithms that work with use of machine learning are another of the presented algorithms. Fig. 14 shows the simulation results of routing algorithms before and after the attack on the sensory network (during the simulation process, a learning set with incomplete information about connections between nodes was generated). The analyses show that the use of an algorithm based on machine learning allows to avoid increasing the delay in data transmission despite the attack on a working sensor network.

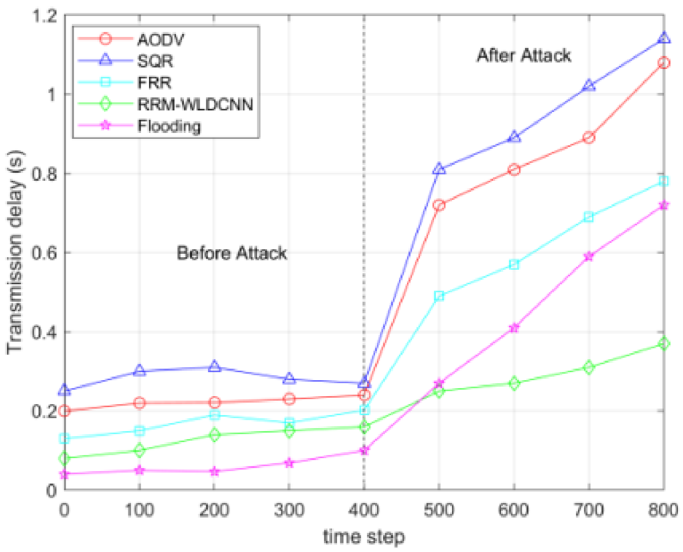

Fig. 14. Simulations with the use of a protocol working with the RRM-WLDCNN machine learning [20]

The analysis of each routing protocol indicate that the highest probability of success of the algorithm implementation in sensory networks operating in a potentially explosive environment are the protocols based on the so-called Swarm Intelligence (SI). These algorithms, regardless of the number of variables in the solutions, adapt to existing constraints and help to solve the optimization problem. The use of these algorithms allows the parameters of data transmission to be maintained at an appropriate level (channel capacity, short time of data reaching the target, high reliability of data transmission). Sensory networks working on the basis of swarm intelligence algorithms are self-organizing and multi-redundant. In addition, if we combine swarm intelligence and machine learning, we can additionally protect the network against deterioration of transmission parameters after attacks that may affect the operation of each network node.

4. Conclusions

The article presents examples of automation of technological processes of mineral extraction. It was suggested to use distributed sensor networks that will enable designing and production of machines and devices in accordance with the idea of Industry 4.0, the Internet of Things, M2M communication and autonomous behaviour. The impact of the use of distributed sensor networks on increasing work safety (multi-redundant communication) and reducing the employment in hazardous areas is presented.

The necessity of appropriate data organization (with the use of routing algorithms) in networks, so extensive as to ensure operational reliability, flexible configuration and operational safety was discussed. Selected simulation tests of sensor network routing algorithms are presented, taking into account the following criteria: packet transmission time, data throughput and energy savings. The analysis of the presented data showed that the algorithms based on the swarm intelligence have the best solution for sensor networks operating in conditions of explosion hazard.

It is necessary to implement the selected routing algorithms in hardware solutions and verifying their operation in real conditions. In the implementation process, it will be necessary to modify the selected algorithms and adapt them to the selected hardware solutions.

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Longwall shearer haulage systems - a historical review. Part 2 – First cordless haulage systems solutions

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Abstract:

Searching for cordless haulage systems started in early 50-ties of XX century. In semi-mechanized longwall faces in Germany and Hungary tracked narrow face cutter-loaders (first continuous miners) were used. Real trials began ten years later in Great Britain. First solutions described in this article were simply an adaptation of the existing Anderson's or BJD's single or double drum shearers. The main idea was to interfere to as less as possible extent with the shearer structure. After the first positive trials and experiences in British and French mines the first cordless solutions such as Rackatrack, Peratrak or ram propulsions were either developed or gone to the past. This article is a review of the first cordless shearer haulage systems.

Keywords: longwall mining, longwall system, coal cutter-loader, coal shearer, shearer haulage system, cordless haulage systems, chainless haulage systems

1. Introduction

Longwall coal cutters, moving along the face floor, using first a traction rope and then a traction chain revealed their drawbacks and limitations quite soon. The appearance of drum shearers in the early 1950s and the increase in the haulage force caused the rope to be replaced by a more durable chain. Drum longwall shearers were moving along the AFC route more and more often with its forced guidance along the conveyor. This made it possible to attach the chain ends to the drives of the face conveyor. The length of the walls and therefore the chain length has also increased. Increasing the efficiency of the longwall shearers caused in an increase in the haulage force (already in the 1960s it exceeded 250 kN) and unfavourable phenomena related to the presence of a tight chain [1,2,3,4] appeared, such as:

- the risk of being hit by the ends of a broken chain,
- the risk of impacts due to transverse chain vibrations,

In fully mechanized longwall systems with the use of powered roof supports and the face (flexible) conveyor following the shearer [5,6], this induced the probability of:

- the shearer power cable or even the powered roof support to be damaged by the chain as a result of horizontal, transverse impacts of the shearer chain.

At the same time, the scope of application of longwall shearers for inclined and pleated–longwalls began to be extended, which resulted in the possibility of further undesirable phenomena, such as:

- an excessive wear of the traction chain in contact with the flight bars, face conveyor chain and raw coal.
- a serious risk of chain breaking off in longwalls with a significant inclination causing the shearer to slide down.

Problems related to the operation of chains in the longwall shearer haulage systems had also occurred earlier, causing the search for more convenient solutions from the beginning of the 1950s. This paper provides an overview of such solutions and it describes how they were achieved.

2. Tracked mining machines in the longwall faces

A rapid development of mining machines intended for narrow-face hard coal mining systems at the turn of the 1940s and 1950s caused that in the German Ruhr region an attempt was made to use the American Colmol (Fig. 1) tracked shearer (crawler undercarriage) in semi-mechanized coal longwalls equipped with a belt conveyor and an individual steel roof support [3]. In the American coal mining industry, machines of this type were used as cutting and loading machines in early varieties of the room&pillar system, cooperating with cars collecting the raw coal at the rear of the machine. The cutting machine worked in parallel to the face. The output material (raw coal) from the internal conveyor was collected by a short belt conveyor installed transversely behind the machine, which loaded the coal onto a longwall belt conveyor installed along the entire length of the longwall. In this solution, the cutting machine pulled a cart equipped with a manual hydraulic pump enabling the setting and expansion of individual hydraulic props following-up the cutting machine.

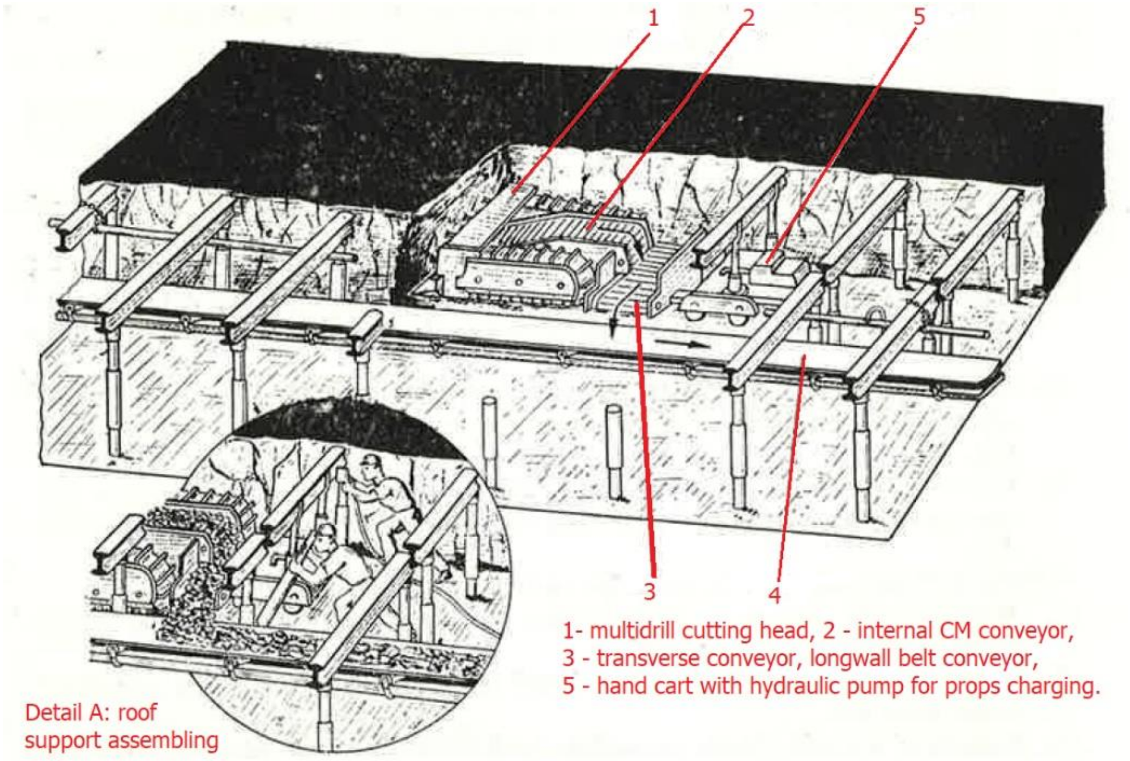

Fig. 1. Colmol continuous miner as a cutting-loading machine in semi-mechanized longwall face [7]

Similar solutions adapted to coal longwalls in the form of narrow-face cutter loaders were developed in 1951 in Hungary (Petofi I) [8] and in Great Britain (Dosco Miner). Both machines were already equipped with an integral transverse belt conveyor intended for working with the face belt conveyor (Fig. 2). The use of belt conveyors in coal longwalls in Great Britain has been widespread against the coal mining with impact hammers and manual loading of raw coal.

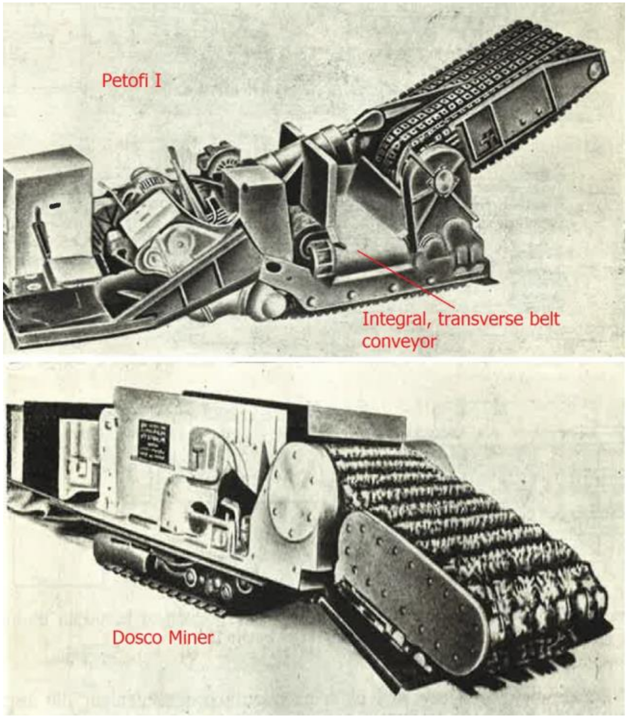

Fig. 2. Tracked narrow-face cutter loaders adapted for longwall mining [3]

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Similar but different solutions were later used in Australia in a so-called Shortwall Mining system, but no longer a face conveyor and a powered roof support were used [9]. The applied solution did not become popular due to its disadvantages, such as low speed of movement and problems with the preparation of the next operation cycle of the machine. The problem was also to lay and run the machine power cables.

3. Classic longwall shearers with chainless haulage systems

In the countries with an extensive hard coal mining industry with developed industrial facilities for the production of mining equipment, such as Great Britain and Germany (FRG), solutions were intensively sought for the chainless haulage system of the longwall shearer. By the end of the 1960s, it was estimated that at least 40% of accidents in the longwalls were caused by vibrations or break of the shearer chain. In 1972, the British Ledston Luck coal mine probably used the first chainless shearer haulage system of Rackatrack type, developed by Pitcraft Ltd. [5].

In a short time, several basic groups of solutions emerged (Fig. 3)

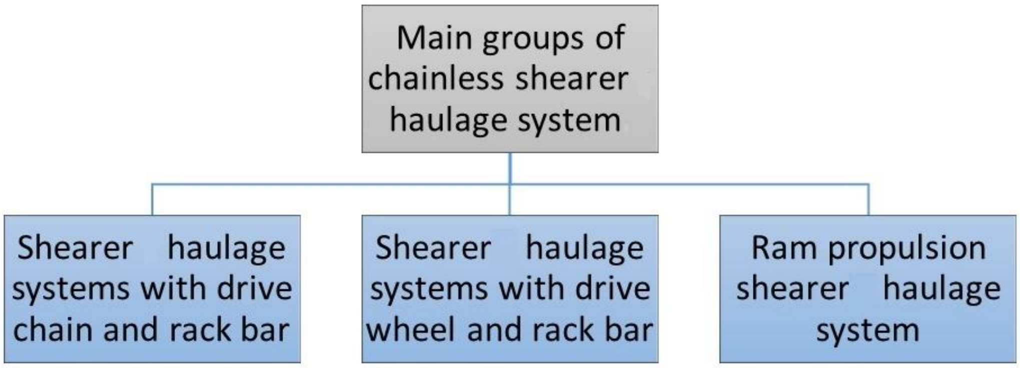

Fig. 3. Main groups of chainless haulage systems of longwall shearers [author]

Haulage systems with a drive chain and ram-propulsion systems have been discontinued quite quickly and nowadays the systems with a drive wheel and a rack bar have been applied in the longwall shearer haulage systems.

3.1. Longwall shearer haulage systems with drive chain and rack bar

When attempting to eliminate the chains from the longwall shearers haulage systems, solutions were originally sought that did not introduce any fundamental changes to the internal structure of the haulage systems. In the longwall shearers haulage systems used at that time, there were two solutions for driving wheels pulling the chain: horizontal and vertical ones.

The first chainless shearer haulage system was a solution in which the shearer movement was produced by a flat endless chain with pins embedded in it, driven by a vertical, slightly modified drive wheel [10]. The toothed flat chain was to transfer the traction force to the horizontal flat bar with holes (a structural element of the face conveyor), causing the roadheader to move (Fig. 4). This haulage system was originally called the Rack-a-Track with the subsequent commercial brand simplification into the Rackatrack. According to the available data, at the end of 1977, 691 mechanized longwalls were working in British hard coal mines, including 71 equipped with chainless haulage systems. The Rackatrack system was used in 59 longwalls. These haulage systems were used on British one-drum and two-drum shearers by Anderson Strathclyde and BJD; at the same time, this haulage system was tested in German coal mining and three longwall shearers with a Rackatrack haulage system were delivered to the USA.

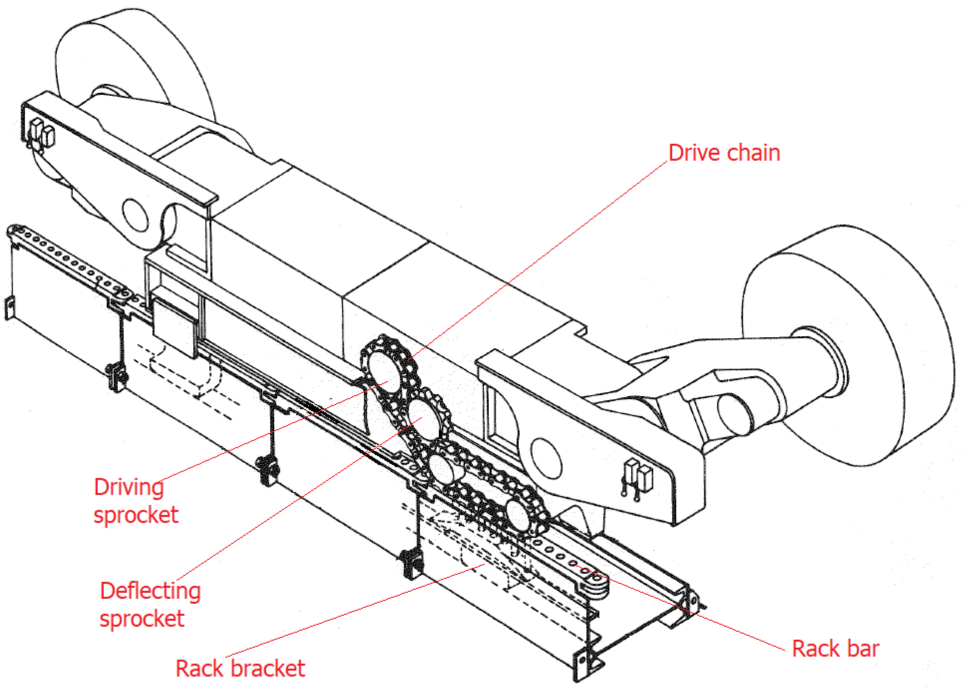

Fig. 4. Chain-less shearer haulage system of the Rackatrack type with a drive chain [author]

In the mid-1970s in the coal mining industry of Great Britain, it was subject to testing in the German coal mining. When using this haulage system, a significant disadvantage of this solution was revealed consisting in rapid wear of the drive chain. Cases of damage to the shearer cable were a great problem. Users indicated the low position of the toothed bar as an advantage, which allowed for a good operation of the haulage system in pleated seams. There was also an attempt to use this haulage system in a steeply inclined longwall (Seafield Colliery). In the end, the Rackatrack system gave way to more reliable and durable solutions.

At the same time, a similar solution for the shearers with a horizontal drive wheel was developed by the British company Perard Engineering Limited. The haulage system called Peratrak [11] used classic mining chains of various diameters (18, 22, 24, 26 and 30mm) as a closed working chain/cord (Fig. 5).

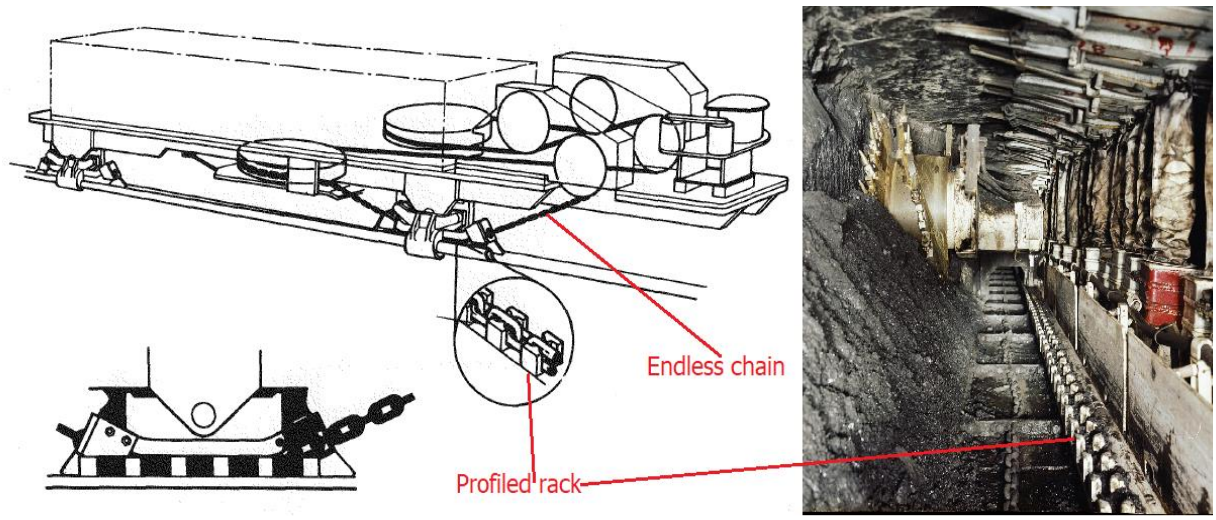

Fig. 5. Peratrak cordless haulage system – main idea and AFC adapted for Peratrak [author]

The Peratrak system was used in low versions of one-drum Anderson Strathclyde shearers with a cutting drum embedded in the harvester's body (mainframe). It was also used in the Trepanner drilling machines. At the end of 1977, nine longwall shearers with this haulage system, were working in the British mining industry. There was also a similar type of haulage system developed by Mining Supplies Ltd. A flat endless (closed) chain with inserted cast teeth was applied in this system called the Reactive Haulage system. These teeth entered the holes of the bar installed in the gob-side part of the face conveyor (Fig. 6).

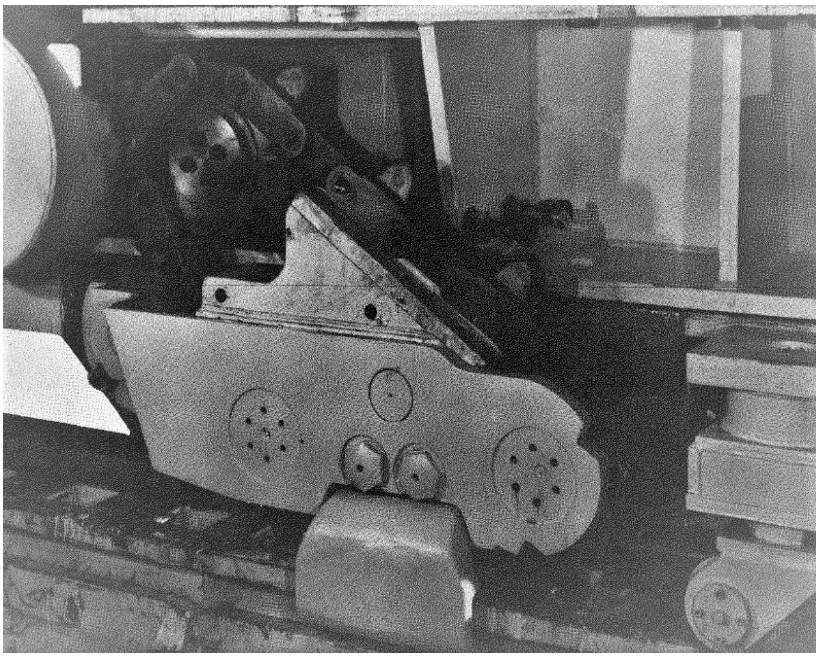

Fig. 6. Reactive Haulage system [10]

The Reactive Haulage system was recognized by the British National Coal Board in the mid-1970s as one of the standard and recommended haulage systems. It was available in two versions:

- For the Trepanner machines and two-drum shearers, the chain was driven directly by the vertical drive wheel of the haulage body.
- For one-drum shearers with a horizontal drive wheel, a solution was applied with the use of a haulage body hydraulic pump for low-speed drive, a hydraulic engine installed in the shearer sleigh (slide base) intended to drive the chain [12,13].

3.2. Ram propulsion haulage systems

At the end of the 1960s, attempts were made in France and Great Britain to develop systems with the traction force to be produced by hydraulic cylinders cooperating with ratchet systems enabling cyclical, alternate moving of the shearer or the ratchet system. The first such haulage system was applied in 1974 in the French Cevennes coal mine (Mains Pincantes – Cerchar) [10] (Fig. 7.).

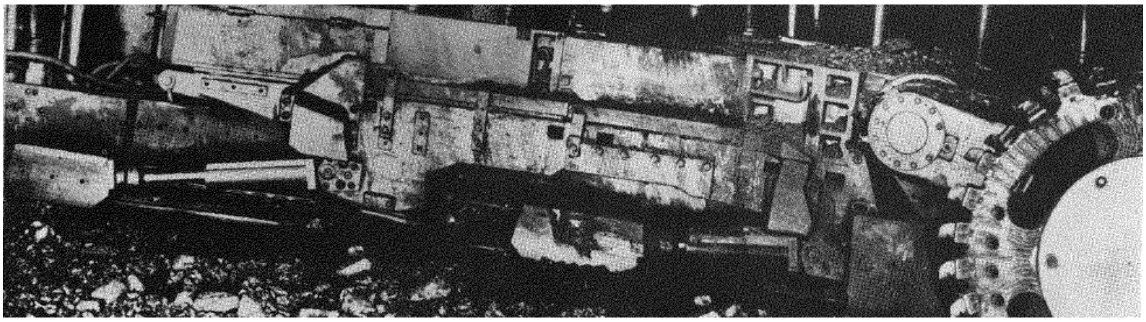

Fig. 7. Ram propulsion haulage system installed in longwall shearer [10]

In the opinion of users, the ram propulsion system eliminated chain-related accidents of the haulage systems, but it was also suitable for higher longwalls. The costs of its maintenance were also low. In the French mining industry, there were at least 8 shearers with such a haulage system.

Similar solutions were also applied in Great Britain. One of them was a system developed at the Mining Research and Development Establishment of the National Coal Board, which consisted of two hydraulic rams mounted at the bottom of the shearer and a hydraulically controlled clamping device along with a clamp cooperating with a special bar attached to the gob-side part of the armoured face conveyor. This solution was tested on a two-drum arm shearer by Anderson Stratclyde, but it was not introduced for industrial use, as the Tandem RamTrack solution by RB Bolton Ltd, in which the ratchet mechanism moved over a horizontal profiled bar being part of the scraper conveyor. The latter solution was tested only in surface conditions.

The ram propulsion haulage systems did not allow for high cutting speeds with the shearer, so they were quickly abandoned.

3.3. Captivated chain haulage systems

In the 1960s, longwall systems with plows as mining machines dominated in German coal mining. The first plows were pulled by drives installed in the gates at the ends of the longwall using first ropes and then link chains. Initially, these chains were run freely. With the increase in the power of plow drives and thus the forces in the chain and with the longwalls becoming increasingly longer, risks similar to those in shearer-operated longwalls occurred, related to the transverse vibrations of the chain and the possibility of its breaking due to the large longitudinal forces. Therefore, solutions were implemented consisting in forced running/guidance of both lines of the plow chain in a way to prevent transverse vibrations, and after the chain break off, to prevent its ends from moving sideways. One of the leaders of the plow technique in Germany was the Halbach-Braun company, which proposed the use of an immobilized chain held in special guides on which the sprocket wheel of the shearer was moving. The first such system was called Dynatrac [14,15,16,17]. Due to the fact that Halbach-Braun has been one of the leading manufacturers of the armoured face conveyors and the key changes were related to the design of the face conveyor, the solution with the captivated chain gained great popularity (Fig. 8).

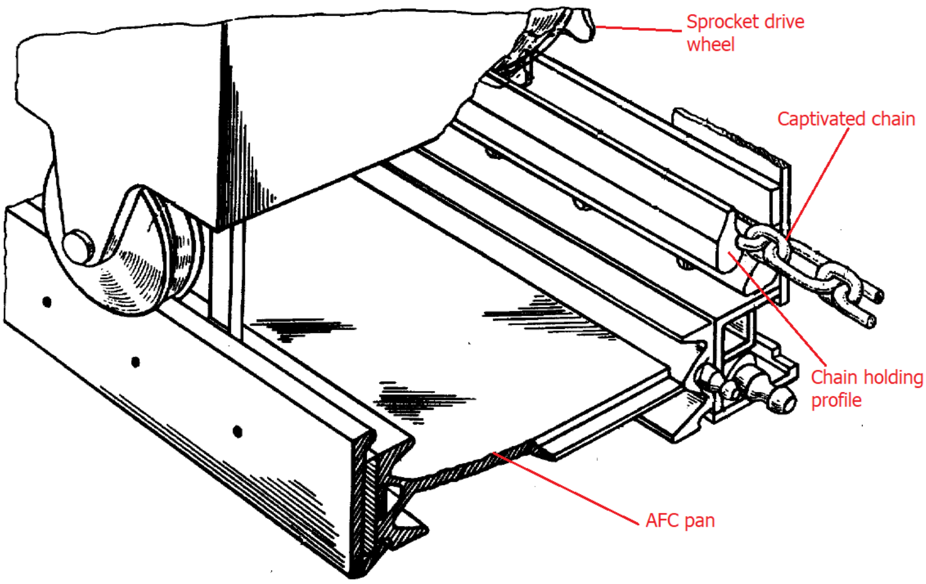

Fig. 8. Shearer captivated chain haulage system [18]

The Dynatrac system was later developed into the Rhinoride system with a chain of larger diameter, and then the Dynarhide system. High strength of the chain and its safe guidance made it possible to introduce high-power drives, allowing for high-speed cutting. The Dynatrac system was most popular in the 1990s. Fig. 9 shows a French longwall shearer with a captivated chain haulage system by Sagem Panda.

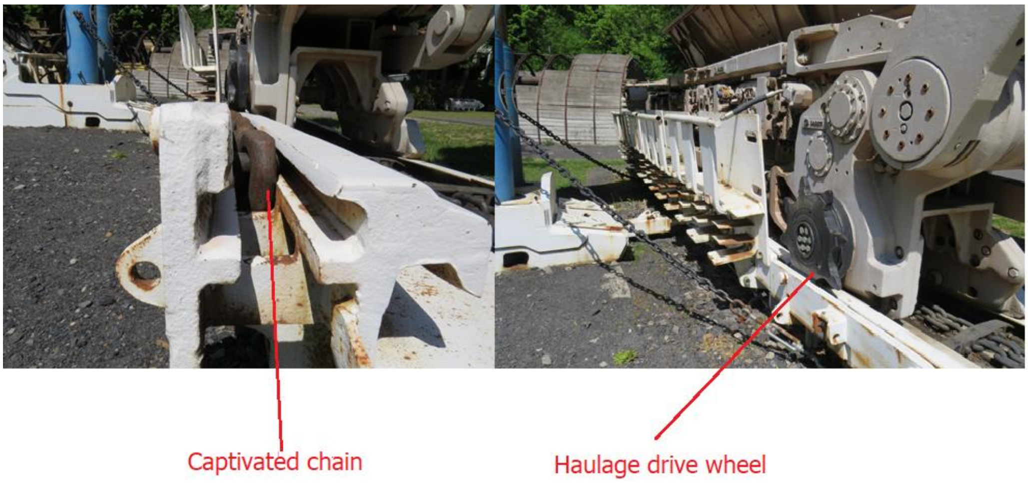

Fig. 9. Sagem Panda shearer with captivated chain haulage system [author]

In this haulage system mostly a fully electric haulage drive with frequency converters has been applied. This allowed to reduce the volume of hydraulic oil and greatly increase the haulage system power. The principle was to use double drive systems with two drive wheels at the ends of the shearer, which improved the cooperation between the drive wheels and the shearer. This system enabled efficient mining in longwalls with a height of more than 3.5 m.

In 1985 in USA was patented solution which eliminated some vices of Dynatrac as uneven chain wear – all chain had to be replaced even if only several links in the chain were broken [19] (Fig. 10).

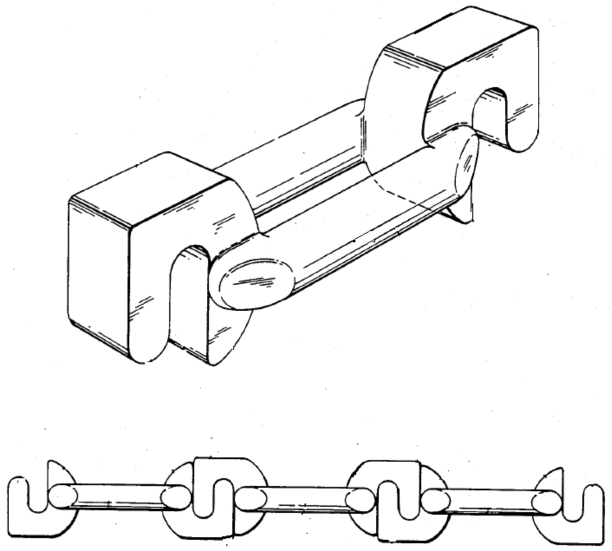

Fig. 10. Improvement of captivated chain haulage system with independent chain links patented by Anderson Strathclyde PLC [19]

4. Summary

The first solutions, eliminating the free chain in the longwall haulage systems of coal shearers were undertaken assuming the smallest possible changes in the technical system of the mechanized longwall, especially in the shearer's design and structure. These attempts were made at the time when single-drum longwall shearers with a cutting drum embedded in the shearer body (mainframe) were still commonly used. Due to the fact that the beginning of improvement of chainless haulage systems was also related to other designs of the mechanized roof supports (chocks), the introduction of powered roof supports (shields) to the longwall systems resulted in changes in the approach to the chainless haulage system of the longwall shearers. The priority was the safety of miners' work and durability and reliability of the mechanized longwall devices. The above described solutions, although satisfying these needs, complicated the design of shearers and face conveyors, in fact not bringing benefits in the form of increased longwall productivity. Therefore, solutions were still sought to be more universal in application and at the same time to enable a large increase in the coal longwalls productivity. However, before the spread of longwall shearer haulage systems based on the Eickhoff solution, many other solutions with a sprocket wheel and a rack bar were developed and implemented, which requires a separate elaboration.

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Determining the possibility of using the Polish aggregates for recovery of rare earth elements

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Abstract:

The high and constantly growing interest in Rare Earth Elements (REE) results from their desirable properties that are required in the state-of-the-art technologies. These elements are widely distributed in nature but most often found in low concentrations. Poland's resources are limited to a few poor deposits. KOMAG has started research projects aimed at extending the knowledge about the content of REE in Polish raw materials. Five Polish natural aggregates were selected for testing. The method of mass spectrometry with inductively coupled plasma ionization (ICP-MS) were used for analyses. Content of REE in the tested materials was found to be in the range of 190.0-14.8 ppm. Basalt aggregate marked with number 1 and halloysite had the highest content, and the lowest content was in the granite aggregate and sand marked with number 2. Then, the grain class 0.045-0 mm was separated to determine REE content in fine grains of materials. The test results indicate different proportions between light and heavy REE in the samples of the tested materials.

Keywords: rare earth elements (REE), screening, natural aggregates

1. Introduction

Rare Earth Elements (REE) is a group of elements which includes lanthanide and group 3 elements. These elements are of great interest which are constantly growing. This interest is related to a number of desirable properties of these elements. These properties are used in many state-of-the-art technologies. There is a division of these elements into light rare earth elements - LREE (La-Eu) and heavy rare earth elements - HREE (Gd – Lu and Y) [1]. There is also a different, more precise division in the literature, more often used in extraction: light rare earth elements - LREE (La – Pm), medium rare earth elements - MREE (Sm – Gd), heavy rare earth elements - HREE (Tb – Sc and Y) [2].

Rare earth elements are the elements widespread in nature. However, their low concentration cause the problem with their recovery. Deposits of high concentration of these elements are very rare. Currently, Poland does not have its own identified raw minerals resources as an economic source of REE. Their presence in the form of lean deposits is limited to the area of Szklarska Poręba, the Sudetes, the vicinity of Białystok and the sands of the Baltic Sea beaches. Heaps of waste from the phosphogypsum industry and ashes from power plants from coal combustion and co-incineration are considered to be a potential source of rare earths elements. These wastes are an important source of REE recovery. Therefore, the KOMAG Institute of Mining Technology has started searching for the sources of rare earth elements in Poland.

Due to the confirmed occurrence of rare earth elements in natural aggregates [3,4,5], an attempt was made to analyse the Polish aggregates. Earlier studies of the KOMAG Institute of Mining Technology confirmed the presence of rare earth elements in the materials of Polish origin but in small concentrations [6,7,8]. Natural aggregate is a material consisting of grains, derived from crumb deposits - gravel and sand aggregates, or solid rock deposits - crushed aggregate. The remaining aggregates available on the market are artificial and recycled aggregates [9,10]. The main applications of natural aggregates are the production of concrete, asphalts, mortars, adhesives, prefabricated products and others. Refined aggregates are used in the glass industry, foundries, for filtration of water, sewage and others [11]. Currently exploited mineral aggregate deposits may be prospective places for recovery of rare earth elements in Poland. The existing technological lines can be used as a stage of preliminary classification of raw material from the deposit. Even a low content of minerals containing rare earth elements creates the possibility of an economically justified investment in machines and equipment for separation. Currently operating mining plants around the world use deposits for recovery of rare earth elements when their concentration is over 500 ppm [12].

This article is aimed at confirming the presence of rare earth elements in the selected natural aggregates.

In nature, there are no deposits of rare earth elements in their pure form. These elements are most often in the form of minerals or compounds formed after ionization of minerals. Today, science knows more than 250 minerals containing rare earth elements. Due to their small accumulation, few of them are suitable for recovery. Currently, deposits containing mainly the following minerals are exploited for REE recovery: bastnasite, monazite, xenotime and sorption-clay minerals [13,3]. These minerals are characterized later in the publication.

Bastnasite belongs to the group of fluorocarbonate minerals. The chemical formula is - $CeCO_3$ (OH, F). Cerium can be replaced by other light rare earth elements (LREE), e.g. lanthanum. This mineral can be found in igneous rocks such as pegmatites and granites. It also occurs in metamorphic rocks, in zones where contact metamorphism plays a dominant role [14]. Other minerals containing rare earth elements such as allanite or fluocerite may coexist with this mineral [15].

Monazite belongs to the group of phosphate minerals. The chemical formula is - (Ce, La, Nd, Th) (PO4). Cerium, lanthanum, neodymium and thorium are interchangeable in the mineral structure. This mineral is most often an accessory mineral. It is most often found in igneous or metamorphic rocks, e.g. granite, pegmatite, basalt, slate and gneiss [16,17,18,19]. Monazite can also be found as a component of sedimentary rocks. This mineral is one of the more resistant to the atmosphere impact. As a result of weathering of the parent rocks containing monazite, the mineral may accumulate in the material left over from this process. The crumb deposit created in this way with appropriate amount can be used to obtain rare earth elements and thorium [20].

Sorption-clay minerals are the minerals of a very small size. Due to the small grain size of these minerals and the large specific surface area, they are able to adsorb large amounts of ions of chemical compounds. Sorption-clay minerals containing rare earth elements form during rock weathering. Then the ionization of the compounds containing these elements takes place and then their adsorb on the surfaces of sorption-clay minerals. The main mother rocks of sorption-clay minerals are igneous rocks - granites [4]. These minerals are one of the main sources of heavy rare earth recovery. Due to the weaker (sorption) binding of rare earth ions, obtaining a concentrate of these elements is much easier [21]. Deposits of sorption-clay minerals, mainly located in China, consist of clay (40-70%). The clays in these deposits are halloysite (25-50%), illite (5-20%), kaolinite (5-10%) and montmorillonite (<1%) [22]. Halloysite belongs to the aluminosilicates of the kaolinite subgroup. It occurs very rarely in pure, homogeneous form, most often it is a mineral accompanying kaolinite, but also iron-bearing minerals, feldspars and quartz sands.

Xenotime belongs to the group of phosphate minerals with the formula YPO_4. One of the main features of this mineral is the content of yttrium above 50% and the low content of light rare earth elements. Compared to monazite, it has a much lower thorium content [23]. This mineral is most often an accessory mineral in igneous rocks. Xenotime may also be found in clastic deposits, the genesis of which is similar to that of monazite-containing clastic deposits [24]. It has been shown that xenotime can also contain tungsten and radioactive elements such as uranium and thorium [25].

Xenothym, monazite and bastnasite are minerals that can be found in rocks such as granite, basalt, pegmatite and others mentioned above. The materials that were used for tests are characterized below.

Granite is a deep igneous rock of an open-crystalline structure. This rock is formed from the slow crystallization of magma beneath the Earth's surface. The main minerals of granite are orthoclase, plagioclase, quartz and biotite. The content of rare earth elements in this rock depends on the content of accessory minerals. Some of the granite accessory minerals contain REE. They are, among others: monazite, xenotime, allanite, titanite and anatase [26,27].

Basalt is an alkaline, pourable (volcanic) solid rock with a very fine-grained (cryptocrystalline) or aphanite structure, sometimes porphyry. The main minerals of this rock are pyroxene, plagioclase, mica, amphibole. Many studies have demonstrated the presence of rare earth elements in basalt rocks [5,28,29]. The presence of rare earth elements also in these rocks is related to the content of accessory minerals [30].

Conical separators, coiled stream separators, flotation machines, magnetic separators, electrostatic separators or Multi-Gravity separators are used in the mechanical processing of raw materials containing rare earth elements. The mentioned machines and devices can be divided according to their separation efficiency. Devices of relatively low separation efficiency are usually used at the beginning of the technological line for the production of pre-concentrates. Devices of a relatively low separation efficiency of upgrading include conical separators and coiled stream separators. The pre-concentrates are then directed to the devices of higher separation efficiency as a feed. Devices of a relatively high separation efficiency, such as magnetic separators or electrostatic separators, are usually used for the production of high purity final concentrates [31]. Classification the material according to its grain size could be another way to increase the concentration of rare earth elements. The effectiveness of this method will be greater if the rare earth elements are concentrated in the grains of a certain size. According to the literature information, greater concentration is expected in grains of smaller size [32].

Identification of the material that, when subjected to processing, will allow to obtain a concentrate containing about 60% of rare earth minerals, what, according to the literature, is a condition for the material usefulness in production of high purity rare earth elements is the main objective of tests carried out at the KOMAG Institute of Mining Technology [33]. To achieve this objective, the following testing schedule was drawn up:

a. Acquisition of raw materials being the natural aggregates. Extracting the representative samples from the acquired materials. Analysis of the samples for the content of rare earth elements. Selection of the three materials with the highest REE content.
b. Separation of grain classes 0.045-0 mm from previously selected samples. Chemical analysis of the separated fine grain classes of the materials in terms of the content of rare earth elements to check if rare earth elements are more concentrated in the finest grains of the tested

raw material. This will make it possible to determine the variability in rare earth elements content depending on the grain size of the analysed raw materials.

c. Analysis of the results obtained in items a and b. Determining the suitability of new materials. Summary of the work carried out.

2. Materials and Methods

2.1. Materials

Aggregates from igneous deposits: granite, basalt and aggregates from sedimentary deposits: sand and halloysite were selected for testing. Each of the sample weighed 20 kg. The characteristics of the materials used in the tests are presented below.

- Granite aggregate.

This material was taken from a granite mine conventionally marked by the symbol "A". This mine produces basalt aggregates in a wide range of grain sizes. The mine deposit is mined by drilling and blasting. Technology includes multi-stage classification and crushing. Material used in the tests is one of the mine's commercial products: 2-0 mm granite aggregate. The granite was collected by miners.

- Basalt aggregate 1, basalt aggregate 2.

These materials was taken from the "B" and "C" granite mines. The mines produce basalt aggregates in a wide range of grain sizes. Deposits of these mines are mined by drilling and blasting. Technology includes multi-stage classification and crushing. One of the mine's commercial products: 2-0 mm basalt aggregates was the material used in tests. The aggregates were collected by miners.

- Halloysite.

This material was taken from an open pit halloysite mine marked by the symbol "D". Halloysite from the mine deposit is a product of basalt rock weathering. The raw material has a homogeneous composition throughout the cross-section, there are no interlayers and vein-type inclusions.

Composition of the mineral is as follows:

- halloysite: 75-80%,
- iron oxides (mainly hematite and magnetite): 18-22%,
- iron and titanium oxides (mainly ilmenite): 2-4%.

Raw material taken from the deposit by miners was the material used in testing.

- Sand 1.

This material taken from the sand mine marked by the symbol "E". The mine extracts a sand and gravel from the deposit. Technology involves extraction of raw material from the deposit using a suction dredger. The material undergoes several stages of washing, classification and dewatering. Vibrating screens, circular dehydrator or pulsating classifier were the devices used for this purpose. Bottom product from the pulsating classifier sieves with a grain size <2 mm was the material used in the tests. The sand was collected by the personnel of gravel plant.

- Sand 2.

This material taken from the sand mine marked by the symbol “F”. The mine extracts backfilling sand from the deposit as the main mineral and a sand and gravel mix as an accompanying minerals. The deposit is excavated using a bucket-wheel excavator. Then the material is transported to the processing plant, where it is washed, classified and dried. The commercial products are the following: construction sands, washed and dried sands and gravel. The material was collected from the deposit by employees of the KOMAG Institute of Mining Technology.

2.2. Methods

Reducing the samples to 0.5 kg by the quartering method was the first stage of testing. Reduced samples were sent to the Laboratory of Materials Engineering and Environment at KOMAG for determination of rare earth elements content. In the laboratory, the material samples were mineralized in a wet closed system. Microwave mineralizer was used for this purpose. Dissolution of the test samples was visually inspected. As a result of the mineralization process, a colourless and clear solution was obtained for most of the samples. The solutions were analysed for the of rare earth elements content using the mass spectrometry method with inductively coupled plasma ionization

(ICP-MS). On the basis of the test results, 3 materials of the highest rare earth elements content were selected, and were used in the further part of testing. Laboratory vibrating screen was used to obtain grain classes 0.045-0 mm. Samples of the selected materials weighing 1 kg were separated using the quartering method. The screening process was wet, using a sieve with a square mesh of size 0.045 mm. After the process completion, the products were dried and their mass output was determined. Then, the dried samples were sent to the laboratory for the determination of their content of rare earth elements using the ICP-MS method.

3. Results

Content of rare earth elements in the raw samples are presented in Table 1 and in Fig. 1. HREE is marked in red, MREE in orange and LREE in blue.

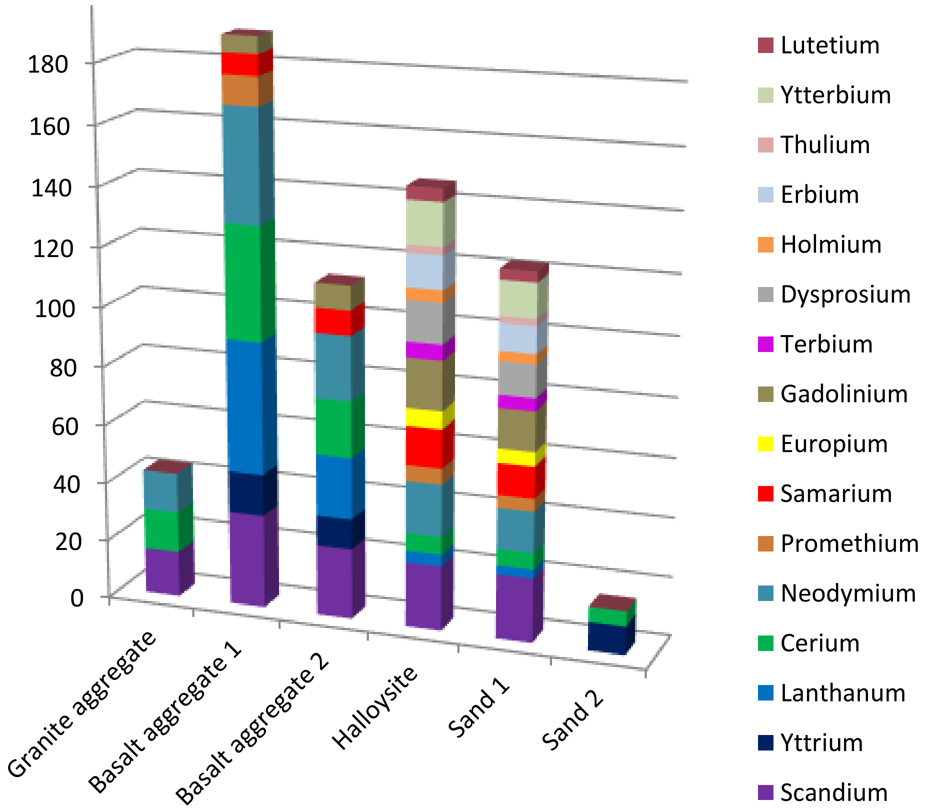

Fig. 1. Diagram of REE content in the raw materials [own source]

Table 1. Results of REE content [own source]

Material	Content of rare earth elements [ppm]								
Granite aggregate	La -	Ce 14.0	Nd 13.5	Pr -					
	Tb -	Dy -	Ho -	Sc 15.5	Y -	Er -	Tm -	Yb -	Lu -
	Sm -	Eu -	Gd -	ΣREE=43.0					
Basalt aggregate 1	La 45.0	Ce 38.4	Nd 38.2	Pr 9.7					
	Tb -	Dy -	Ho -	Sc 31.9	Y 14.1	Er -	Tm -	Yb -	Lu -
	Sm 7.0	Eu -	Gd 5.7	ΣREE=190.0					
Basalt aggregate 2	La 20.9	Ce 19.1	Nd 21.7	Pr -					
	Tb -	Dy -	Ho -	Sc 24.0	Y 10.3	Er -	Tm -	Yb -	Lu -
	Sm 8.4	Eu -	Gd 8.1	ΣREE=112.5					
Halloysite	La 4.0	Ce 6.1	Nd 17.6	Pr 5.4					
	Tb 5.3	Dy 13.5	Ho 4.0	Sc 22.0	Y -	Er 11,1	Tm 2,8	Yb 14,2	Lu 4,4
	Sm 13.1	Eu 6.1	Gd 16.6	ΣREE=146.2					
Sand 1	La 3.0	Ce 5.6	Nd 13.9	Pr 4.3					
	Tb 4.3	Dy 11.0	Ho 3.3	Sc 21.8	Y -	Er 9,1	Tm 2,3	Yb 11,5	Lu 3,5
	Sm 10.7	Eu 4.8	Gd 13.4	ΣREE=122.5					
Sand 2	La -	Ce 5.1	Nd -	Pr -					
	Tb -	Dy -	Ho -	Sc -	Y 9.7	Er -	Tm -	Yb -	Lu -
	Sm -	Eu -	Gd -	ΣREE=14.8					

From the tested raw material samples, basalt aggregate has the highest total content of rare earths, i.e. 190.0 ppm. The next material, in terms of the total content of the analysed elements, is halloysite - 146.03 ppm and sand 1 - 122.22 ppm. These materials were used in the further part of the testing aimed at determining the content of rare earth elements in fine grain classes. Table 2 presents the contents of HREE, MREE and LREE in the raw material samples.

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Table 2. Total content of HREE, MREE and LREE in raw materials [own source]

Material	Content of rare earth elements [ppm]		
	LREE	MREE	HREE
Granite aggregate	27.5	0	15.5
Basalt aggregate 1	131.3	12.7	46.0
Basalt aggregate 2	61.7	16.5	34.3
Halloysite	33.1	35.8	77.3
Sand 1	26.8	28.9	66.8
Sand 2	5.1	0	9.7

The previously mentioned material samples, which showed the highest content of rare earth elements, were used to determine concentration of these elements in a fine grain class of 0.045-0 mm. Then, the percentage yields of the obtained grain classes were calculated and presented in Table 3.

Table 3. Output of 0.045-0 mm grain class in the samples of halloysite, sand and basalt [own source]

Material	Output of class 0.045-0 mm [%]
Basalt aggregate 1	11.5
Halloysite	38.7
Sand 1	0.65

After determining the outputs, the samples were analysed for the content of rare earth elements, using the ICP-MS method specified at the beginning of this section. Results of the analysis are given in Tables 4, 5 and in Fig. 2.

Table 4. Results of REE content in 0.045-0 mm grain class [own source]

Material	Content of rare earth elements [ppm]								
Basalt aggregate 1	La 73.6	Ce 151.4	Nd 61.3	Pr 15.4					
	Tb 1.7	Dy 8.4	Ho 1.5	Sc 17.2	Y 4,6	Er 3,8	Tm 0,5	Yb 2,9	Lu 0,3
	Sm 11.6	Eu 4.3	Gd 15.8	ΣREE=374.3					
Halloysite	La 2.0	Ce 8.4	Nd 2.3	Pr 1.0					
	Tb 0.1	Dy 0.9	Ho 0.1	Sc 16.9	Y -	Er 0,5	Tm -	Yb 0,5	Lu -
	Sm 0.7	Eu 0.3	Gd 1.0	ΣREE=34.7					
Sand 1	La 3.9	Ce 8.3	Nd 5.6	Pr 1.2					
	Tb 0.3	Dy 1.6	Ho 0.3	Sc 12.3	Y -	Er 0,6	Tm -	Yb 0,5	Lu -
	Sm 1.6	Eu 1.0	Gd 2.0	ΣREE=39.2					

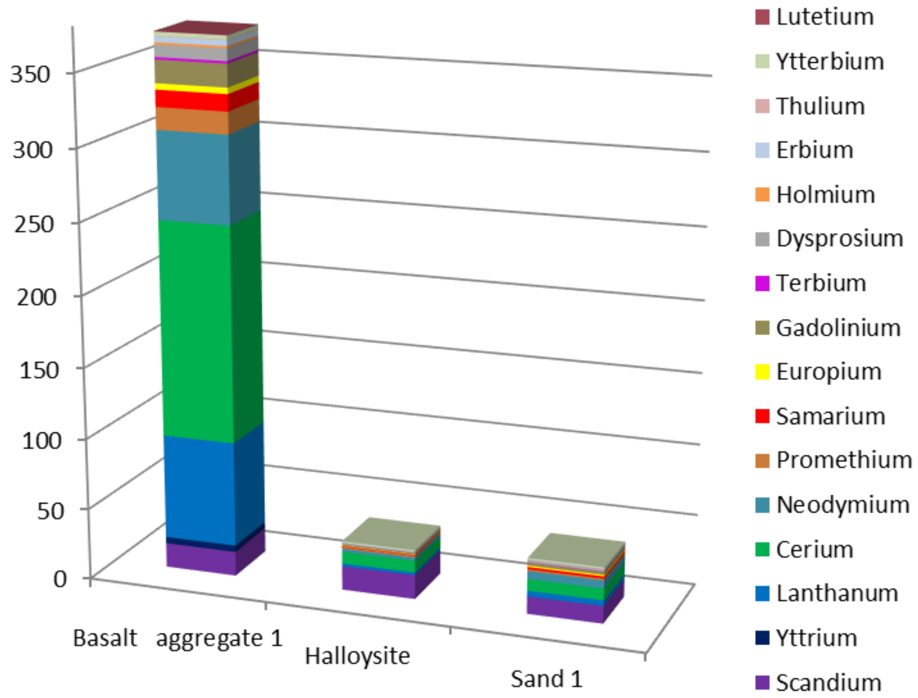

Fig. 2. Content of REE in analysed minerals [own source]

Table 5. Content of HREE, MREE and LREE in raw materials [own source]

Material	Content of rare earth elements [ppm]		
	LREE	MREE	HREE
Basalt aggregate 1	301.7	31.7	40.9
Halloysite	13.7	2.0	19.0
Sand 1	19.0	4.6	15.6

4. Discussion

Tests of granite aggregate showed the total content 43.0 ppm of 3 rare earth elements i.e. scandium 15.5 ppm, cerium 14.0 ppm, neodymium 13.5 ppm. The total 8 REE content in the basalt aggregate 1 was 190.0 ppm, of which lanthanum was of the highest content (45.0 ppm). Basalt aggregate 2 had 7 REE of total content 112.5 ppm. In the basalt aggregate 2, scandium has the highest content (22.0 ppm). Halloysite had 15 REE of total content 146.03 ppm, of which scandium has the highest content equal to 24.0 ppm. Sand 1 had an REE content of 122.5 ppm, comprising 15 elements, of which scandium had the highest content - 21.8 ppm. Sand 2 had REE concentration of 14.8 ppm. Yttrium - 9.7 ppm and cerium - 5.1 ppm were found only in this material.

Table 2 shows the share of heavy, medium and light rare earth elements in the tested raw materials. Crushed igneous aggregates: granite aggregate and basalt aggregate have a greater affinity for light rare earth elements (LREE). Other materials such as halloysite, sand 1 and sand 2 have a higher affinity for heavy rare earth elements (HREE).

From among the raw material samples tested, basalt aggregate has the highest total content of rare earth elements, i.e. 190.0 ppm. Halloysite - 146.2 ppm and sand 1 - 122.5 ppm were the next materials, in terms of total content of the tested elements. The lowest total content of rare earth elements was found in granite aggregate - 43.0 ppm and in sand 2 - 14.8 ppm.

The following materials: basalt aggregate 1, halloysite and sand 1 were selected for testing the content of rare earth elements in the grain class <0.045 mm. Halloysite had the highest content of grains <0.045 mm - 38.7%, and sand 1 the lowest - 0.65%. The expected increase in the content of rare earth elements after fine material separation was found only in the case of the basalt 1 aggregate. Total content of REE in this material increased from 190.0 ppm to 374.3 ppm, what means an increase of about 97%. Based on the results from Table 5, it can be concluded that the content of light rare earths increased the most. Before separation of a grain class 0.045-0 mm from the raw material, light rare earths accounted for 68% of the total REE content. After screening, total content of light rare earth elements in the grain class <0.045 mm was 81% of the total REE content. However, the increase in REE content was still insufficient for using the basalt aggregate for beneficial recovery of rare earth elements.

5. Conclusions

In 2009, the international Organization for Economic Cooperation and Development included rare earth elements on the list of the so-called strategic resources. In 2011, the European Union published a list of critical raw materials for the Union, raw materials of strategic importance for the development of state-of-the-art technologies. This list also includes rare earth elements. Due to strategic importance of these elements, it is necessary to look for their alternative sources. For this reason, tests were carried out on the content of rare earth elements in natural aggregates.

The aim of the project was to determine if the analysed natural aggregates contain rare earth elements at concentration enabling their economic recovery. The results of the tests indicate the presence of rare earth elements in the tested material. The results indicate a predominance of light rare earth elements (LREE) in basalt aggregate 1 and 2 and granite aggregate, while heavy rare earth elements (HREE) are predominant in halloysite, sand 1 and sand 2. Moreover, it was found that the cerium is the most common element, as it was determined in all samples of the tested materials.

In the further part of the tests, three materials of the highest content of the tested elements were selected, from which grain classes of 0.045-0 mm were separated. A decrease in the content of rare earth elements in halloysite 1 and sand 1 was observed. The only increase in the content of REE elements was found for the basalt aggregate 1. The content of REE in this material increased from 190.0 to 374.3 ppm, what gives an increase of about 97%.

The content of rare earth elements in the collected materials was in the range of 190.0-14.8 ppm. Even in the case of material containing the REE highest content, i.e. basalt aggregate, it is too low for beneficial recovery of these elements. The expected increase in the content of tested elements in the finest grains of materials was achieved only in the case of basalt aggregate - 374.3 ppm. The obtained, higher concentration of the REE is also insufficient for an economically justified recovery of rare earth elements.

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Harmonization of technical requirements in the scope of machines for underground mines

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Abstract:

In the European Union different methods of harmonizing technical requirements are accepted. The main legal instrument includes, among others, directives and European standards which are a key component of the European Single Market. European Standardization plays an important role in the development and consolidation of the European Single Market. The fact that each European Standard is recognized across the whole of Europe, and automatically becomes the national standard in 34 European countries, makes it much easier for businesses to sell their goods or services to customers throughout the European Single Market. This article presents general principles of implementing uniform technical requirements contained in the harmonized standards following the example of mining machines, in particular powered roof supports. The article concerns the standard EN 1804-Parts:1; 2; 3, i.e. Machines for underground mines - Safety requirements for hydraulic powered roof supports:

- Part 1: Support units and general requirements,
- Part 2: Power set legs and rams,
- Part 3: Hydraulic and electrohydraulic control systems.

The authors described the work results of the Technical Committee CEN/TC 196 "Mining machinery and equipment - Safety", over the years 2017-2020, oriented onto establishing three new edition of standards. These new edition of standards have been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association and supports essential requirements of EU Directives.

Keywords: European Standard, mining machines, hydraulic powered roof supports

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1. Introduction

In the process of opening markets to international trade within the EEA - European Economic Area, an elimination of technical barriers is based, among others on two basic documents:

- The Single European Act,
- The White Paper from 1985, in which the European Commission formulated projects of about 280 directives foreseeing an elimination of fiscal, technical and physical barriers in dealings among the EU countries.

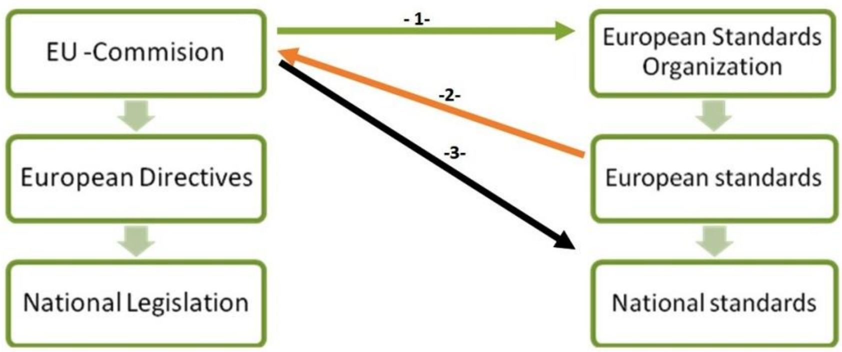
An essential element of the free flow of goods is the creation of the Community harmonization legislation, i.e. regulations (EC), decisions (EC), directives (so-called "hard" law) supported by voluntary standards, in principle, including in particular harmonized with the given technical harmonization directive (so called of new and global approach) as well as with the procedures of conformity assessment whose goal is to test the conformity with declared requirements.

The "New Approach" to product safety has been applied in Europe. EU directives and regulations set out essential requirements, which in turn are supported by harmonized European standards. The arrangements for some aspects of the system were modified recently [1].

At present the main legal instrument of harmonizing requirements includes directives. A directive is a legislative act that sets out a goal that all EU countries must achieve. However, it is up to the individual countries to devise their own laws on how to reach these goals.

Due to the fact that directives contain only essential safety requirements for technical products, detailed requirements are related most often to European standards, harmonized with the directives, elaborated on the basis of a mandate from the Commission given to the CEN and CENELEC and then introduced to national standards in an unchanged form.

Harmonized standards are elaborated by the European standardization organizations (CEN, CENELEC, ETSI) on the basis of a mandate given by the European Commission and they are accepted by these European standardization organizations according to their internal procedures. The European Commission, after having accepted them, makes their numbers and additional information concerning the date od edition, possibilities of taking advantage of the supposition privilege, are published in the Official Journal of the European Union (Fig.1).



1-Mandate; 2- Verification process; 3- Publication in the Official Journal of the EU Harmonized Standard

Fig. 1. Elaboration process of harmonized standards

If the EN standard, elaborated on the European level, becomes the national standard, due to its introduction to the set of national standards by at least one number country, this standard becomes the “harmonized standard”. It should be highlighted that about 20% of all the European standards are elaborated following up such an order from the European Commission.

Despite a close connection of harmonized European standards with directives, these standards still maintain the status of a voluntary application document.

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The harmonized European standards specify in total or partly essential safety requirements included in a given directive, and the statements contained in the harmonized standards determine an acceptable level of technical safety.

Machine safety standards are divided into type A, B and C standards. The A-type standard is framework and very general. This standard sets out basic strategies and conditions that users must observe in order to reduce risk to an acceptable level. Type B standards describe principles of a safety aspect or requirements. Type C standards govern a specific product (Fig. 2).

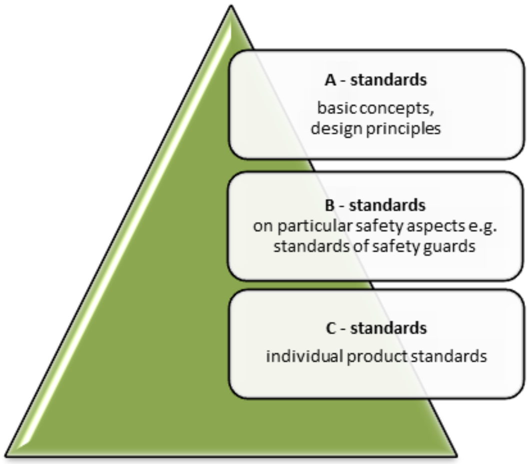

Fig. 2. Structure of harmonized standards

European Committee for Standardization CEN is one of three European Standardization Organizations (together with CENELEC and ETSI) that have been officially recognized by the European Union and by the European Free Trade Association (EFTA) as being responsible for developing and defining voluntary standards at European level. CEN, the European Committee for Standardization, is an association that brings together the National Standardization Bodies of 34 European countries [2].

National standardization bodies, which accept and publish national standards manage the standardization process on the national level. The national standardization bodies also introduce all the European standards as identical national standards and they simultaneously withdraw any national standards which are not in accordance with the new ones.

The objective of this article is to present the results of the TC 196 - Mining machinery and equipment- Safety, in particular the TC196/WG3 – Machines for underground mines – Roof support course of activities.

2. Materials and Methods

2.1. Business environment of the CEN/TC 196 - international trade and standardization aspects

The activities of the CEN/TC196 concentrate on ensuring that the health and safety of workers are maintained and on ensuring that the applied safety standards, previously in place at the national level, remains. It should be borne in mind that European standards satisfy the Essential Safety Requirements of EN Machinery Directive (2006/42/EC). It is recognized throughout the world that European manufacturers have traditionally produced machinery to high safety standards. It needs to be highlighted that there is a definite move towards an acceptance of European standards and testing facilities globally giving the European manufacturers increased competitive edge. The priorities of CEN/TC 196 include safety requirements for mining machines and equipment and a significant improvement of safety in mine sites.

There are real or potential technical barriers to trade related to the scope of the CEN activity. Political, economic, technical, regulatory, legal, societal and/or international dynamics describe the business environmental of the industry sector, products, materials, disciplines or practices related to the scope of the CEN /TC 196 activity, and they may significantly influence the relevant standards development processes and the content of the resulting standards. Market access outside the European Community is frequently restricted by technical barriers to trade, based on national regulations for health, safety and environment issues. A free market access can be achieved by applying justified European Standards transferred to the ISO level and vice versa. Those standards have to be supported by the national legislation in the particular countries for being effective. The international model of UN Economic Commission for Europe (UN ECE) is an excellent example for creating those technical legislation procedures at the national level [3].

The technical details within this this international model are specified by international standards which enable a harmonization of the market access.

With regard to current international trade and standardization aspect, many countries of the world, particularly: China, Russia, Australia, South Africa and the GSO (Gulf Cooperation Council Standardization Organization) adopt and accept the standards generated in Europe.

Certain other countries, such as India are ready to follow.

All the CEN national members are entitled to nominate delegates to the CEN Technical Committees and experts to the Working Groups, ensuring a balance of all interested groups.

The main objectives of the CEN/TC 196 include a transition from a legal framework based on an approval of machinery safety through national requirements and standards to one of essential requirements supported by technical standards, an elimination of trade barriers across the European market and a provision a of common set of European Standards for use internationally thereby promoting a global market.

The work programme of the CEN/TC196 is divided into seven subject areas with three active working groups established [2,3]:

WG 1 Mobile machines at the face (active)
WG 2 Mobile machines for underground mines (active)
WG 3 Machines for underground mines - Roof support (active)
WG 4 Mining ventilation machinery (no activities)
WG 5 Armoured face conveyors (no activities)
WG 6 Continuous handling equipment and systems (no activities)
WG 7 Noise requirements (no activities).

In the following chapters detailed information is given on standardization activities in the field of hydraulic powered roof supports and on the work results of the CEN/TC196-WG3 Members.

2.2 The European system of standardization activities in the field of hydraulic powered roof supports

The standardization activities of CEN are steered by the CEN Technical Board (BT), who has full responsibility for the execution of CEN's work programme. Standards are prepared by Technical Committees (TCs). Each TC has its own field of operation (scope) within which a work programme of identified standards is developed and executed. TCs work on the basis of national participation by the CEN Members, where delegates represent their respective national point of view. This principle allows the TCs to take balanced decisions that reflect a wide consensus [2].

Hydraulic powered roof supports are qualified as the equipment of increased risk of hazards, which requires a specific procedure before their introduction into operation, what is included in the 2006/42/EC Directive (Machinery) [4].

This Directive contains only essential safety requirements for supports, but detailed requirements are referred to groups of the European standards, harmonized with the directive, elaborated on the basis of the Commission’s mandate by the CEN and the CENELEC.

As regards the mining machinery and equipment the CEN/TC 196 deals with an elaboration of standards. It concentrates its activities on standardization relating to safety aspects of specialized mining machinery and equipment for opencast mining and machinery and equipment for underground mine development. It also deals with standardization concerning additional safety requirements for other machinery primarily designed for use outside mines but also intended for use in underground mines.

The CEN/TC 196 consists of three Subcommittees and seven Working Groups, and effects of their work include publishing of ten different standards [2]. All the tasks, undertaken by the Committee, are realized according to the guidelines included in the Internal Regulations [5,6].

In the 2017 CEN/TC 196/WG 3 Machines for underground mines – Roof support started its activities in scope of amendments to three standards belonging to Type C safety standards.

They were as follows:

- EN 1804-1 Machines for underground mines - Safety requirements for hydraulic powered roof supports - Part 1: Support units and general requirements,
- EN 1804-2 Machines for underground mines - Safety requirements for hydraulic powered roof supports - Part 2: Power set legs and rams,
- EN 1804-3 Machines for underground mines - Safety requirements for hydraulic powered roof supports - Part 3: Hydraulic control systems.

As it has already been mentioned all the above given standards belong to Type C, which covers a specific type of machines and all the included requirements are specific to that type of machines, where the Working Group for the Type C safety standard has members vertically involved with that type of machines.

It is worth mentioning that the first edition of the above mentioned standards from the EN 1804-1;2;3 series appeared in 2001 and in 2006, and during the following years they were subject to several reviews and minor corrections resulting from a necessity of their adoption to the changed machinery directive (2006/42/EC). However, these reviews have never been ended with real amending of documents with a simultaneous review and modifications of the requirements included in them.

During twenty years three documents mentioned above, constituted the basis for designing new solutions, conducting stand tests of supports and conducting conformity assessments of these machines and equipment.

The leading countries which conducted tests with use of these standards have been: Germany, Poland and the Czech Republic. A scope of using these standards and results of tests, conducted on their basis, are mentioned among others in [7,8,9,10,11,12].

The methods and results of tests of powered roof support units and of their components, realized in Poland mainly at the KOMAG Institute of Mining Technology as well as a comprehensive analysis of testing capabilities of laboratories, realizing tests of powered roof support units and their components, are presented in the publication [13]. Results of tests of powered roof support in China are presented in [14].

3. Results

3.1. Realization of activities by the Members of CEN/TC 196-WG 3

The following companies delegated their representatives to participate in the activities of CEN/TC 196-WG3:

- Marco Systemanalyse und Entwicklung GmbH, Germany,
- JOY GLOBAL (UK), Great Britain,
- TECHNICKE LABORATORE OPAVA, Czech Republic,
- Caterpillar Global Mining Europe, Germany,
- DIN - Deutsches Institut für Normung, Germany,
- ZMJ Germany GmbH, Germany,
- KOMAG Institute of Mining Technology, Poland,
- TIEFENBACH Control Systems GmbH, Germany.

The activities were conducted by the representatives of the countries, mentioned above during the following meetings among others [3]:

- 17th June 2016 – Plenary Meeting of CEN/TC 196 - an announcement of starting activities on introducing changes to the EN 1804-1;2;3 Standards (Stockholm, Sweden)

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- 28th-30th March 2017 – a preparatory meeting in Frankfurt - a presentation of WG3 members and invited experts (Frankfurt, Germany),
- 28th-29th March 2017- Plenary Meeting of CEN/TC 196 - a presentation of scheduled work programme (Madrid, Spain).
- 22th-23th March 2018 - WG3 Meeting to discuss critical remarks submitted by the Members (Frankfurt, Germany)
- 12th-14th July 2018 - Plenary meeting of CEN/TC 196 - a presentation of scheduled work plan and organizational changes (Warsaw, Poland),
- 24th-25th July 2018 - WG3 Meeting - a discussion on modifications to be introduced in the EN 1804-1; 2; 3 - a clarification of opinion differences (Frankfurt, Germany),
- 21th- 24th May 2019 - WG3 Meeting of CEN /TC 196 EN 1804-1; 2; 3 "Safety requirements for hydraulic powered roof supports" - a discussion of received comments of the HAS Consultant and a discussion of received comments on pr EN 1804-1, pr EN 1804-2, pr EN 1804-3.
- 21st- 22nd October 2019 - WG3 Meeting dedicated to the issue of eliminating the yield test – visit to KOMAG Laboratory (Gliwice, Poland).
- 12th November 2020 - WG3 Web Meeting - final discussion on opinion differences leading to conclusions.

3.2. Course of scheduled work programme

Draft Proposal pr **EN 1804-1 Standard**

The discussions were dominated by the producers of powered roof supports who were oriented onto a reduction or even an elimination of certain stand tests due to economic reasons. KOMAG representatives highlighted the fact that such an approach would have a negative impact on operational safety of powered roof supports. Tests of convergence caused a lot of controversies. In the case of a very important requirement, concerning the support unit yield capability, a method of testing the yield capability by the roof pressure was deleted. In such an approach a withdrawal of testing the support unit yield capability eliminates a standard requirement i.e. the support yield by an active roof. The deleted test may have a negative impact on the operational safety of powered roof supports. Alternative procedures of verifying the yield capability do not reflect the support yield from the roof. The first suggested procedure assumed an application of the least 300 kN external force to the support unit.

As at present the state-of-the-art roof support units have an operational load-bearing capacity above 6000 kN (20 times greater), the force of 300 kN does not simulate yield of the support unit effected by the roof and it does not make it possible to verify the strength of the support unit kinematic system. The liquid from the legs should be released at the pressure corresponding to the operational load – bearing capacity of the support units. The second alternative procedure is technically contradictory. It is not possible to generate the force yielding the support unit by releasing the liquid from the under the piston area of the legs. In the opinion of the KOMAG experts an implementation of alternative procedures will make a full strength verification of a powered roof support unit impossible.

In addition, a number of other structured comments were made, such as:

- The enumeration of hazards should refer to the EN ISO 12100:2000 standards, because some requirements should be completed an added.
- Normative references were updated in the result of discussions.
- Requirements of replacing a dynamic task with the FEM (Finite Elements Methods) calculations for legs (props) of 400 mm in diameter and more were introduced. The FEM verification method should be validated for at least 3 legs (props) of different diameters. It was suggested that other methods of dynamic loading, causing an effect, specified in the requirements, should be acceptable as well.

Draft Proposal pr **EN 1804-2 Standard**

- It was suggested to introduce separate definitions of legs and canopy supporting rams as the canopy supporting ram does not ensure load bearing capacity of the support unit.
- In the former text of standard the definition of yield pressure of actuators was not precise and it did not apply to the actuators operating without the pressure limiting valves. Thus all the requirements, concerning yield pressure could not be applied to these actuators. It was suggested to complete a definition of an actuator yield pressure. The same suggestion concerned the definitions of a "stationary overflow valve", "internal valve" and a "bottom valve".
- It seemed to be worth considering an introduction of a correlation between the standard requirements and the requirements included in the 2006/42/EC Directive.
- In the Leakage Test there was a requirement of applying load for eleven minutes and in Annex B2 there was a requirement that the test time should last three minutes. As an assessment criterion one requirement should be met: "without external leakages".
- In the case of central axial load the range of applied pressure (from 1.1 to 0.1 maximum permissible working pressure) should be increased by a tolerance of ± 5% in analogy to the pressure during an application of eccentric load. The measured yield or extension force was agreed to be within +10% -5% of the rated leg or support ram force.

Draft Proposal pr **EN 1804-3 Standard**

- The yield of a pressure limiting valve, in the new draft standard, is hydraulic pressure to which a pressure limiting valve is adjusted and at which it should operate (pressure specified by manufacturer).
- As leaktightenss is concerned the following formulation of the requirement was proposed: valves shall be leaktight. Type A valves shall be leaktight to 95% of adjusted pressure.
- In the case of endurance test a pressure reduction to 10% of adjusted pressure (yield pressure) was accepted.
- Normative references should be updated. Several standards are mentioned e.g. EN 853, EN 854, EN 857. However, in each of them there is information that they do not concern underground mining. Hazards are classified according to EN 1050 which is out-of-date. It is indispensable to complete the new standard with the hazards/risk as in the EN ISO 12100 Standard. It was also recommended to consider an introduction of a correlation among the requirements included in the 2006/42/EC Directive.
- Values of pressures are given in bar instead of MPa.
- As regards the switching test a schematic diagram of each service part connections should be given.

4. Agreed changes in the EN 1804-1; 2; 3:2020 Standards

In the result of discussions among the Members of the Working Group 3 and consultations with the CEN representatives the changes were introduced into the final versions of the aforementioned standards.

In 2020, CEN/TC 196 "Mining machinery and equipment – Safety" finalized the revision of the EN 1804 series in support of the Machinery Directive (2006/42/EC) on "Safety requirements for hydraulic powered roof supports" which consists of three parts:

Final EN 1804-1:2020 Machines for underground mines - Safety requirements for hydraulic powered roof supports - Part 1: Support units and general requirements (approved 2020-12-23) versus EN 1804-1:2001+A1:2010

- Normative references were updated.
- List of significant hazards in Annex C was revised.

- Requirements for prop anchorages were deleted.
- Requirements for steel for welded components were updated and modified.
- List of tests for confirmation was updated.
- Acceptance criteria for test results were modified.
- Measurements and criteria for deformations after the test were added.
- Requirements for convergence test were modified.
- Cyclic fatigue test for canopy side shield was added.
- Figures, formulae and pictures were revised, modified and added.

Final EN 1804-2:2020 Machines for underground mines - Safety requirements for hydraulic powered roof supports - Part 2: Power set legs and rams (approved 2020-12-23) versus EN 1804-2:2001:2001+A1:2010

- Normative reverences were updated.
- Terms and definitions were modified.
- List of significant hazards in Annex C was revised.
- Requirements for steel were updated and modified.
- Requirements for static and dynamic overload were revised and modified.
- Requirements for overload in fully retracted conditions were deleted.
- List of tests in Annex B was updated.

Final EN 1804-3:2020 Machines for underground mines - Safety requirements for hydraulic powered roof supports - Part 3: Hydraulic and electrohydraulic control systems (approved 2020-12-23) versus EN 1804-3:2006+A1:2010

- Normative references were updated.
- Terms and definitions were revised, modified and enhanced.
- List of significant hazards in Annex B was revised and enhanced.
- Requirements for automatic hydraulic functions were deleted.
- Requirements for in- and inter-shield hose routing were added.
- Requirements for pipe and hose assemblies were updated.
- Requirements for type “A” valves were modified.
- Requirements for electrohydraulic control systems were added.
- List of verification tests was updated and enhanced.

According to the CEN procedures voting on the standards started on 30th July and it ended on 24th September 2020. The EN 1804-1; 2; 3 documents have been prepared by the Technical Committee CEN/TC196 “Mining Machines and equipment – Safety”, the secretariat of which is held by the DIN – Normenausschuss Maschinenbau (NAM). This European standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by June 2021, and conflicting national standards shall be withdrawn at the latest by June 2021.

5. Conclusions

A definition and implementation into use of uniform settlements in the scope of technical requirements on an international level undoubtly has a positive impact on a liquidation of technical barriers. It can be stated that the European Standardization activity serves gaining an optimum, in given circumstances, degree of settlements in the determined scope, as these standards are based on best practices. Their creation results from experience of stakeholders and they meet the requirements of the society and technology.

Where standards are developed in response to a standardization mandate from the European Commission and are listed in the Official Journal of the EU, they are deemed "harmonized", and give rise to the "presumption of conformity". Users of the standard can presume that by applying it, they satisfy the essential requirements of the EU directives covered by the standard. Where standards are up to date and reflect the state of the art, a high level of safety can be assured.

However, it is worth highlighting that meeting the essential safety requirements, described in directives and relevant standards, cannot be sufficient without exception to protect a manufacturer against claims resulting from his responsibility for a product. It should be borne in mind that in directives the basic requirements should be applied for a given product.

In 2020, CEN produced 1150 documents in which 982 European Standards can be found. The activities of the Technical Committee "Mining Machinery and Equipment – Safety" over the years 2017-2020 are presented in the article as an example of procedures oriented onto a formulation of European standards. The revision of EN 1804: Part 1 and Part 2 addresses the practical requirements of the test procedures. Uniform requirements are defined in the scope of designing as well as conducting tests. Due to such an approach the results of tests and analyses, in the fields connected with applying powered roof support in the mining industry, are reliable and precise. The EN 1804: Part 3 introduces requirements for electrohydraulic control systems, thus reflecting the introduction of new technologies. The authors of this article decided to share their knowledge and experience in a creation and a revision of standards to make the European standardization process easier to understand.

The European Standard EN 1804-1; 2; 3 shall be given the status of a national standard, either by a publication of an identical text or by an endorsement, at the latest by June 2021, and conflicting national standards shall be withdrawn at the latest by June 2021.

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Occupational health and safety management in hard coal mines in the aspect of dust hazard

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Abstract:

The article presents interdisciplinary knowledge on the management of occupational health and safety in hard coal mines with special attention paid to a control of the dust hazard. Shaping the safety culture is analyzed in the social, organizational and technical aspects. It should be borne in mind that accidents at work-places result not only from dangerous conditions but also from dangerous behaviours of workers. Shaping of safe work conditions in the mining industry is essential due to a high degree of complexity of technological processes and also due to natural hazards. In the article some information is given on the reasons of accidents in the coal mining industry. A model of the safety culture impact on a frequency of accidents and occupational diseases as well as the conditions for undertaking safe behaviours are discussed. It is highlighted that safety culture requires a complex approach oriented onto an investigation of relationships among: man-labour-environment. The article is ended with a description of the conception of occupational health and safety management in the aspect of dust hazards. It sorts out the knowledge and gives pragmatic guidelines, concerning the safety issues.

Keywords: work safety, work safety culture, work safety culture management, dust hazards

1. Introduction

Work safety management is a method of professional risk management in a given enterprise or organization. It is perceived as a process of taking decisions in the scope of considering the safety criteria and also as a process meeting the assumed state on an acceptable risk level by workers [1].

The occupational health and safety management in underground mine workings is regulated by the Decree of the Minister of Energy dated 23rd November 2016 on detailed requirements concerning conducting operations in underground mining plants [2]. The Decree regulates conducting operations in underground mining plants in the scope of occupational work and safety including an assessment and documenting of the professional risk and an application of indispensable solutions reducing this risk.

Among the research priorities in the scope of work safety in the EU-27 countries there were tests concerning shaping of occupational health and safety through an introduction of the occupational health and safety management, strengthening the role of the business social responsibility and a dissemination of scientific discoveries and examples of good practices [3]. A commonly known fact is that the occupational health and safety regulations constitute the law but life develops in its own rhythm. That is why the culture of occupational health and safety becomes so important, both from the point of view of the occupational health and safety as well as from the social aspect of work. Tests and analyses of reasons of experienced events indicate that most often an inabidance by elementary safety regulations, and in consequence a human error, lead to a disaster [4].

Accidents in work-places result from dangerous conditions and from dangerous behaviours. An approval of dangerous conditions, a permission for their existence and also taking and tolerating dangerous behaviours of co-workers is a symptom of low and unwelcome safety culture, contributing to accidents [5].

Undertaking activities in the scope of an identification and shaping work conditions in the mining industry is essential due to a high degree of complexity of technological processes. A big number of collaborating technical means, the people working in their direct vicinity, in difficult environmental conditions, require a consideration of a series of factors, which have a direct impact on work safety. An elaboration of new design solutions requires a series of analyses differentiated in relation to the work conditions as well as to the condition of technical means. Shaping of safe work conditions requires, in turn, an application of engineering tools as well as of the knowledge repositoria, enabling a quick implementation of developed methods [6].

2. Work safety culture in underground mines

Polish underground mining is characterized by complex geological and mining conditions and the occurrence of the natural hazards such as: methane, coal dust explosion, rock bursts, caves, fire, water, gas and rock outbursts and climatic.

The reasons of accidents in the coal mining industry differ in individual countries, what results from mining-and-geological conditions, conducted prevention and to a large extent from the level of the safety culture. In different countries the occupational health and safety management, whose part incorporates the safety culture, is on a very differentiated level. Safety management systems, implemented in most of the mines may be characterized by low efficiency, if simultaneously the workers' attitudes towards hazards and risks are not changed and if acceptable values are not connected with the behaviours being in compliance with the regulations and safety standards when a risky behaviour is not assessed negatively and treated as unwelcome.

According to 0 many accidents and incidents in a mine have a reason due to misunderstood regulations which are to prevent against an incident occurrence. The reasons include a lack of awareness or understanding, an ignorance or intentional breaking the rules. The tests, presented in the work 0, unianomously show that accidents are mainly caused because of a low training level of the occupational health and safety, and in consequence avoiding emergency barriers, insufficient trainings and a lack of equipment knowledge and additionally other factors creating the safety culture.

Another test, presenting 25 accidents in coal mines all over the world, showed that many incidents happened because miners 0:

- did not know the rules,
- were aware but did not understand the rules,

– followed the rules in an incorrect way,
– ignored the rules,
– intentionally broke the rules,
– took risk,
– were not capable of identifying dangerous situations,
– were badly trained or did not have sufficient education.

An impact of safety culture on an occurrence of accidents and occupational diseases shows the diagram below (Fig.1).

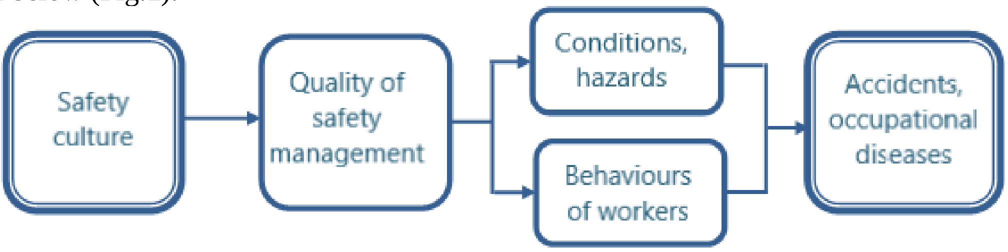

Fig. 1. Model of safety culture impact on a frequency of accidents and occupational diseases 0

In the work 0 an assumption was made that safety level of workers' behaviours is a function of possibilities and motivations (Fig. 2). The possibilities concern organizational aspects, facilitating an undertaking of safe or risky behaviours (efficiency of safety management systems and work organization) and subjective factors, i.e. workers' professional competences and competences connected with safety (knowledge of procedures, correct risk assessment, ability of hazards control, talents, abilities, personalities). Motivations for undertaking safe behaviours should encompass an internal necessity of acting according to the requirements of formal standards (resulting e.g. from a high level of safety in an individual hierarchy of values) attitudes towards the hazards standards, risks and formal safety standards as well as preferred patterns of behaviour.

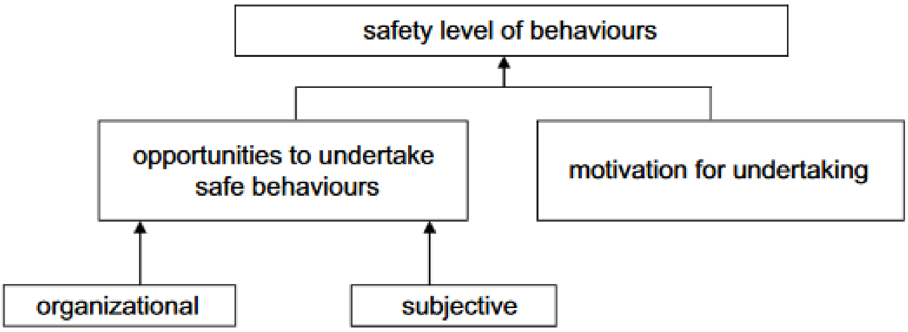

Fig. 2. Conditions for undertaking safe behaviours 0

The safety culture 0 in an enterprise is shaped by an involvement of all the workers, their work in groups and a feeling of belonging to the company as well as their proper education. Special attention should be paid to three elements:

– Work physical environment (tools, machines, organization of work-places).
– Behaviours of workers (compliance with occupational health and safety regulations, transmission of information and collaboration, demonstration of care as regards safety exceeding duties)
– Internal features of workers (knowledge, abilities, motivation).

Shaping the expected safety culture must be a continuous process because a real cultural change is difficult and it requires time. Technical and organizational activities 0 form frames for work safety culture. According to the state-of-the-art concepts of safety management, it is recommended to apply psychological actions (Fig. 3) apart from preventive technical and organizational actions. Beside the present technical-and-organizational activities, it is essential to equip people with knowledge, experience, but in particular with a motivation for undertaking safe behaviours and avoiding risks 0.

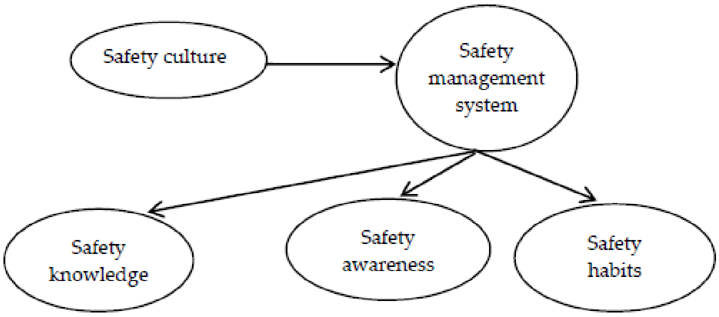

Fig. 3. Safety culture – aspects of assessment 0

Lack of social acceptance of work in the conditions threatening the health and life of workers can be seen more and more clearly. At present, technical means, used for an improvement of occupational health and safety, have achieved the level satisfactory enough, so the reasons of accidents (dangerous events) result mainly in the sphere of attitudes (behaviours) of the people engaged in the work processes. Due to that, human mistakes, reasons of their occurrence and potential consequences to which they can lead 0, are analyzed more and more often. In other words, apart from testing reasons and circumstances of accidents, the activities of preventive character, oriented onto testing of so called hazard potential (analyses of dangerous situations) caused by a human behavior, are undertaken. Apart from observing the occupational health and safety, it is extremely important to convey information and to collaborate as well as to demonstrate care of safety through motivating workers to observe the occupational health and safety regulations, making them aware of the consequences resulting from risky behaviours such as a hazard of losing health or life an also a dismissal from work. It lacks motivating techniques in mining plants, used in other branches of industry such as motorization or electronics. Recently imposing of objectives and an assessment of workers, among others with use of Kaizen programme [1], is one of popular methods used in these branches of industry. This method enables the workers to suggest improvements at their work-places and in their plant, for which they obtain additional points in periodic assessments. A use of this technique causes an involvements of workers in the activities of their organization and it has a positive impact on work organization. It also improves relationships among the managerial staff and the workers, supporting a construction of the workers' good attitudes and behaviours.

An assessment of the safety culture level is conducted mainly based on a survey among workers of all the positions 0-0. Six equal safety aspects, as regards their weight factor such as: values in the scope of safety, relationships among workers and affiliation to the company, responsibility and awareness in the scope of occupational health and safety, safe behaviours, an involvement of the managerial staff and a participation of workers as well as occupational health and safety trainings and analyses of accidents, were used in one of such tests 0. An assessment of the culture level of work safety was determined as an average of these assessments (Fig. 4).

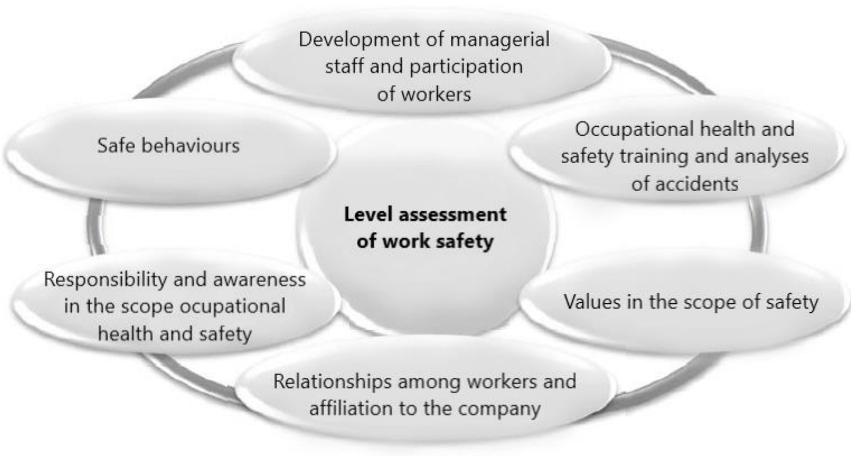

Fig. 4. Safety culture in an enterprise – aspects of assessment [17]

The assessment results showed that in the enterprises with the implemented certified and formalized system of the occupational health and safety management, the level of work safety culture was higher than in those which did not implement the management systems. A higher assessment of the level of work safety culture is related to all the aspects. Simultaneously it can be seen that irrespective of implementing the management system of occupational health and safety, the occupational health and safety trainings and analyses of accidents were assessed in the lowest way.

3. Hazards caused by dust

The content of dust in the air is one of the biggest hazards, occurring in hard coal mines. It is generated in the result of mining seams and driving roadways. Coal dust has explosive properties and in the determined conditions it may cause a disaster, whereas rock dust has a harmful impact on human respiratory system, contributing to pneumoconiosis. Both kinds of dust occur in the mine air simultaneously but in different proportions and concentrations 0.

As regards rock dust, a long-term exposure of the respiratory system to this dust causes pneumoconiosis which belongs to the oldest occupational diseases and it is inseparatebly connected with the mining industry. Pneumoconiosis is defined as an accumulation of dust in lungs and a reaction of the lung tissue to its presence. This disease is caused, inter alia, in the result of breathing in, by a miner, of dust generated during a drivage of coal and stone workings and mining of hard coal 0.

The workers, employed at work-places, where there is a hazard of harmful dusts (containing free silica), are equipped with appropriate means of individual protection of respiratory tract, adapted to the size of the occurring hazard and meeting the requirements of the Act from 13th April 2016 on systems of conformity assessment and market supervision (Official Gazette, Item 542, 1228 and 1579 as well as from 2017, Item 1089).

A selection of means for an individual protection of respiratory tract is executed for individual work-places, based on measurements results of dust concentrations in the air, conducted during the technological process generating the biggest amount of dust (CIP-10 dustmeters, Barbara 3A dustmeters and AP-2000EX type aspirators). In mining plants, exploiting hard coal, workers employed at work-places, where the highest permissible concentrations of dust are exceeded, have a possibility and a duty of using single use half-masks or multi-use masks completed with cleaning elements – filters of appropriate protective class (P-1, P-2, P-3 classes).

An anti-dust mask should protect the worker's respiratory system and it should be comfortable for wearing and breathing. An incorrectly selected anti-dust mask may cause breathing difficulties and cause a hazard of loosening or an accelerated tiredness due to breathing. A relinquishment of using masks may have a negative impact on health after a significantly longer period of time, even a dozen years or so.

The values of the highest permissible dust concentrations can be accepted as a criterion for an assessment of occupational risk as regards an exposure to dusts. The PN-ISO7708:2001 Standard gives definitions of dust fractions used for an assessment of health hazard:

- total dust – all the particles contained in a determined volume of air,
- inhaled dust – a part of the total dust mass breathed in by nose and mouth. Additionally, respirable dust is distinguished which is a part of the inhaled dust reaching the direct part of respiratory tract.

Hard coal mines, collaborating with the entities supervising work safety and with research organizations, conduct expanded activities oriented onto a reduction of dust in the air of mining plants, protecting the people against its harmful impact 0. It is assessed that in the year 2019 3800 miners working in longwalls, and 1150 miners working in roadway drivage experienced an impact of harmful dusts. According to the State Mining Authority, which conducted its own statistics **Błąd! Nie można odnaleźć źródła odwołania.** of pneumoconiosis rates in active hard coal mines over the years 2015-2019, despite of the increase in 2019 from 4 to 9 cases concerning professionally active workers and from 131 to 145 cases concerning ex-workers, a decreasing trend is maintained.

4. Technical and organizational means preventing dangers in the aspect of dust hazards

An efficiency of activities, oriented onto an improvement of workers safety and health protection, requires their conducting within the framework of well-ordered management system implemented in these organizations. The International Labour Organization defines the management system of occupational health and safety as a system of interconnected and interacting elements serving an establishment of the policy and objectives of occupational health and safety and an achievement of these objectives.

This system requires a broader approach to the issues of occupational health and safety – a complex approach requiring a look at the system: man-labour-environment. Safe labour conditions and safe behaviours do not appear autonomously. A correct management is the most efficient way of ensuring appropriately high level of occupational health and safety. The management of occupational health and safety is an element of the Integrated Management System implemented in each of the Polish mining companies 0-0. Within the framework of the System the activities, oriented onto a maximization of protecting workers against hazards, are conducted. The common element of creating and implementing the Integrated Management System by mining enterprises is a so called social responsibility.

A creation and implementation of the management system of occupational health and safety is only the first step towards an improvement of occupational health and safety in an organization. This system must be supervised, i.e. monitored to operate efficiently. It must be subject to controls and audits. Such an audit concerns an assessment of work safety level and of activities, undertaken by the organization leading to a reduction of hazards and a reduction of the occupational risk level. The basic task of audit is a total assessment of the system of work safety functioning and detecting potential infringements of managing staffs and an elimination of these mistakes.

The first element in the process of reducing, inter alia, of the dust hazard, includes trainings in the scope of compliance with the rules and standards, concerning occupational health and safety at work-places. One of the basic legal acts, regulating this issue is the Decree of the Minister of Economy and Labour from 27th July 2004 on training in the scope of occupational health and safety. The basic trainings include: introductory training and periodic training. Introductory training is indispensable before allowing a worker to start his work. It consists of two stages: general training and work-place training. Work-place training is conducted for each employee at his work-place, where a hazard resulting from harmful, arduous or dangerous factors, occur.

It is also conducted for a worker who is transferred to a new work-place. A worker, doing his work at a few work-places, should have work-place trainings on each of these work-places. However, in the case of organizational changes at the work-place or changes of the technological process, the worker employed at this work-place must have a work-place training again in the changed labour conditions. The objective of periodic training consists in up-dating and grounding of knowledge in the scope of occupational health and safety and getting the training participants acquainted with new technical-and-organizational solutions in the scope of occupational health and safety.

The knowledge transfer to workers is not limited only to periodic trainings, but it is also realized in a continuous mode, using different forms of knowledge presentations. A training efficiency depends, to a big extent, on its form, so mining plans started to use Internet as a medium enabling a knowledge transfer. It is oriented onto increasing an involvement of trainings participants and thus absorbing a bigger amount of information by them. An availability of the internet platform to the workers does not cause itself an increase of the involvement in the learning process. A motivation for learning is very important. Therefore, the occupational health and safety as well as trainings departments organize competitions in the scope of knowledge of occupational health and safety regulations, in which attractive prizes are given. It causes an increase of the workers' interest in this kind of platforms and has a positive impact on their involvement in the process of a continuous improvement due to deepening of knowledge 0. For example in the first stage of the competition "I work safely", lasting from April till the end of September 2020 the workers of the PGG Company solved 215 thousand tests, which included 6.5 million questions projected on the screens 0.

Correct behaviours at work-places may be also shaped by schooling films, which are used during trainings. They are developed most often on the basis of a real event and show an impact of a dangerous behaviour on health or life. These films also serve for gaining knowledge, how a worker should behave in the case of a dangerous event occurrence.

As regards shaping of safety in the scope of dust hazards, it is inadmissible to use machines and equipment which generate dust in technological processes and they are not equipped with efficiently operating devices, reducing dustiness and inefficient devices and means used for a reduction of dust concentration in the air. Designing of such devices must take into consideration work comfort of their future users. It is inadmissible to use solutions which decrease work comfort, leading to their intentional switching off.

The basic corrective measures, which reduce dust in mines, also include spraying installations of longwall shearers and roadheaders. Although they are applied obligatorily in all the cutting machines, they rarely enable to reduce dustiness to the values below the highest permissible concentrations.

Dust control equipment and spraying installations are usually located in the areas of 0:

- cutting machines (on cutting drums and cutting heads),
- canopies of powered roof supports,
- run-of-mine transfer areas of conveyors,
- in roadways – as safety barriers,
- as a part of a ventilation system.

Water, low pressure spraying installations, supplied directly from the fire-pipelines achieve a small degree of water spraying through the nozzles at the water output in the range of 10 dm^3/min. Additionally, they often impede activities of the workers in the area of transfer points, which results in their intentional switching off. An optimization of water consumption, in relation to the achieved effect, is very important because an increase of the water amount may not give the effect of dust reduction. It is essential to conduct tests of the optimum location of spraying installations before their placing in the areas of the ventilation air stream 0. Due to the fact that an excessive amount of water should not make the work more difficult, in each individual case it is needed to establish a proper water flow intensity, build the installation correctly and condition its operation e.g. on an operation of the conveyor or on a presence of the feed on the belt or on the dust concentration, controlling the spraying installation by the dust sensor.

In recent years air-and-water systems, using the pressure of compressed air for a generation of mixture and spraying of the water stream to droplets of very small diameters, find more and more broad applications for a reduction of dustiness in hard coal mining industry. This type of spraying is characterized by a big efficiency of dust reduction and one of the leaders of such an approach is the KOMAG Institute 0, where the majority of air-and-water spraying installations, functioning in the Polish mining industry, have been designed.

The first spraying systems of such a type have been designed for longwall shearers. After having conducted stand and exploitational tests, they were implemented in mines. These implementations enabled to confirm their higher efficiency in comparison with the systems used so far.

Problems with exceeding dust concentrations in the air also occur in roadway faces. There are many solutions of internal and external water spraying installations for roadheaders. The first ones are characterized by a big degree of complications and high maintenance requirements and the other ones – by a low efficiency of dust reduction.

An alternative is an external, air- and- water spraying installation ensuring an efficient protection of the cutting process against methane ignition and a high efficiency of dust reduction. This installation operates on a similar principle as the installations developed at the KOMAG Institute, which are described above 0.

Apart from longwall shearers and roadheaders the air- and water spraying installation of the BRYZA type is used for a dust reduction in roadway workings of mines. Another possibility of using this solution concerns transfer points of conveyors, where too big dustiness is a real problem. In the case of conveyors, transporting the-run-of-mine, it is most essential to apply the spraying stream directly to the place, where the biggest amount of dust is generated during a discharge of the-run-of-mine from one conveyor to the other one. These installations have an efficiency of about 70% as regards dust reduction 0.

The last solution, discussed in the article, is dedicated for use in exploitational longwalls. It is a spraying installation of selective operation in the spot, where the cutting machine, generating dust, appears. Its design solution consists in a construction of spraying batteries on selected powered roof support units, along the whole longwall and in a generation of the air- and- water mixture in the zone of dust laden air in the result of a longwall shearer operation 0.

5. Conception of occupational health and safety management in the aspect of dust hazard

Occupational health and safety management in the aspect of dust hazards, both rock ones as well as coal ones, should be started and ended with the safety culture. Introductory trainings as well as those at work-place must be designed in an interesting and attractive way. An application of computer methods for shaping safe labour conditions is a requirement of our times. A typical lecture, as the basic form of training, has become an inefficient tool. The available IT solutions enable to stimulate to activity the participants of trainings, using inter-active games or ensuring an interesting form of the knowledge transfer through e.g. a presentation of an accident reconstruction, using computer animations. The developed materials take into consideration a change in the way of thinking of the young generation 0. Following this path, it should be borne In mind that designing of means and devices for a protection against excessive dust must take into consideration work comfort of a future user. Starting from the means of individual protection of respiratory tract, which apart from a correct selection to the kind of threat should be adjusted to the worker, who should have knowledge about their wearing and using in the way, ensuring their efficiency. In the case of designing machines and equipment, the designers, due to a development of IT tools have broad possibilities of assessing the developed design solutions with use of ergonomic analyses. They can evaluate not only an efficiency of designed solutions, but also an impact of the solution on servicing machines and equipment. Designed solutions cannot cause arduousness, because then they will be intentionally ignored by the personnel.

Summing up, the safety model must contain technical and organizational activities based on the occupational health and safety regulations in power. These activities must be reflected in all the available types of trainings, in work-place trainings, theoretical ones and practical trainings at work-places, taking into consideration available knowledge and technical means. A creation of safe labour conditions must predict equipping work-places with protective means both of personal protection (half-mask), as well as devices or infrastructure, ensuring a safe work environment (e.g. spraying or dust control installations). Ensuring the proper level of safety should be realized with use of remote monitoring of the hazard level or cyclic controls performed by servicemen, monitoring the mine safety conditions or by the staff, supervising the work in hazardous areas. A prevention at work-places is essential because e.g. by using proper exploitation, ventilation system or by protecting against generating dust by haulage equipment (Fig. 5), the hazards can be controlled.

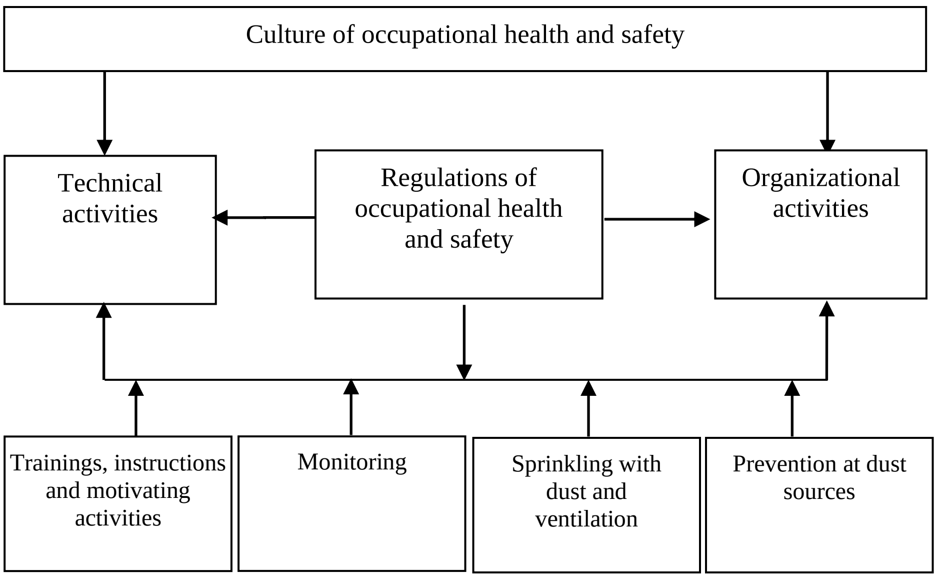

Fig. 5. Complex model of safety culture in the aspect of dust hazard (own work).

A hazardous condition is usually generated, when more than one of the factors, included in the complex model of work safety, are neglected and active functioning of all its elements guarantees the work safety level which has no negative impact on a worker's health in a hazardous work environment.

6. Conclusions

The mining industry should be characterized by high safety culture because it is an industry which is most dependent on natural conditions and an unseparable element of its functioning includes many hazards to health and life of workers. Dust hazard occurs in each mine nearly in all the areas both in the exploitational ones as well as in the processing ones. Work safety management in the aspect of dust hazard consists of a series of means starting from trainings, through personal protection means and ending with equipping machines and devices with installations reducing dust in the ventilation air. The regulations establish the majority of issues in the scope of individual protection means as well as of monitoring. The superintendent of the mining plant decides about equipping machines and devices with installations along the whole route from the place of the-run-of-mine cutting to its exit from the preparation plant. In the Polish mines the trend of pneumoconiosis cases is still significant, although it decreases year to year. It is connected both with a reduction of coal production, as well as with use of more and more innovative installations, designed by research institutes. A dissemination of scientific discoveries is in accordance with the research priorities from the scope of occupational health and safety in the EU-27 countries.

In an enterprise not only employers or designated staff should be responsible for the matters of occupational health and safety but all the workers should perceive the occupational health and safety issues in the categories of rights which they are entitled to, but mainly duties or simply an absolute necessity. The safety level of workers, employed in a given enterprise, depends on the safety culture in it. Therefore, it is extremely important to equip people mainly with the knowledge about hazards and about their behaviour in the conditions, threatening their health and life.

A generation of regulations, concerning the issues of occupational health and safety and an application of innovative solutions, improving work safety, will be successful if the people become aware and convinced of the advantages resulting from a use of certain equipment and about complying with the occupational health and safety regulations. Such an approach is connected with a continuous increase of the safety culture level. Such initiatives as competitions, organized by the Polish mining companies (PGG S.A. - I work safely, JSW S.A. – Competition on the knowledge of occupational health and safety principles and regulations for the Cup of the Chairman of Jastrzębska Spółka Węglowa S.A, LW BOGDANKA – Safe Mining), motivate for deepening knowledge on the principles of safe work and for using this knowledge in everyday life. It is inadmissible to mention lack of using the required individual protection means by the workers or intentional switching off the spraying installations as reasons and circumstances of accidents connected with dust hazards.

A development and use of newer and newer safety management models, which contain experience resulting from the technical solutions functioning up till the present time and beneficiate from new technical solutions and developed management models, may contribute significally to a further increase of the safety level.

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Concept of a Drill Press Rotary Tool Workstation Stand with a strength analysis

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Abstract:

Comparative analysis of the strength properties of a drill stand intended for a power tool made by the selected manufacturer and the stand of own design is the paper subject. The specifics of high-speed power tools as well as their capabilities, practical applications and limitations are described. The design of a commercially available drill stand for a drill press rotary tool is presented. Basic issues in the field of CAD modelling, as well as the most important concepts related to the finite element method, as well as the stages of strength analysis using the above-mentioned method, are presented. Based on the simplified model and the analysis of the presented stand, a CAD model of a drill press stand, designed in accordance with own alternative concept is given. Results of the analysis of the static stiffness of both models using the finite element method and the conclusions drawn on this basis are presented.

Keywords: drill stand, power tools, FEM analysis, static stiffness, CAD

1. Introduction

High-speed power tools are compact, hand-operated electric tools designed for minor machining work. Versatility is their most important feature. Wide range of auxiliary accessories extends the device's capability, so the following operations are possible [1]:

- drilling,
- cutting,
- carving,
- engraving,
- milling,
- grinding,
- sharpening,
- sanding,
- polishing.

Due to the manual control of drill pressed rotary tools, it is impossible to drill precisely without the use of additional accessories. For this reason, such power tools are usually combined with stands. An example of a drill stand is shown in Fig. 1.

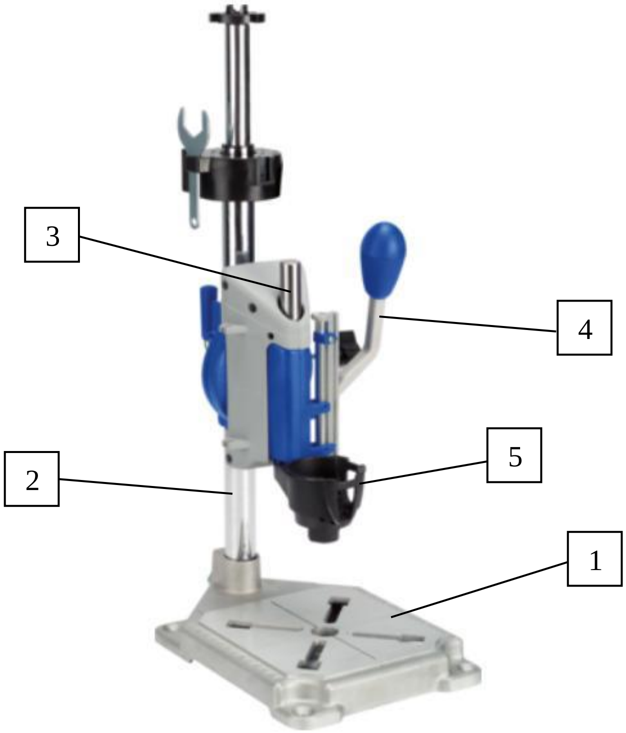

Fig. 1. The drill stand of 220 type [1]:
1 – base, 2 – telescopic column, 3 – rack and pinion mechanism,
4 – lever, 5 – tool holder

The 220-type stand consists of an aluminum base bolted to the base of a working area of dimensions 143x153 mm, on which the workpiece is mounted. The base is connected to a telescopic stand to adjust the height of the power tool by unscrewing the bolt, moving the handle and tightening it. The rack and pinion mechanism enables moving the drill. Pulling the lever down rotates the gears and lowers the tool holder. The return spring brings the tool to its original position, when the lever is released. Drill press rotary tool is screwed to the tool holder by a threaded head of the device. The maximum feed of the mechanism is 50 mm and it is adjustable. A large part of the construction components, including the tool holder, are made of plastic [1].

A simplified CAD model of the discussed drill stand (Fig. 1), developed for the purpose of static analysis is shown in Fig. 2. Structure and geometrical features of the 220 type drill stand, were measured and recreated in the model.

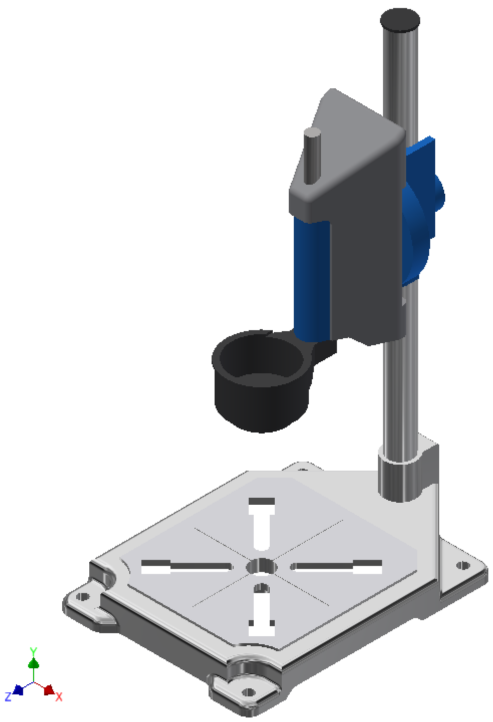

Fig. 2. Simplified CAD model of 220-type stand [12]

2. Materials and Methods

Development of advanced computer technologies led to creation of Computer Integrated Manufacturing (CIM), which resulted in shortening of production cycles and an increase in the degree of utilisation of manufacturing potential. Computer Aided Design (CAD), which supports technical design processes through the use of specialized computer software is one of the basic CIM subsystems. Following processes are aided [2,3]:

- geometric modelling,
- strength analysis,
- creation and development of technical documentation based on the model,
- development of technological documentation,
- prototyping, simulations.

CAD software allows the creation of digital geometric models. The model is expressed by geometric elements consisting of a series of points. Each point has specific coordinates in the adopted coordinate system. The geometric element can be a single point, line, area, or a solid. Digital models present structural form of the product. The product may be a simple element consisting of one object or an extended unit consisting of many interconnected objects [3].

The finite element method is one of the basic tools used in engineering calculations. It is an advanced method of numerical solving of boundary problems, used already at the designing stage for structural strength analysis and simulation of displacements, deformations, stresses, heat and fluid flow. The method consists in using a digital CAD model of a structure to build a discrete model for the needs of strength analysis [4,5]. There are the following stages of the method [5,6]:

- division of the analyzed area into finite elements connected by nodes,

- specification of the element and approximate solution for each of the elements (selection of approximate method, selection of interpolating functions, determination of the algebraic equation system of the tested element),
- creating one system of algebraic equations of the tested element based on the equations of elements taking into account continuity between them,
- equation of boundary conditions of the entire system,
- solution of the created system of equations,
- calculation of values dependent on the determined discrete values.

A model which surface is divided into confined sub-areas called finite elements is known as a discrete model. Finite elements form a mesh that covers the entire model. The mesh density depends on the number of finite elements it has and it significantly impacts the results accuracy. As the mesh density increases, the accuracy of analysis also increases, but also time required for calculation and the demand for computing power increases. It is possible to densify only a certain area of the mesh in the key places of the structure. Some simplifications of the model structure details, which are irrelevant to the results of analysis and significantly extending process duration are often applied to the discrete model [7, 8, 9].

A finite element is a separated fragment of a structure that connects with other finite elements in nodes. Nodes are the points that define the geometry of each finite element. The number of nodes in each finite element depends on the geometrical shape of the element, and each node may belong to several finite elements at the same time [4,10]. There are many types of finite elements. The criteria that characterise the features of each type of element are as follows [11]:

- element dimension: one-dimensional, two-dimensional, three-dimensional,
- geometric shape: point, segment, triangular, quadrilateral, polygonal, tetrahedral, pentagonal, cuboid, axisymmetric,
- type and polynomial degree of the assumed shape function,
- number of nodes in the element,
- general constraints imposed on the element.

The concept of FEM is based on the use of a discrete model divided into sub-areas defining the sets of continuous functions to approximate any continuous function. This translates into a significant simplification of analytical processes as differential equations are replaced by algebraic equations [4]. By the use of finite elements during the analysis, it is possible to replace complicated calculations with algebraic functions of the displacement field. Most often they are low-degree polynomials [10].

It is assumed that the measure of the structure stiffness - in the case of a drill stand - significantly affecting the accuracy of machining, is the stiffness index - j, determined from the relationship (1):

$$j = \frac{P}{f_{max}} \tag{1}$$

where:

j – stiffness index [N/µm],
P – force [N],
f_{max} – maximum displacement [µm].

The concept of stiffness index was used in this publication for a comparative analysis of drill stands of various designs.

3. Results: the concept of a drill stand

Analysis of designs and functional features of drill stands available on the market, in particular the drill stand shown in Fig. 1, enabled developing the own concept of this device, presented in detail in [12]. When designing the drill stand, the following assumptions were made:

- The stand is made of as many as possible commercially available components.

- The power tool feed mechanism is designed to ensure smooth movement of the required length.
- The materials selected for each component of the stand are to ensure the highest possible stiffness of the entire structure, which affects the accuracy of the drilled holes.

Final design is presented in Fig. 3.

The base of the stand is made of milled aluminium sheet. As in the 220 type stand (Fig. 1), it is possible to screw the base to the floor. There are also mounting holes on the surface of the metal sheet, needed to screw the stand column in the form of a square tube. The work table, of dimensions 195x130 mm, has grooves for fixing the workpiece and a hole for drilling that prevents the drill from contacting with the base when drilling outlets. The feed mechanism is based on the cooperation of a rapezoidal screw with a nut. The end of the screw is seated in a flange bearing bolted to the base

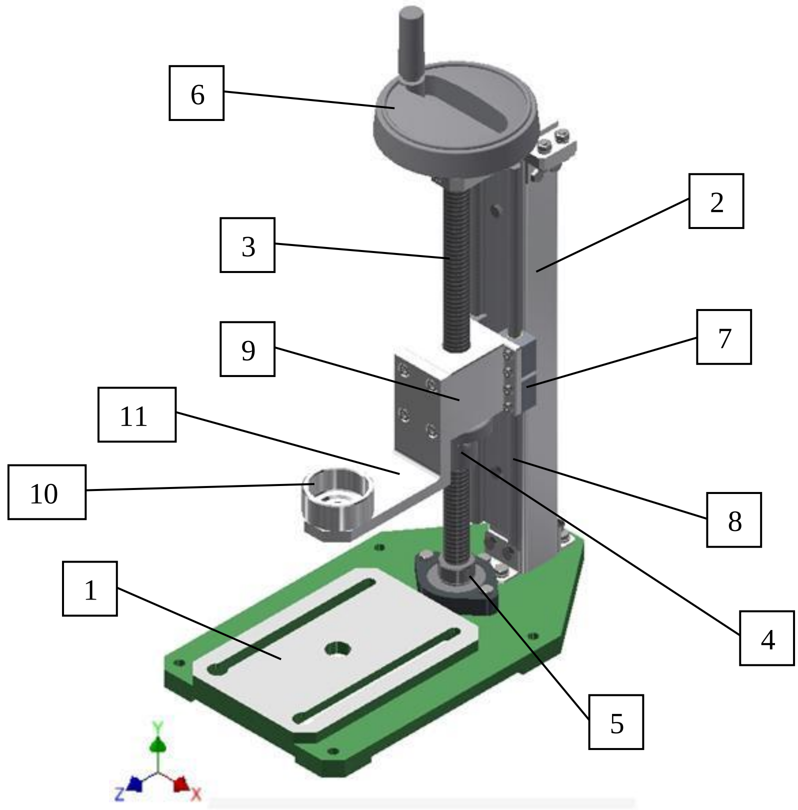

Fig. 3. Model of the drill stand of own design [12]:
1 – base, 2 – stand, 3 – trapezoidal screw, 4 – nut with a trapezoid tread, 5 – flange bearing, 6 – hand wheel, 7 – linear bearing, 8 – double-sided guide, 9 – connector, 10 – tool holder, 11 – holder arm

The base of the stand is made of milled aluminium sheet. As in the 220 type stand (Fig. 1), it is possible to screw the base to the floor. There are also mounting holes on the surface of the metal sheet, needed to screw the stand column in the form of a square tube. The work table, of dimensions 195x130 mm, has grooves for fixing the workpiece and a hole for drilling that prevents the drill from contacting with the base when drilling outlets. The feed mechanism is based on the cooperation of a trapezoidal screw with a nut. The end of the screw is seated in a flange bearing bolted to the base. There is a handwheel at the other end. By turning the wheel, the operator rotates the bolt, as a result of which the nut mounted on the bolt moves linearly up or down, depending on the direction of the screw rotation. Such a movement of the nut is possible thanks to four linear bearings, cooperating with a double-sided guide of a circular profile, which were screwed with the nut by an aluminium element. As the stand is supposed to work together with power tools of a given brand, a threaded hole in the handle of the stand is provided for mounting the device, matching the thread in the head of the tool. The tool handle is screwed into the hole of the arm made of a fragment of the angle bar. The maximum height at which the drill can be place is 245 mm. The overall dimensions of the structure are 190x340x523 mm [12].

Rigidity is an important property of a drill stand, significantly affecting its functional features. Taking the above into account, the own stand and the 220 type stand models were compared for the static stiffness. The calculations included the materials of both structures. In the case of a own stand, most of the elements were made of aluminium, while the structure of the type 220 stand consisted of steel and plastic elements. It was assumed that the drill is at a height of 115 mm from the working area of the stand base, and the force loading the model is 10N. The place and direction of the force applied is shown in Fig. 4 [12].

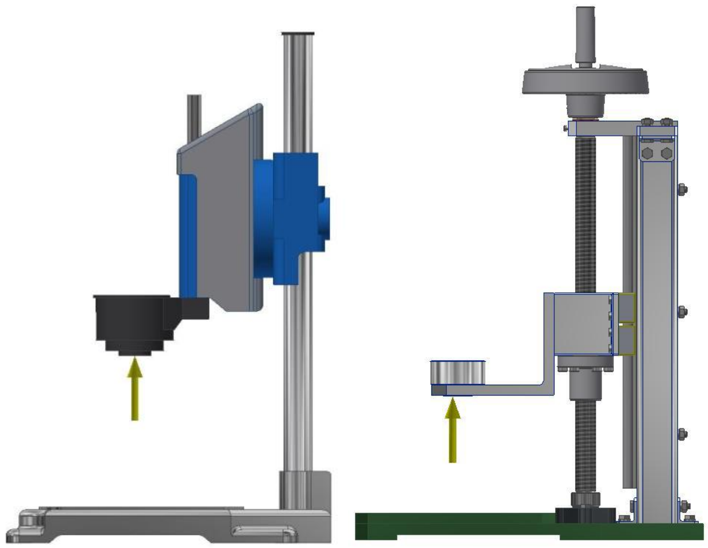

Fig. 4. Place and direction of applying force to both models [12]

In Fig. 5 the removed degrees of freedom of the stand models are schematically marked.

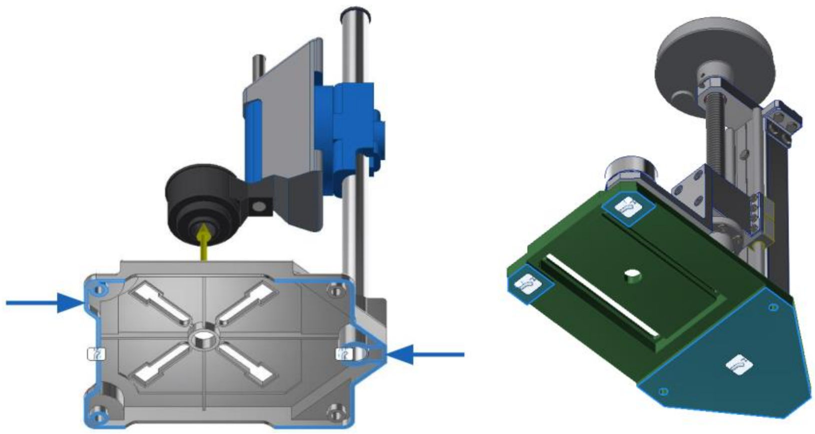

Fig. 5. Places of removing all degrees of freedom in the models are marked in blue [12]

The next stage of the static analysis was to discretize the models. Too low density of the mesh could result in a significant error, while with the increase in density, the duration of the calculations would significantly increase. For this reason, several calculation attempts were made for various mesh parameters to estimate its optimal compaction. Additionally, in the places, where the greatest stresses are predicted, the mesh was compacted. The mesh consists of triangular three-node finite elements (Fig. 6) [4,8,12].

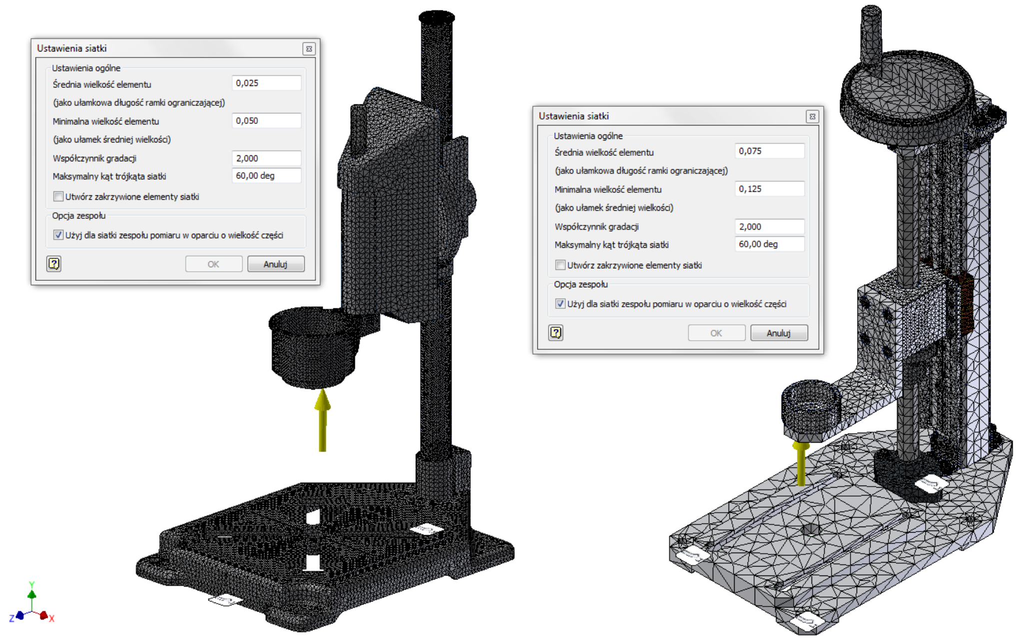

Fig 6. Finite elements mesh of the stand model [12]

As a result of the analysis, it was found that in both models the highest stresses caused by the given force arose within the tool holder arm. In the case of the 220-type stand model, the maximum stress was 3.2 MPa, while for our own design, it was 5.1MPa (Fig. 7-8) [12].

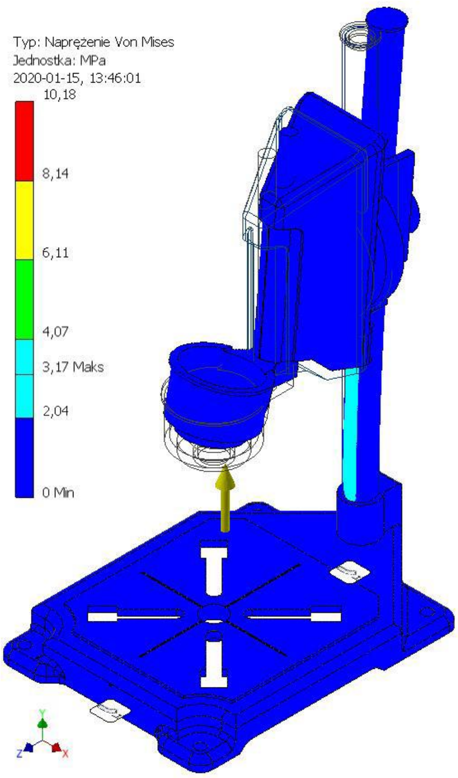

Fig. 7. Distribution of stresses on 220-type stand model according to the Huber hypothesis [12]

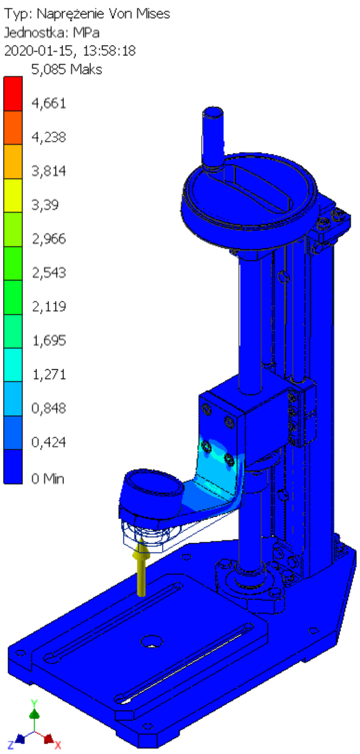

Fig. 8. Distribution of stresses on own developed stand model according to the Huber hypothesis [12]

In the case of the displacement analysis for the 220-type stand model, the greatest total displacements were recorded at the tool holder and in the upper part of the stand. The maximum total displacement was 0.156 mm (Fig. 9). For the stand model of own design, displacements appeared only on the tool holder and the holder arm. The maximum total displacement was 0.03 mm (Fig.10) [12].

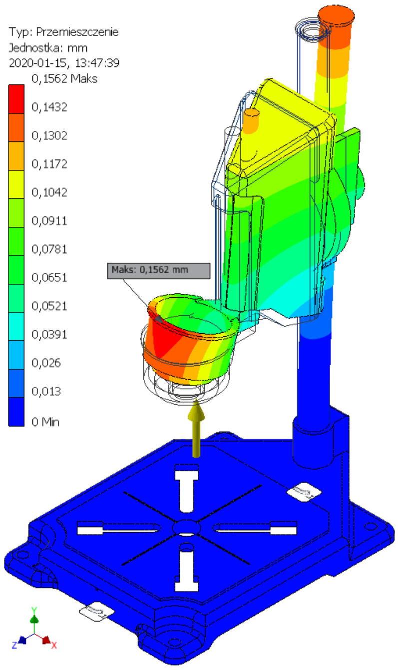

Fig. 9. Total displacements on 220-type stand model [12]

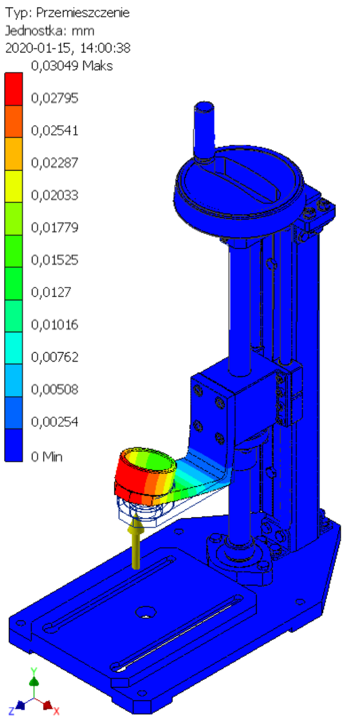

Fig. 10. Total displacements on the stand model of own design [12]

Using the formula (1), the static stiffness index in the direction of the loading force along the Y axis of the coordinate system for both analysed models of the stand was determined. For the 220-type stand model, the maximum displacement in relation to the Y axis was 0.146 mm, and the stiffness index was 0.068 N/µm (Fig. 11). For the stand of own design, the maximum displacement in relation to the Y axis was 0.03 mm and the stiffness index was 0.332 N/µm (Fig. 11) [12].

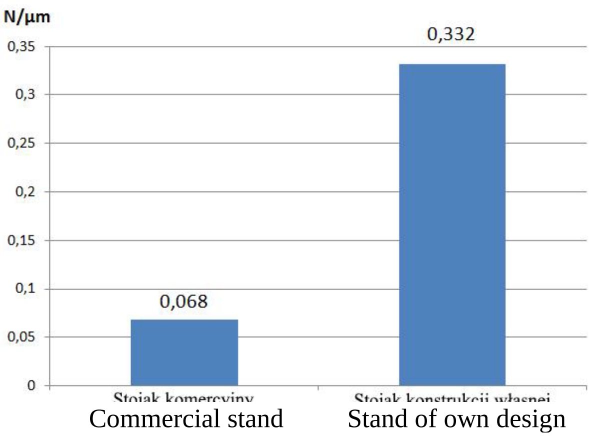

Fig. 11. Bar graph of the stiffness index in a direction of force action for both models [12]

4. Conclusions

The CAD models enabled analysis of the static stiffness, the results of which showed that the use of stronger materials and a stand of a bigger cross-section surface area resulted in significantly better strength parameters. The stiffness index was almost five times higher than in the case of existing stand. The analysis allowed to specify the areas with the greatest stresses and the elements with the greatest displacements when drilling, what would affect the machining accuracy. In the case of the custom-made stand, arm with the tool holder attached was the element most susceptible to displacement and greatest stress. However, the displacements and stresses were so small that it was not necessary to modify the structure. The use of the finite element method allowed to verify and compare the strength of the structure of both models at the designing stage. If structural modifications were necessary, the method would reduce designing costs and time, as there is no need to make a test stand prototype model.

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