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Results of stress measurements on the guide rail supporting beams in a hoisting installation operated in the shaft Regis in relation to modelling data

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Abstract:

Presently the hoisting installation operated in the Wieliczka Salt Mine is mostly used for transporting visitors to the underground mine sections. It comprises two elevators which are able to effectively transport groups of up to 42 people during a single ride. Design objectives developed prior to its mounting at the shaft bottom and observations made by maintenance engineers clearly indicate that the guiding system in the shaft is very stiff and so deformations are in fact negligible. The components of the guiding system which have the highest stiffness are bunton beams, designed in accordance with pertinent regulations having relevance to hoisting installations.

To verify the rationale of implementing the stiff steelwork frame, the digital model of the steelwork frame was created and numerical procedures were applied, taking into account the maximal design loads and operational loads. Numerical results were validated through measurements of real stress values at selected components of the guiding system in the hoisting installation operated in the shaft "Regis", under variable operating conditions. The analysis of measurement data allows a preliminary evaluation of structural parameters of the car frame, highlighting the potential of reducing the mass of components selected to be optimised.

Keywords: measurements, mine hoist, FEM, stress, shaft steelwork

1. Introduction

The full technical specification of the hoisting installation operated in the shaft “Regis” is provided in the article contributed to the KOMTECH 2021 conference materials [1]. The arrangement of two identical shaft-mounted elevators offers the lift capacity similar to that of the mine hoist operated in the shaft “Daniłowicz”. Besides, the energy demand is reduced (shaft “Regis”-0.08 kWh/person; shaft “Daniłowicz”- 0.11 kWh/person) and the operation and maintenance costs of the elevators, unlike the mine hoists, do not require extra staff as operators.

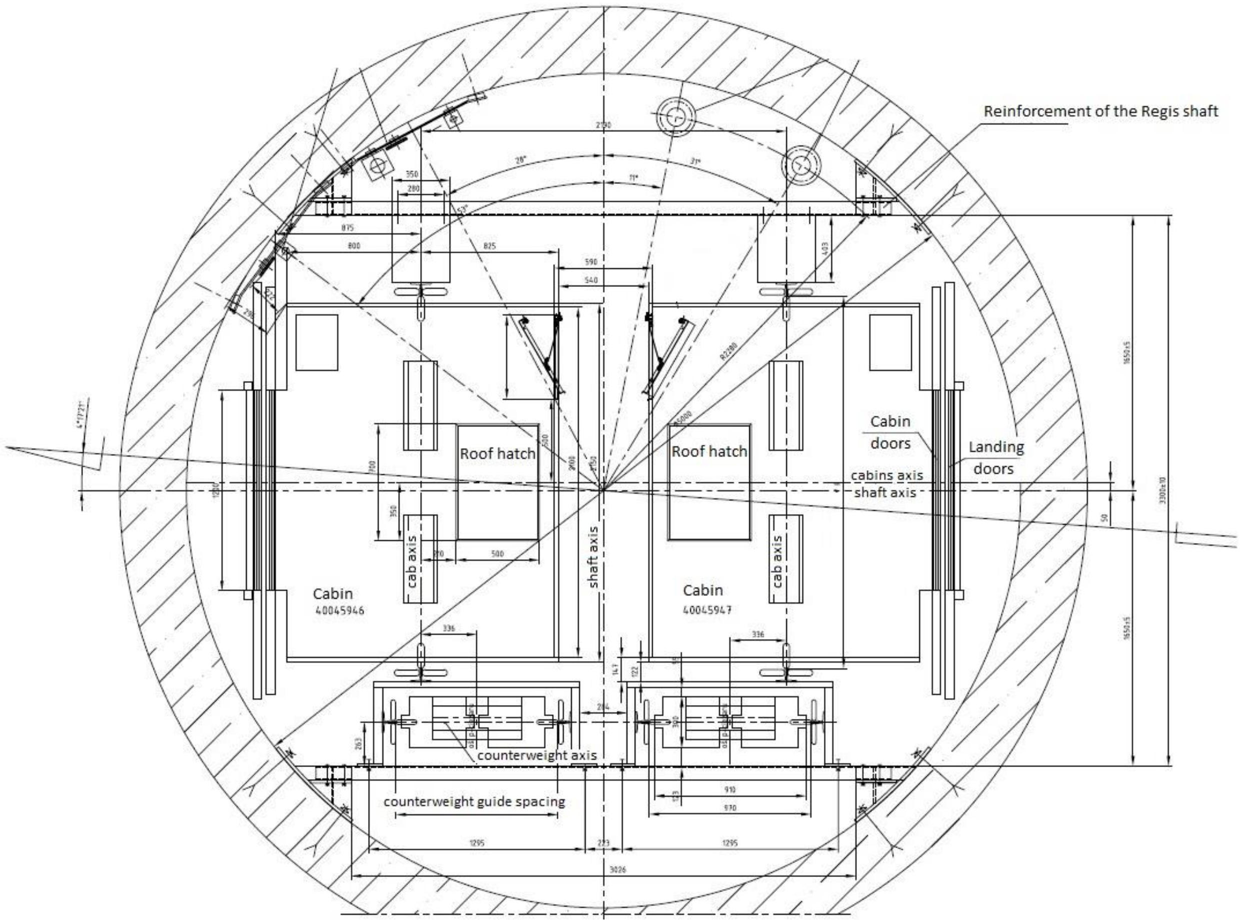

Fig. 1. Cross-section of the Regis shaft with wall-mounted equipment [2]

2. Analysis and modelling of buntons and supporting beams

Basing on the available engineering and technical specifications of the elevators and using the data from the inventory-taking in the shaft “Regis’, the 3D models were created of buntons and beams supporting T-guide rails T125x82x16B, machined. The modelled guiding system comprises a beam with symmetrical brackets used for mounting the column of guide rails upon which the elevator can travel.

Two variants were considered in the modelling and analysis. In the first variant the existing bunton structure is analysed, comprising a c-profile C 240 with the mass of 115 kg. The second variant considered was that of a modified bunton (with its mass reduced) in the form of a c-profile C120 weighing about 46 kg [3]. The static analysis was supported by Autodesk Nastran 2021 software. Fig. 2 shows a 3D model of the bunton in its east-side section with brackets for mounting the guide rails, and the system of maximal acting forces (design loads) due to the release of the catching device [4].

The bunton was designed and fabricated from structural steel (a carbon steel), in the form of rolled c-profiles made of steel grade S355J2 (yield strength Re=355 MPa, tensile strength Rm= 470 MPa). According to endurance limits and fatigue stress data [5], [6], endurance limit for steel S355 is given as:

- Zgo- 170 MPa (endurance limit under cyclically repeated bending load).
- Zco- 130 MPa (endurance limit under cyclically repeated tensile load).
- Zso- 100 MPa (endurance limit under cyclic torsional load).

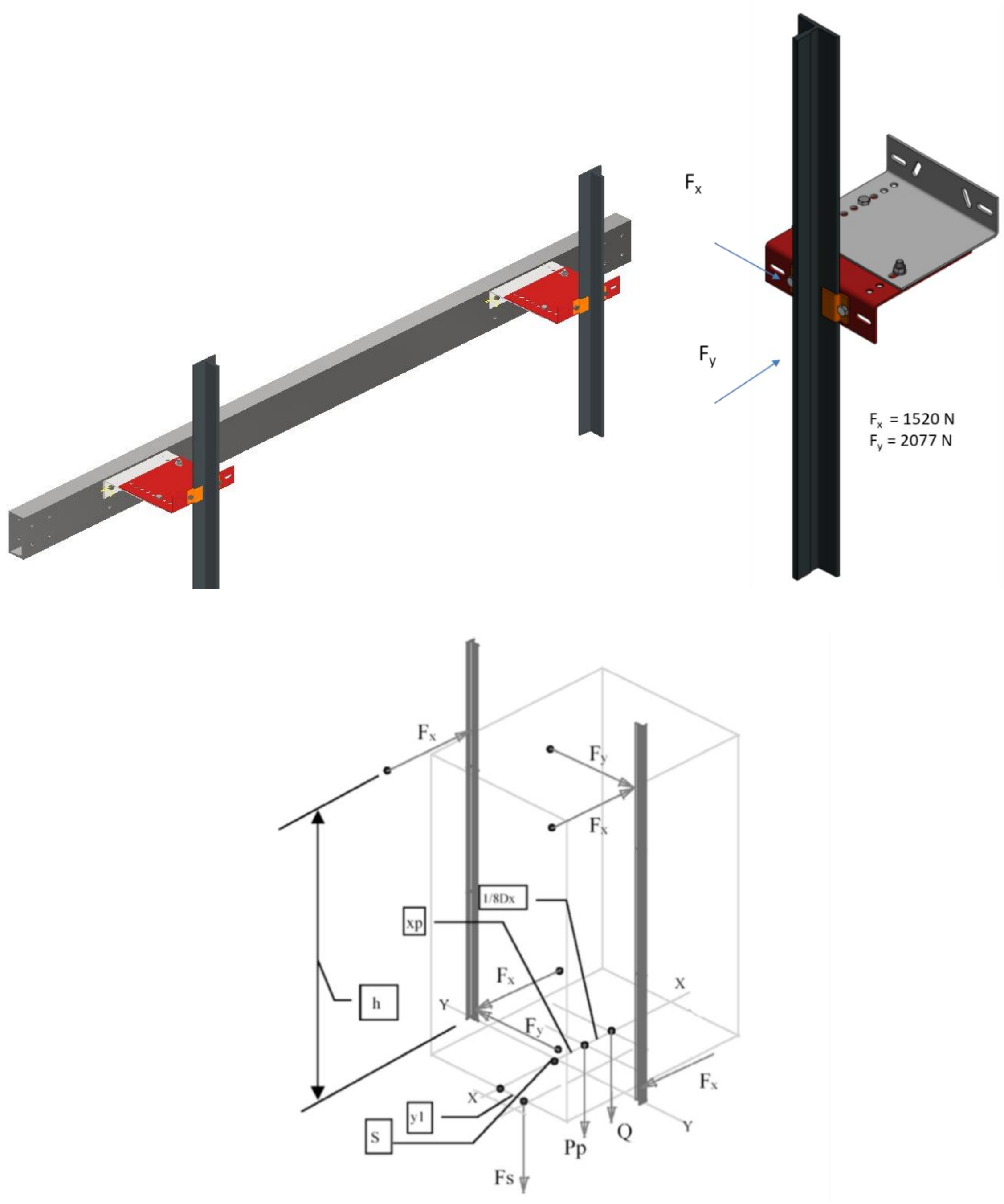

Fig. 2. 3D model of the guiding system with guide rail sections, with indicated loads [4]

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3. FEM analysis of the original guiding system - design loads

Forces considered in the FEM analysis are the maximal horizontal design forces induced after the release of the catching device in the elevator. The adopted system of concentrated loads is shown in Fig. 2. The magnitude of two horizontal forces acting in the plane normal to the direction of the ride is taken to be: Fx=1520 N and Fy=2077 N. The support is modelled at the point the bunton is secured to the supporting beam (i.e. at endpoints).

The FEM mesh used in the calculations comprises 10-node parabolic tetrahedral finite elements:

- Number of finite elements: 1 097 107
- Number of nodes: 261 211

Static analysis of endurance strength reveals small displacements of the bunton beam, within the elastic regime.

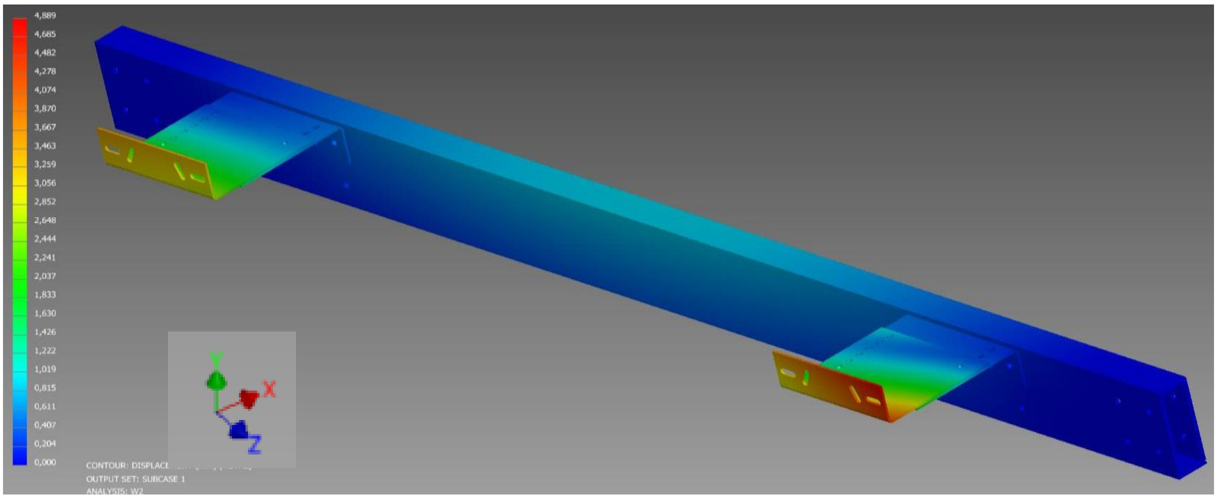

Fig. 3. Total displacement in millimeters of the bunton and supporting beam

In the central section of the bunton, on the upper part of the c-profile the displacement is observed of the order of 0.4-0.5 [mm] Displacements registered in vicinity of the supports and mounting brackets are less than 0.2 [mm], as shown in Fig 3. In most part the registered displacement is in the Y-axis. Maximal total displacement in the elastic range are observed on the brackets, at points where the guide rail is secured. The maximal total displacement of the bunton connection is about 4.9 [mm]. The length of the beam is 3,450 millimeters and the wheelbase of the supports is 2,190 millimeters. Even though supporting beam displacements are considerable, they do not adversely impact on the passenger safety. Actually, these modelled load levels are possible only in emergency conditions, for instance due to breaking of all hoisting ropes in the elevator installation. Displacements registered in the Z-axis are negligible, being of the order.

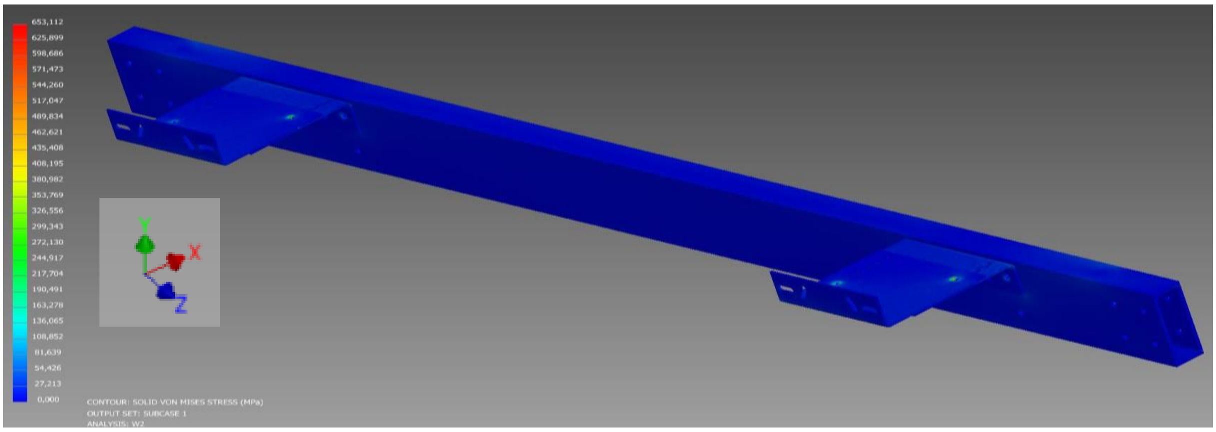

Fig. 4. Stress map: Equivalent stresses in bunton and supporting beam

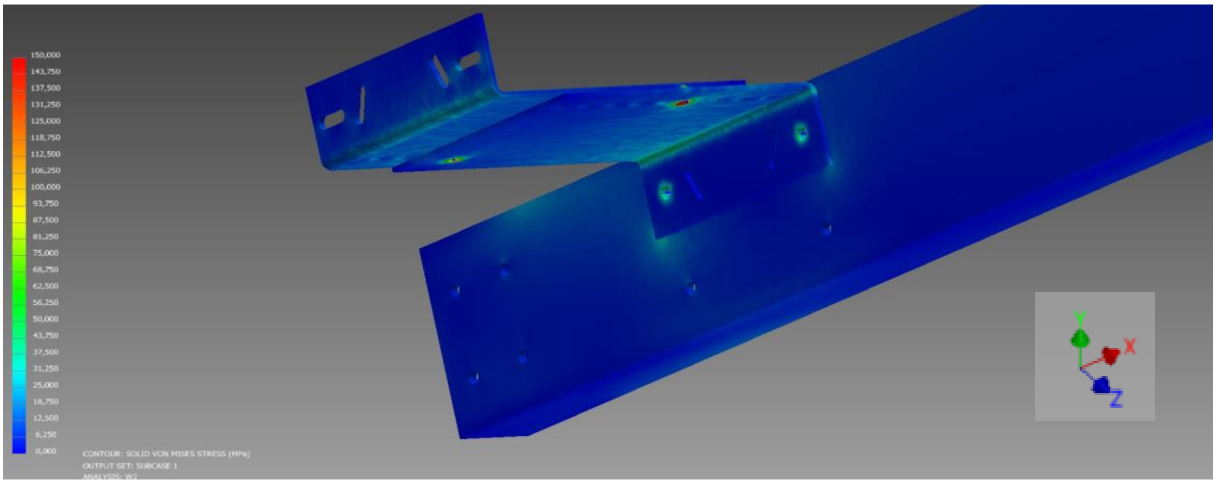

Fig. 5. Stress map: Equivalent stresses in bunton and supporting beam sections with indicates stress concentration zones - view from the car end

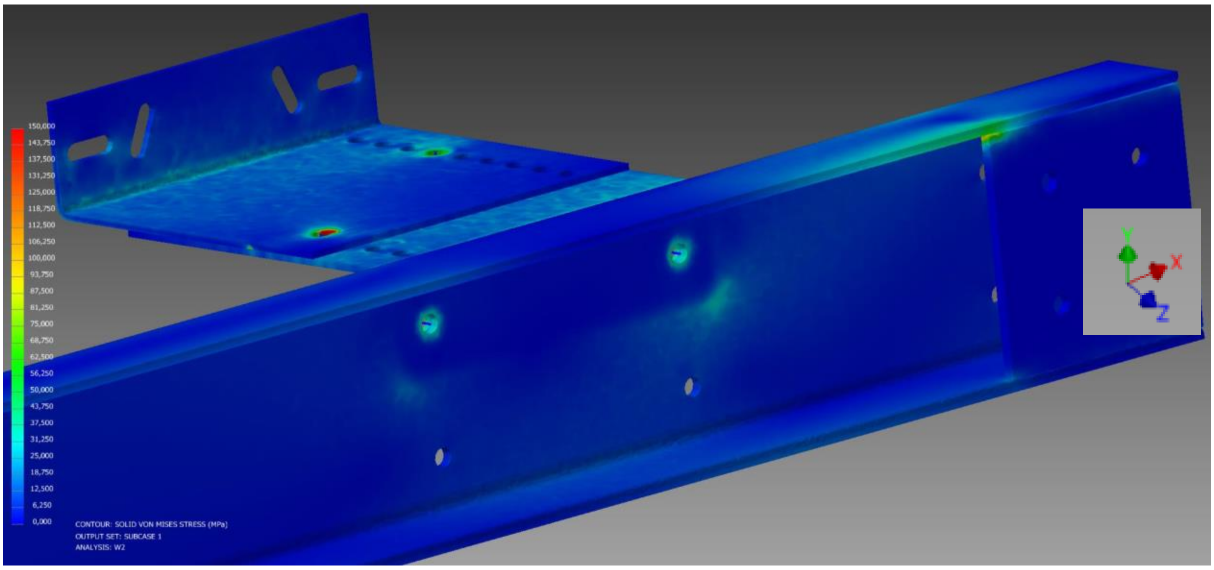

Fig. 6. Stress map: Equivalent stresses in bunton and supporting beam sections with indicates stress concentration zones - view from the shaft steelwork

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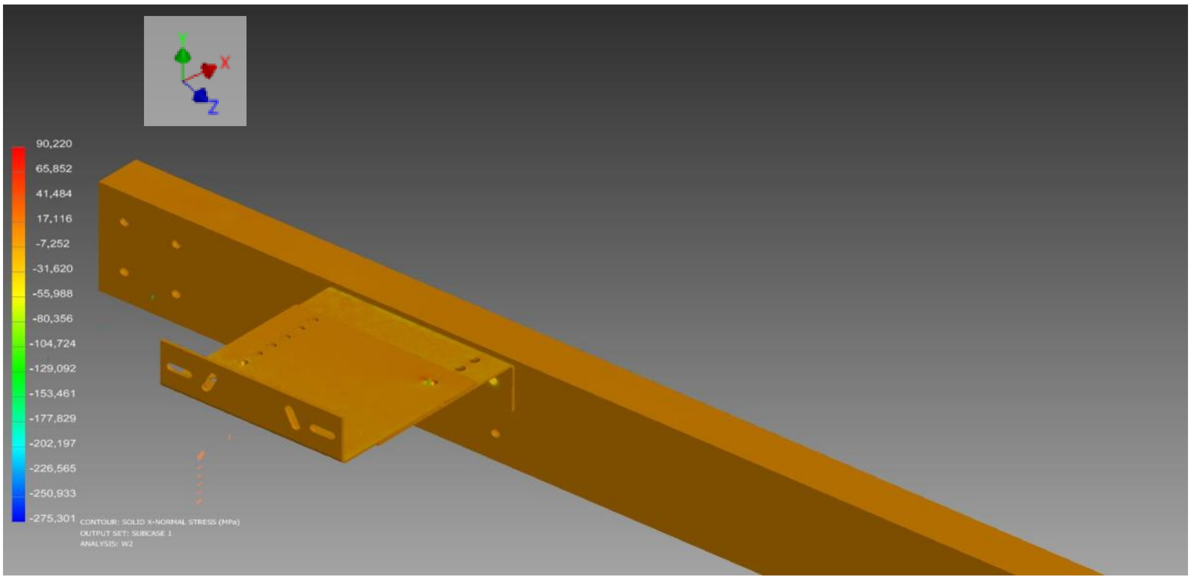
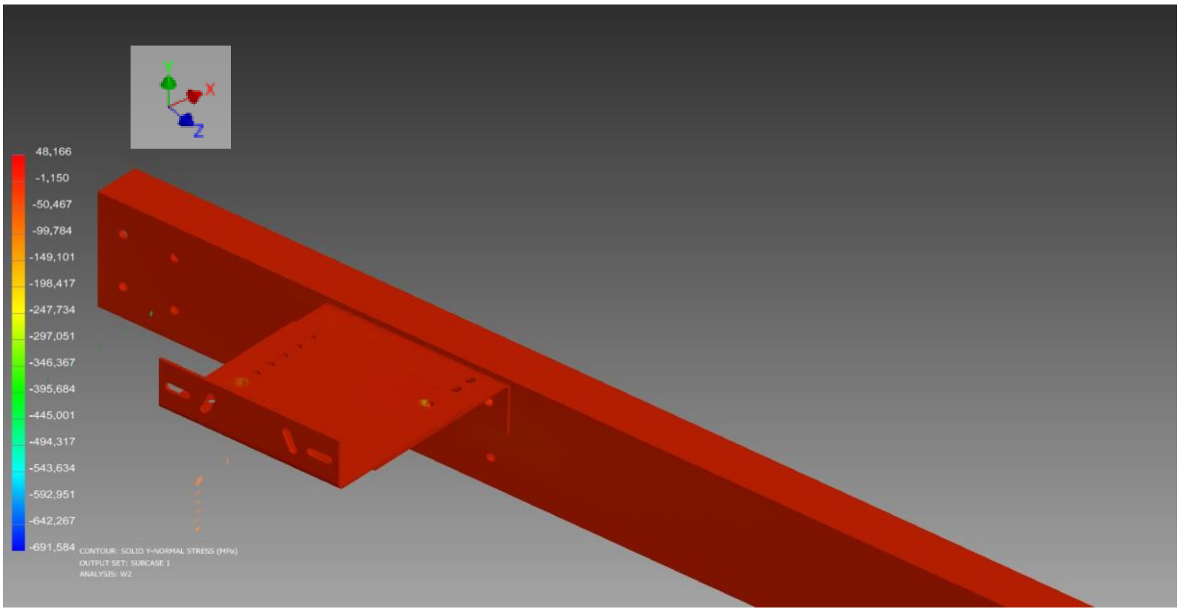
The analysis of equivalent stresses in a large part of the bunton and supporting beam surface shows the stress levels not exceeding 65 MPa (see Fig. 4, 5, 6). The revealed local stress concentration zones are attributable to surface pressure exerted in bolted connections. Equivalent stress concentration levels derived by the modelling procedure and shown in Fig. 5 and Fig. 6 do not exceed 150 MPa.

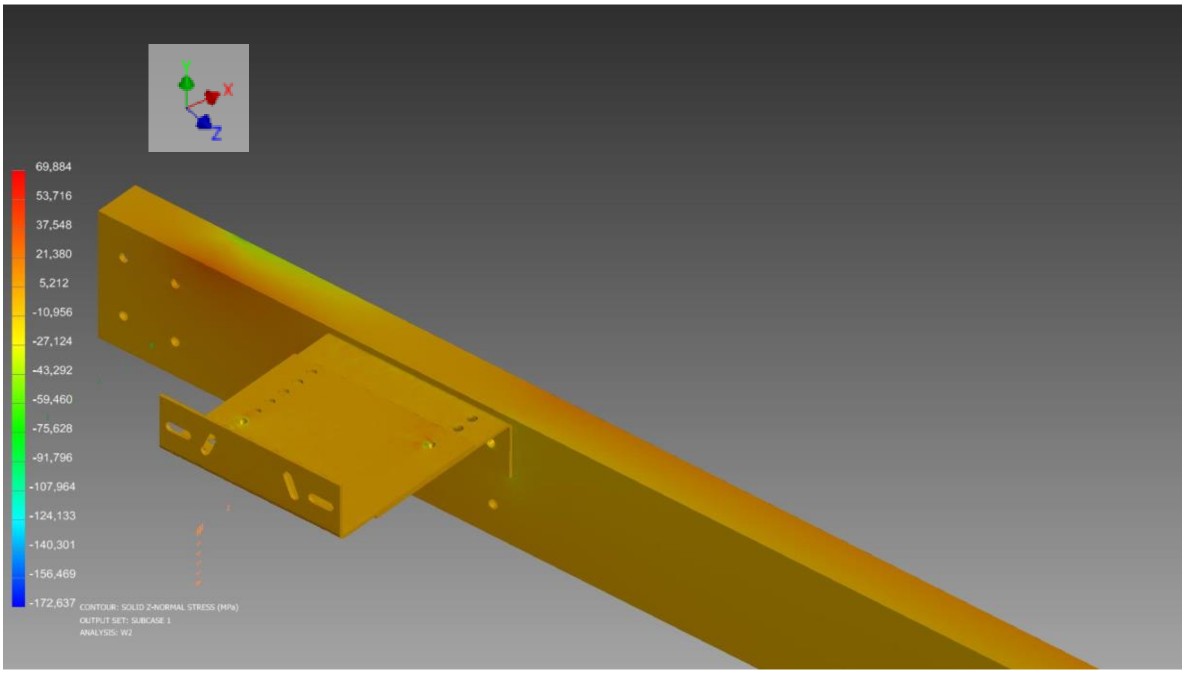
Bolted connections are modelled with the use of the module Bolt available in Autodesk Nastran 2021 software, the selected bolt material, the axial force and tightening torque are those of the 8.8 bolt. The analysis of the real system indicates that the solution adopted by the elevator manufacturers in order to distribute the surface pressure loads through the use of square - shaped or round washer pads is fully adequate. Resting on these assumptions, the stress increases resulting from surface pressure in bolted connections can be neglected in the modelling procedure.



a



b



c

Fig. 7. Stress maps: a) normal stress in X axis, b) normal stress in Y axis, c) normal stress in Z-axis

Examination of stress distribution patterns on the larger fragment of the bunton reveals the normal stress in the X-axis (Fig. 7a) fluctuating in range from -50 MPa to 90 MPa. The largest values are stress concentrations registered next to openings in the supporting beam-bunton connection. The underlying causes of those local stress increases were highlighted in the previous section and will be duly taken into account. The analysis of respective normal stress distributions in Y- axis and Z-axis shows that their increment value should not exceed ± 60 MPa (Fig. 7b, 7c).

4. FEM analysis of the variant 2 (with reduced mass) - design loads

The underlying assumption was made that forces and loads acting on the guiding system with reduced mass are those highlighted in section 4.

The FEM mesh used in the modelling procedure comprises 10-node parabolic tetrahedral finite elements:

- Number of finite elements: 563 268
- Number of nodes: 152 327

The analysis of endurance strength of the modernised bunton with reduced mass reveals certain displacements in the elastic range, as shown in Fig. 8.

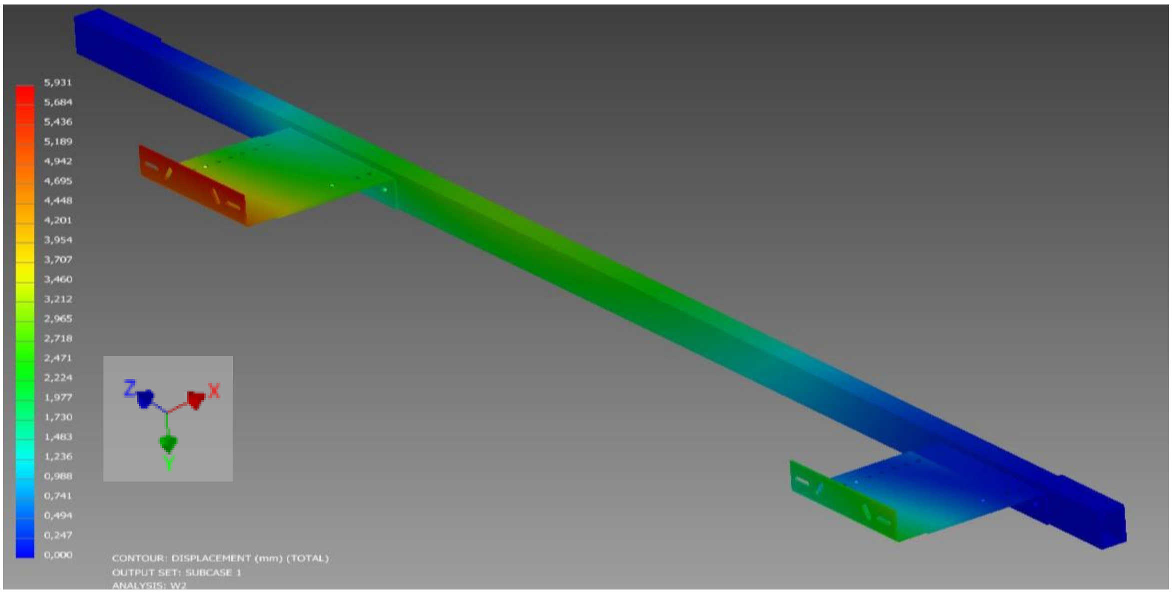


Fig. 8. Total displacements in milimeters of the bunton beam and supporting beam

The total displacement registered in the central section of the bunton, on the upper part of the c-profile, is of the order of 2.5 [mm]. Displacements registered in vicinity of the supporting beam and mounting brackets are less than 0.5 [mm], as shown in Fig. 8. In the largest part, the displacements are registered in the Y-axis. Maximal total displacement in the elastic range are observed on the brackets, at points where the guide rail is secured. The maximal total displacement of the bunton connection is about 5.9 [mm]. Displacements registered on the supporting beam are considerable, yet similar to the case highlighted in section 4, their mass is not subject to reduction, apparently their selection by the manufacturers selection was justified and correct. Displacements registered in the Z-axis are negligible, being of the order of 1/10000 of mm.

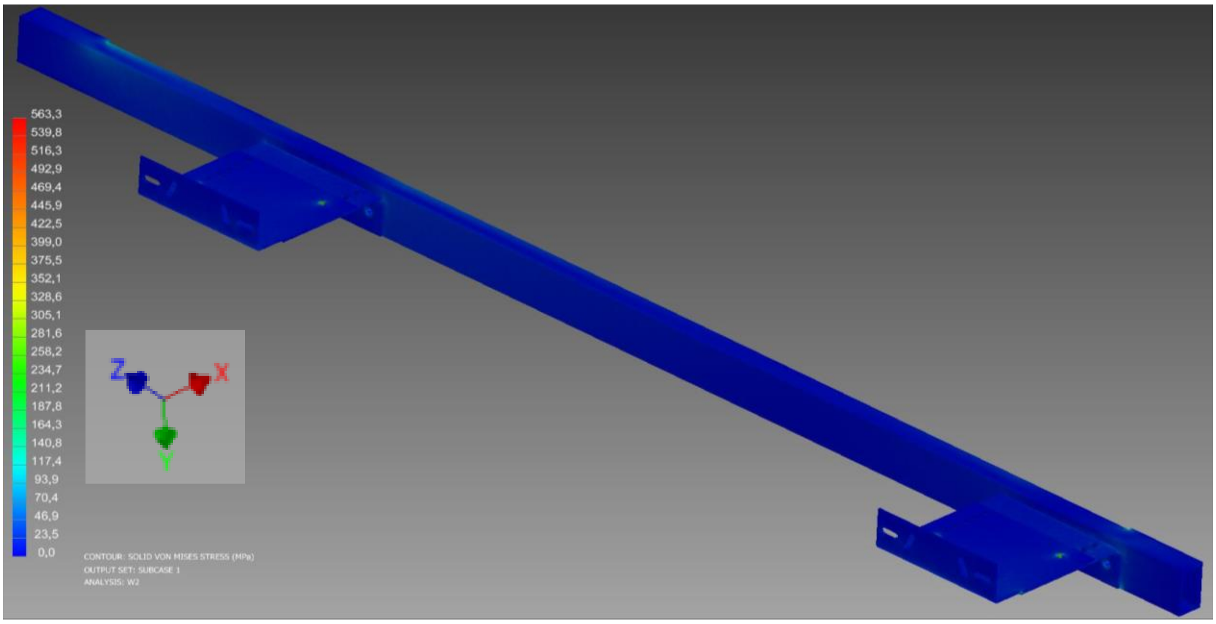


Fig. 9. Stress map: Equivalent stress in bunton and supporting beam

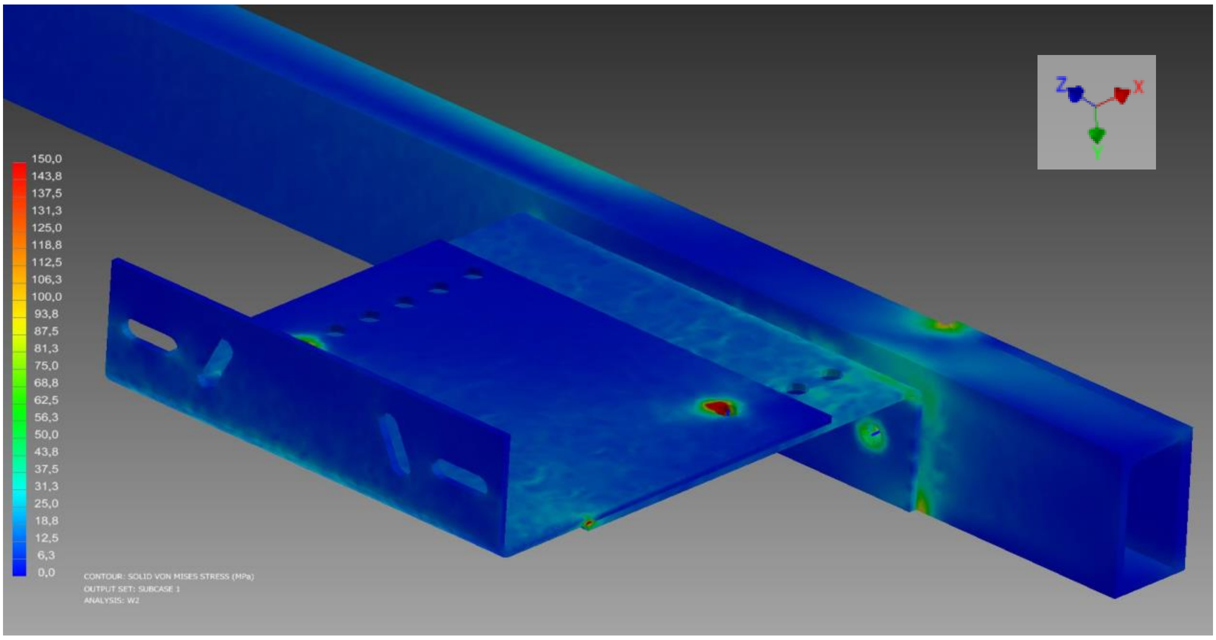


Fig. 10. Stress map: Equivalent stresses in bunton and supporting beam sections with indicates stress concentration zones - view from the car end

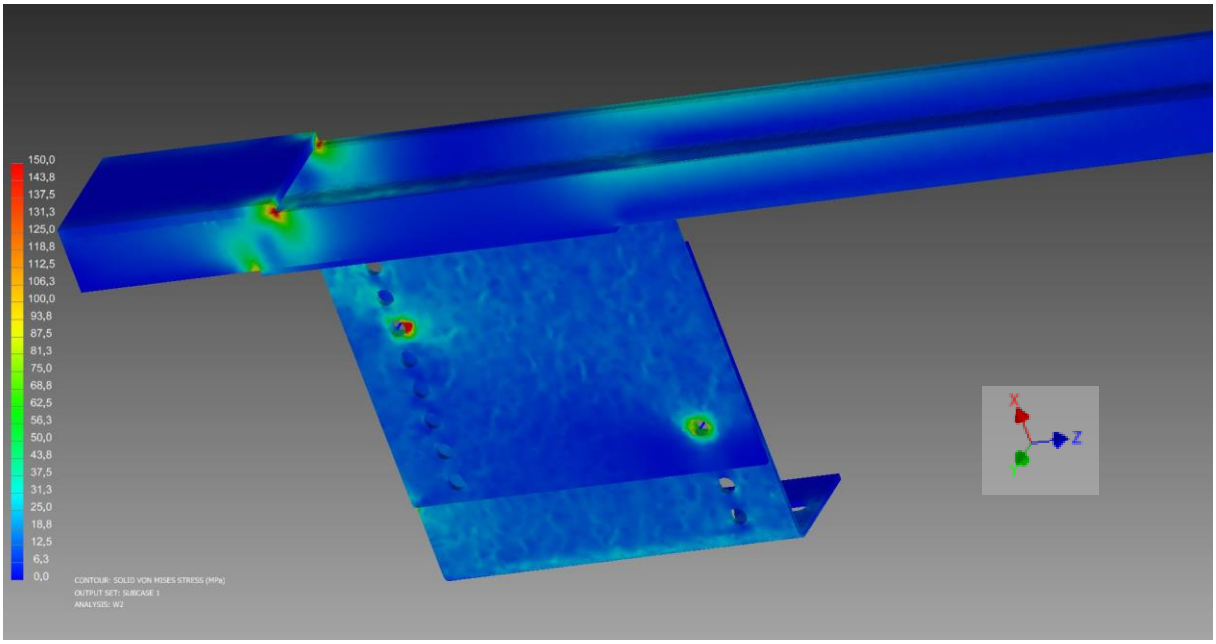
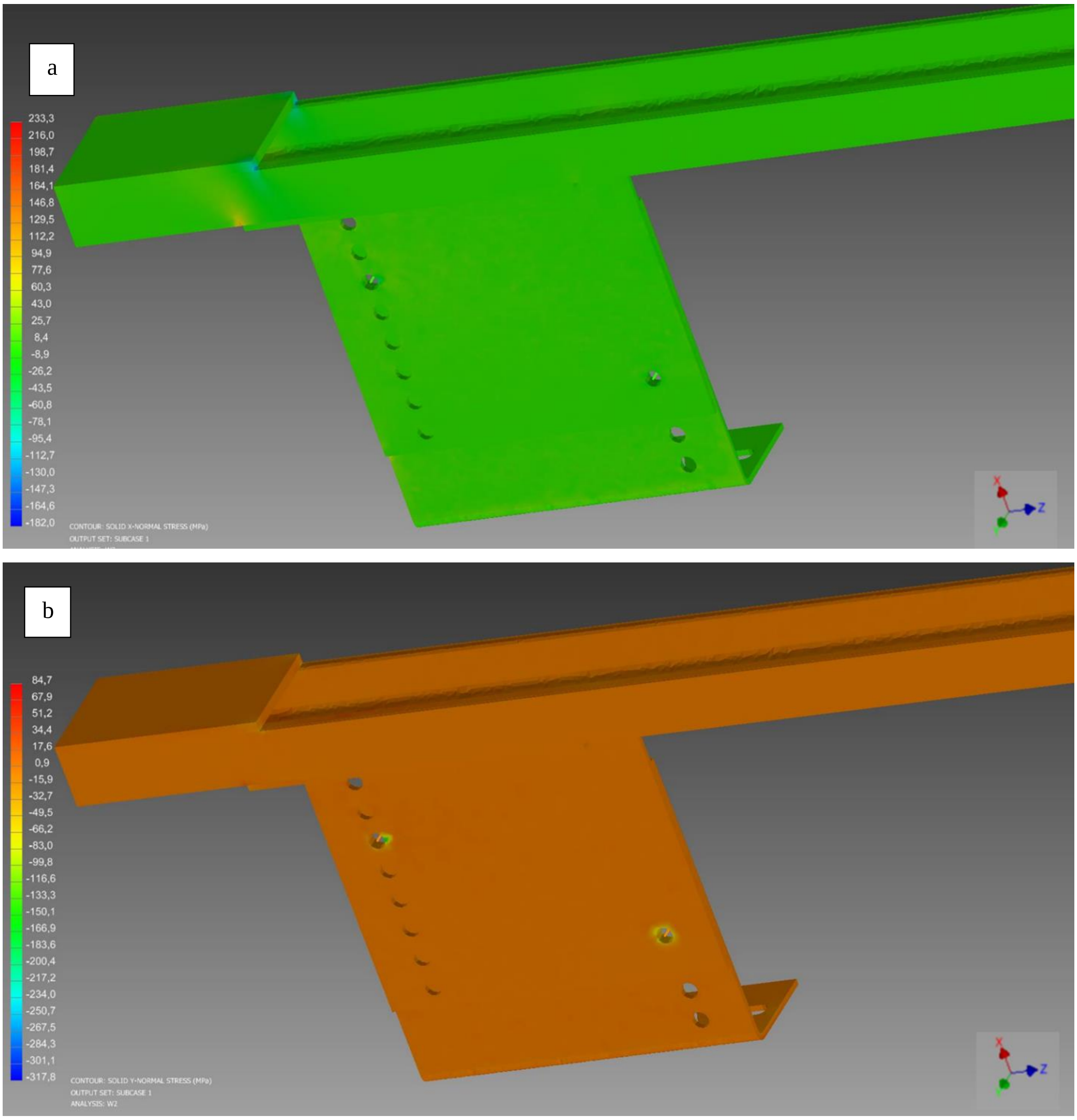


Fig. 11. Stress map: Equivalent stresses in bunton and supporting beam sections with indicates stress concentration zones - view from below

The analysis of equivalent stress distributions in this variant of the guiding system reveals the stress levels on the bunton and supporting beam not exceeding 85 MPa (see Fig. 9, 10, 11). Similar to the case highlighted in section 4, the revealed local stress concentration zones are attributable to surface pressure acting in bolted connections. Modelled equivalent stress concentrations, shown in Fig. 10 and 11, do not exceed 150 MPa.



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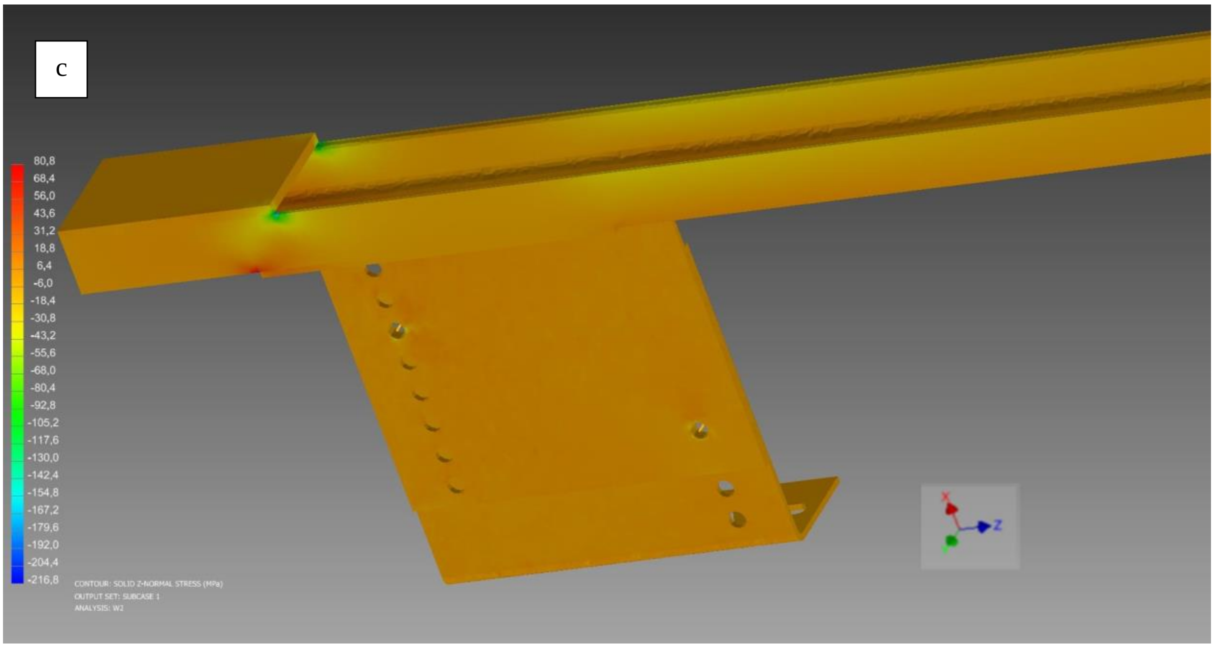

Fig. 12. Stress map: a) normal stress in X-axis b) normal stress in Y-axis c) normal stress in Z-axis

The normal stress in the X-axis (Fig. 12a) varies from -60 MPa to 95 MPa, the largest registered stress levels are at the stress concentration zones near the openings for bunton mounting brackets and at welded joints. The underlying causes of these local stress increases are highlighted in earlier sections. The distributions of normal stresses in the remaining two axes show that stress increments should not exceed ± 80 MPa (Fig. 12b, 12c).

5. Measurement set-up

To verify the stress levels obtained by numerical modelling of the elevator car guiding system, measurements were taken on a real object, i.e. the elevator operated in the shaft “Regis”. The location of strain gauge arrays on the supporting beam is shown in Fig. 13 and Fig. 14, the detailed description of the measurement set-up is given elsewhere (conference materials KOMTECH 2020 [7]. This particular location of strain gauges was selected because the supporting beam is the only components which does not exhibit excessive stiffness and therefore the results of strain measurements taken with these strain gauges should be regarded as reliable and quantifiable.

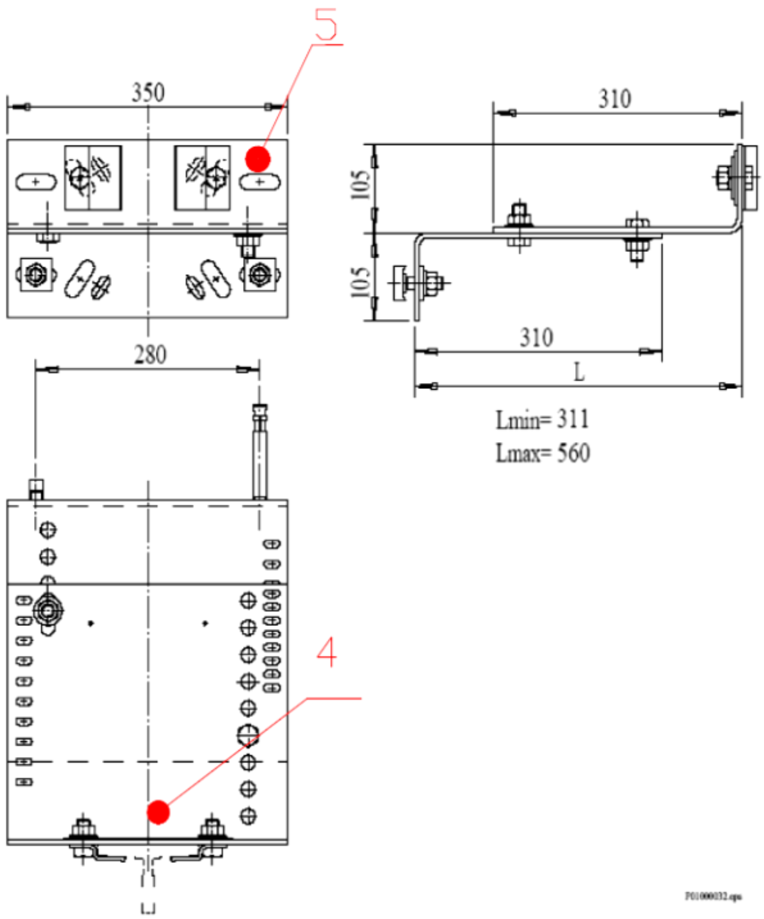

Fig. 13. Mounting bracket [7] with indicated location of arrays of 4 and 5 strain gauges

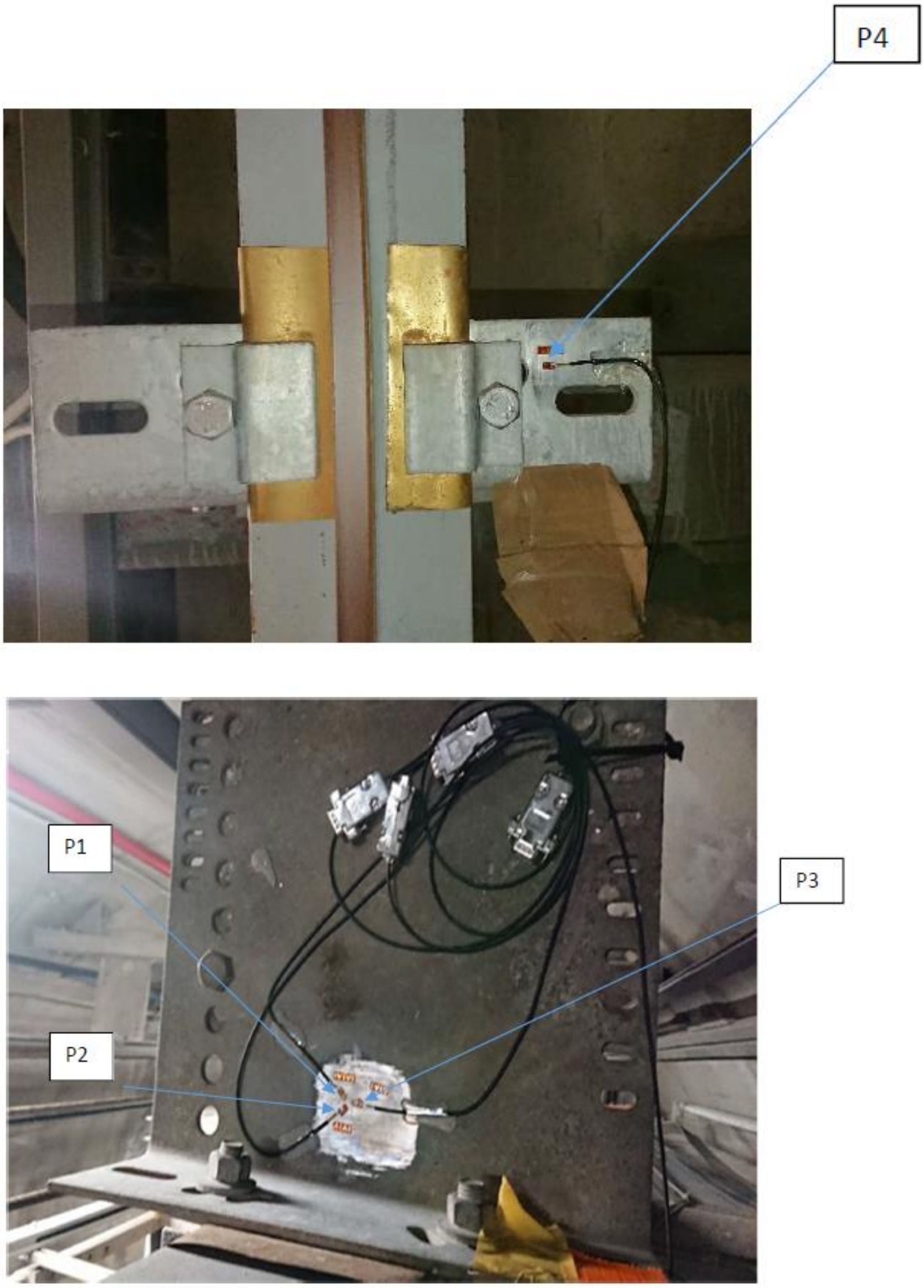

Fig. 14. Strain gauges and their designations

Respective designations of strain gauges attached to the supporting beam are given in Table 1.

Table 1. Designation of strain gauges on the supporting beam

Designation	Name	Location
P1	Strain gauge 1	Horizontal plane of the supporting beam (perpendicular to the direction of the car ride, see array 4, Fig. 13)
P2	Strain gauge 2	
P3	Strain gauge 3	
P4	Strain gauge 4	Horizontal plane of the supporting beam (the points where guide rails are secured, see array 5 in Fig. 13)

6. Results of measurements taken on the supporting beam

This section summarises the three most representative stages of the measurement procedure. Each stage shows distinctive features, representing the least favourable operating conditions in the elevator ride. In the first stage the elevator is travelling in the test mode at the speed limited to 0.3 m/s, with the possibility to stop the elevator immediately. The car was loaded with the maximal admissible load Q=1600 kg. Two cases were considered in the stress measurement procedure. In the first case the top roller linear guide carriage is interrupted during the downward ride near the beam section with the strain gauges. In the second case the car the roller linear guide carriage at the bottom is stopped near the analysed beam section during the upward ride. In this stage of the procedure, significant stress changes were registered in two situations only.

During the second stage of the procedure, the elevator travelled at the nominal speed of 4 m/s with full load Q=1600 kg.

During stage 3, the elevator travelled with full load, with an emergency braking and release of the catching device during the downward ride at the rated speed of 4 m/s. The loading conditions in this case are the worst possible, impacting on the structural elements of the guiding system and thus must be accounted for in design load calculations. The acting loads obtained by FEM modelling are highlighted in section 4.

Plots of stress changes registered by respective strain gauges at selected points on the supporting beam in the first stage of the measurement procedure are shown in Fig. 15, stress changes registered in Stage 2 and 3 are plotted in Fig. 16 and Fig. 17.

Sample designation	Ride in inspection mode with rated speed GW down and DW up – decreasing when approaching the support			
006	[MPa]	Absolute, maximum value		
P1	P2	P3	P4	Comments
22	14	2	-4	GW
66	30	6	-28	DW

GW- roller linear guide carriage (TOP)

DW- roller linear guide carriage (BOTTOM)

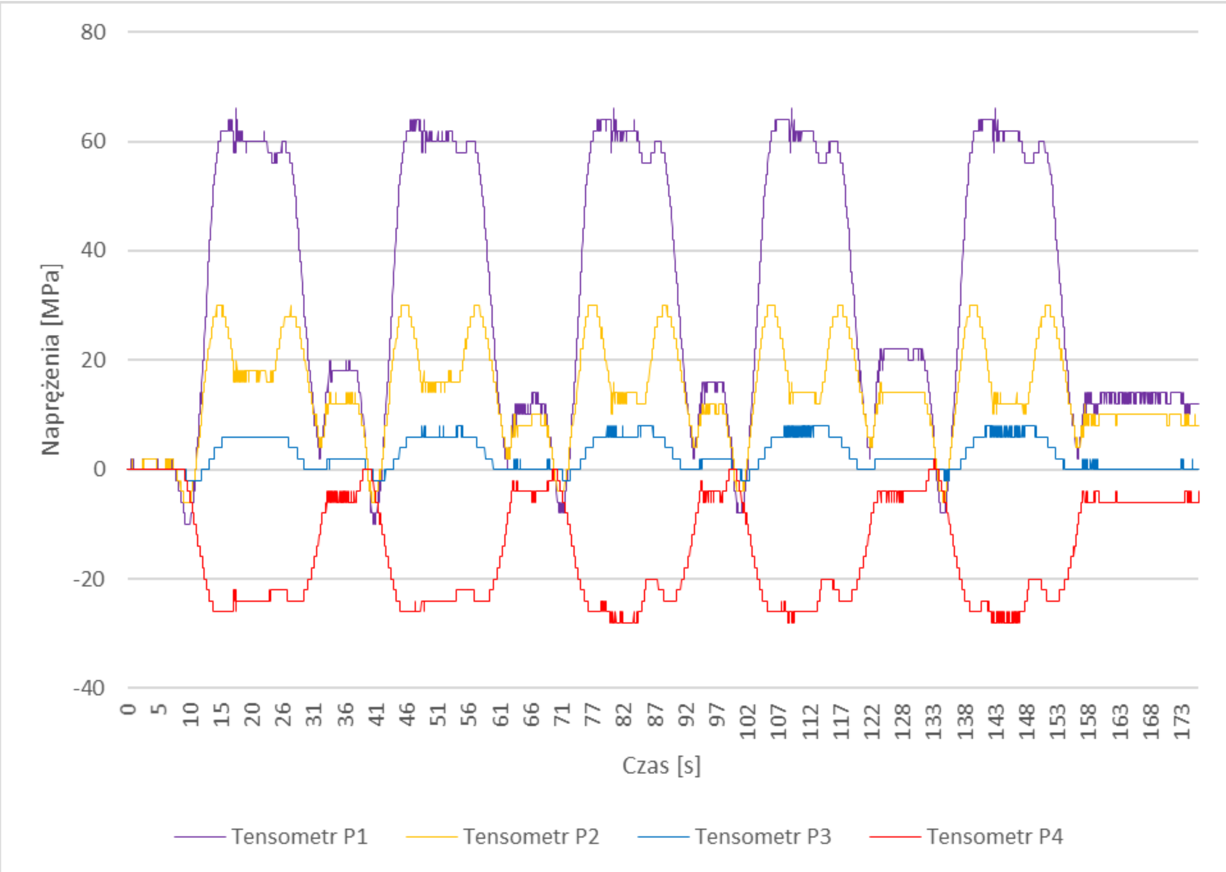

Fig. 15. Measurement results- Stage 1- inspection mode, V=0.3 m/s, Q=1600 kg

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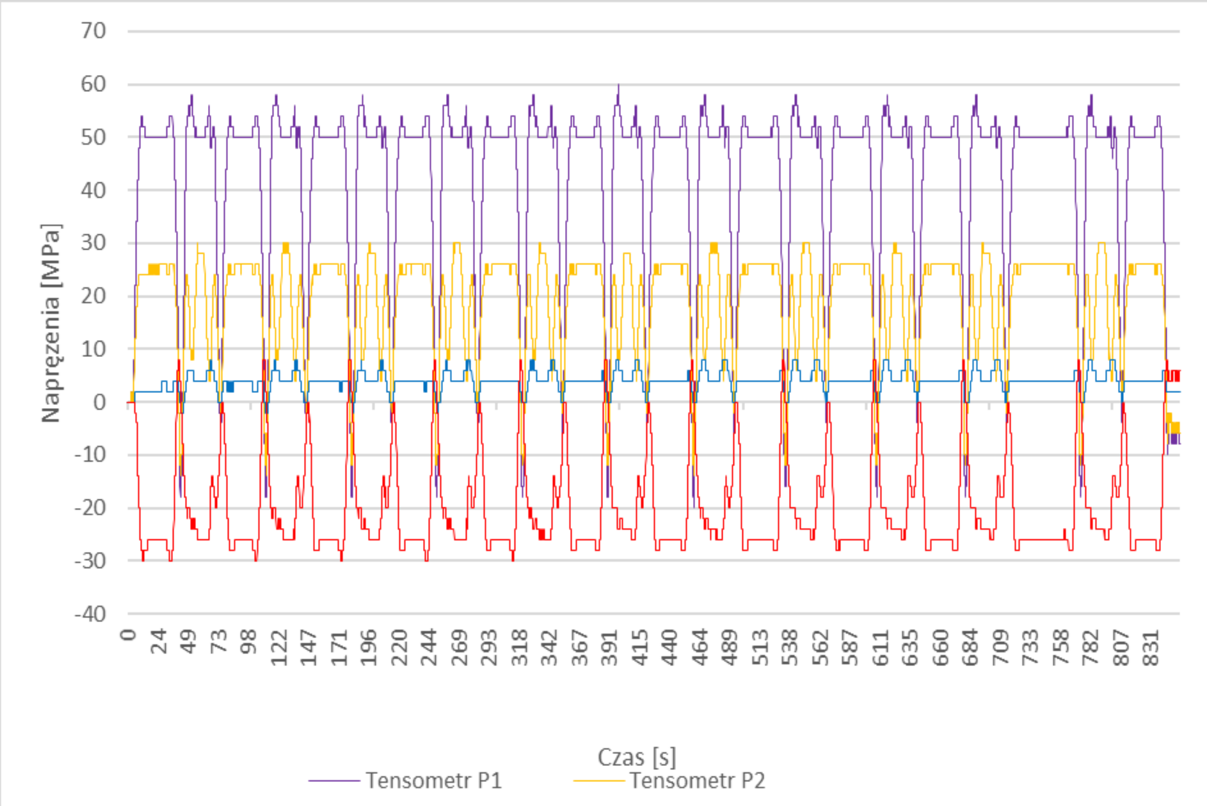

Fig. 16. Measurement results - Stage 2- 10 travels at nominal speed V=4 m/s, Q=1600 kg

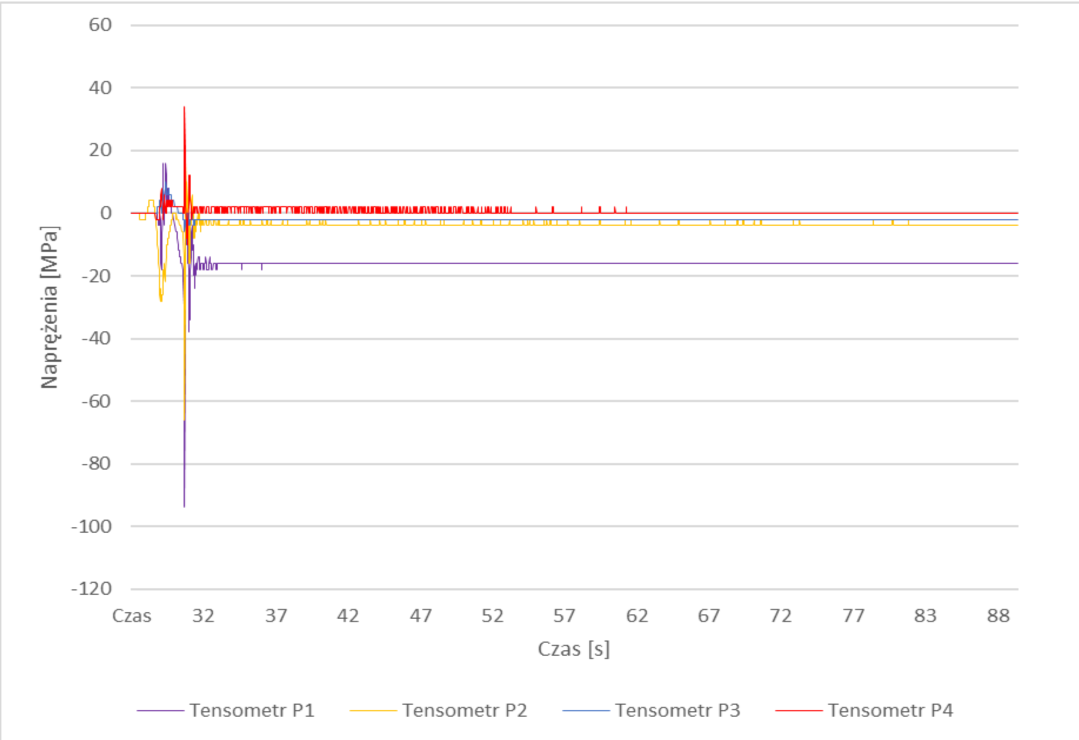

Fig. 17. Measurement results - Stage 3- triggering of the catching device, V=4 m/s, Q=1600 kg, downward ride

The analysis of measurement data collected during three stages of the procedure clearly shows that real stress changes in structural elements of the elevator guide system are insignificant. The maximal stress changes were registered by strain gauge P1 in the first stage of the procedure (release of the catching device), amounting to 94 MPa (Fig. 17). Considering the specificity of the duty cycle of hoisting installations, the registered stress increments are associated with bending and torsion, their values approaching 60 MPa [1].

Summing up, the analysis of measurement results has confirmed that the elevator car guide system operates within a narrow limit of endurance strength range designed for the type of construction and material used, which is indicative of its high strength parameters. This fact has some implications relating to the mass of the entire guiding system. Application of numerical methods to evaluate the mass redundancy of its structural elements might lead to vast reduction of costs involved in construction of hoisting installations, at the same time maintaining the required safety levels.

7. Conclusions

Numerical analyses and measurements have demonstrated that stress increments due to bending and torsion of load bearing cross-profiles in structural elements of the elevator car guide system operated in the shaft "Regis" are insignificant in relation to the endurance limit of the material used. Stress increments registered under the duty loads are less than 60 MPa and during the emergency braking with the release of catching devices the stress should increase by no more than 94 MPa.

FEM modelling reveals that equivalent stresses in the large fragment of the load-bearing structure should not exceed 65 MPa for the existing system and 85 MPa for the modernised one (with its mass reduced). The enhanced stress concentration levels are found near the bolt connections. Local stress concentrations of up to 150 MPa obtained by FEM modelling are attributed to simplifications of the computational models and to surface pressure exerted by heads and nuts in bolted connections. In real conditions, this effect has been effectively eliminated through the application of square-shaped or round washer pads with large contact surface (Fig. 13). Fatigue endurance limits [5], [6] are not addressed in the study because measurement data fall well below the rated endurance limits for steel grade S355J2 (the material from which the bunton is made).

The analysis of measurement results from testing of the beam supporting the guide rails of the elevator operated in the shaft "Regis" followed by examination of modelling data reveals certain over dimensioning in the bunton design. This fact was verified and confirmed through modelling of the upgraded bunton (with its mass reduced), which satisfies the endurance strength criteria even though its cross-section area is smaller.

When planning new investments involving the installation of conventional mine hoists, the full endurance analysis of structural elements of the elevator guide system is fully merited. Moreover, the environmental conditions prevailing in the shaft have to be considered. One has to bear in mind that standards developed by maintenance engineers relating to air humidity and steelwork stability criteria are most rigorous and must be strictly obeyed during the entire service life of the installation. Every time a hoisting installation is to be implemented in the shaft, a full case-specific analysis of safety aspects is required and merited.

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The influence of technological parameters of plasma cutting on the quality and surface roughness when cutting thick steel sheets

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Abstract:

The purpose of this study was to analyze the effect of selected parameters on the quality of plasma cutting. The main parameter studied was the cutting speed and how it affects the roughness of the cut surface. The second parameter analyzed was the current intensity adjusted depending on the thickness of the material being cut, which also has a significant effect on the surface quality of the metal being cut. The evaluation of the quality of the cut surface was carried out on 8, 20, 30 and 35 mm thick sheets of S235JR grade steel. Several samples were selected from each thickness for measurement and testing. The samples were cut with a MAGNUM CUT 160 plasma cutter. The results show that the current intensity and the speed of the torch pass have a significant effect on the quality of the cut surface.

Keywords: plasma cutting, surface quality, roughness, S235JR steel, MAGNUM CUT 160 cutter

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1. Introduction

Cutting is one of the basic technologies for manufacturing parts. Depending on the choice of the cutting method, a certain quality of the product can be obtained. One of the most advanced methods of cutting through material is thermal cutting. Currently, the most common methods of thermal cutting include plasma cutting, laser cutting and oxy-gas cutting [1–5].

Plasma cutting is a modification of the tungsten inert gas (TIG) plasma welding process, which involves permanently joining metals using a non-fusible electrode. The processes differ in the design of the gas nozzle, which must produce a rapid increase in gas pressure. The process is typically used for cutting electrically conductive materials such as aluminum, corrosion-resistant steel or structural steel [2–4].

The plasma cutting method is distinguished from the others mainly by the low price of the process. Plasma equipment compared with laser equipment is much cheaper and can produce very similar results. Plasma machines, with the development of technology, are being equipped with increasingly advanced CNC control systems. This method is most commonly found in the engineering, metal, automotive, aerospace, and automotive industries. The course of the cutting process is influenced by many factors, which are mainly technological cutting parameters. Of these, the most noteworthy are the current intensity and the speed of torch pass.

One of the most important parameters for assessing surface quality is surface roughness. Achieving low surface roughness during plasma cutting or plasma machining is a major challenge, considering the complex interrelationships between various cutting parameters, such as speed, gas intensity, and flow rate [6–8].

Currently, it is possible to perform both separating and qualitative cutting of sheets with a thickness of 40–50 mm using air as the plasma gas, whereas a little more than ten years ago, the maximum thickness was typically around 25 mm [2–4, 9]. The following step is a more detailed analysis of the state of the art in the field of plasma arc cutting (PAC).

Gostimirović et al. [10] examined various parameters in the context of the machining quality of low carbon low alloy steel in PAC and their effects on kerf geometry, surface roughness, and heat-affected zone (HAZ) microstructure, underlining challenges in achieving final machining quality due to metallurgical variations in the HAZ. Moreover, Hang et al. [11] explored the impact of various parameters on cutting surface quality in CNC plasma cutting, emphasizing the crucial role of cutting current, air pressure, and torch standoff distance. They concluded that air pressure significantly affects slag formation, and surface roughness is primarily influenced by standoff distance and air pressure, with cutting speed and cutting current having less significant effects.

Loktionov et al. [12] optimized processing modes to minimize deviation from perpendicularity and established relationships between cutting speed, cut width, and material thickness. Kim, S. I. and Kim, M. H. [13] identified optimal cutting speeds and current levels to improve cut quality and straightness for thick steel ship plates, while also revealing challenges in quality for plates 30 mm or thicker, attributed to observations of molten metal flow and HAZ depth. Hema and Ganesan [6] analyzed the impact of PAC parameters on SS 304 alloy, identifying optimal conditions for improved surface roughness and material removal rate.

Koura et al. [14] studied the influence of plasma arc cutting conditions on the surface texture of Hardox400 parts, highlighting cutting speed as the most influential parameter, with results showing surface roughness ranging from 5 to 5.5 µm. Aldazabal et al. [15] investigated the effect of plasma cutting processes on the mechanical behaviour of steel plate edges, concluding that the resulting cut heat-affected zones (CHAZ) are narrow and homogeneous.

Tsiolikas et al. [16] demonstrated a balanced influence of all parameters on surface roughness during CNC plasma arc cutting, where optimal levels were discerned for cutting speed, torch standoff distance, and arc voltage, culminating in refined surface qualities, with further analysis revealing significant contributions of noise factors to variance. Suresh and Diwakar [17] aimed to optimize water–acetone

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plasma arc cutting for TWIP steel plates, utilizing design of experiments and response surface methodology to improve material removal rate, surface roughness, and cut time. Finally, Gani et al. [18] examined the feasibility of plasma machining for cutting parallel thin layers, emphasizing the importance of parameter optimization to minimize deformation and HAZs.

Most publications present information only about plasma arc cutting of thinner steel sheets, that is, 20 mm or less [8, 19], and that is why it is important to investigate the effect of PAC also on thicker steel sheets. This article contains the evaluation of the quality of the cut surface for 8, 20, 30 and 35 mm thick sheets of S235JR grade steel, which encompasses a broader thickness range, including sheets above 20 mm.

2. Materials and Methods

Sheets made of S235JR steel were used as the test material. It is a non-alloy structural steel with a variety of applications. One of its main applications is the creation of building load-bearing structures. This material is used to make long products such as steel profiles and plates, which are used to construct buildings, bridge structures, viaducts, or masts [20]. It is one of the most widely used materials in engineering, e.g., for the manufacture of construction machinery and equipment, and in the mining industry.

The main property of this material is high stiffness and good susceptibility to welding work. The chemical composition of the steel is shown in Table 1.

Table 1. Chemical composition of S235JR steel

C	Mn	P	S	Cu
		%		
≤ 0.17	≤ 1.4	≤ 0.035	≤ 0.035	≤ 0.55

The basic parameters of plasma cutting are [1, 11]:

- current intensity,
- arc voltage,
- cutting speed,
- type, pressure, and flow rate of plasma gas,
- type, pressure, and flow rate of shielding gas,
- type and construction of the electrode,
- diameter of the constricting nozzle,
- position of the torch relative to the object being cut.

Parameters that can be controlled by the operator in the plasma cutting process are:

- current intensity,
- plasma cutting speed,
- distance of the torch position relative to the material being cut.

Current intensity mainly determines the temperature and energy of the plasma arc. The higher the intensity, the greater the cutting speed, and with the given speed, it is possible to cut thicker materials. However, this leads to a decrease in electrode durability. Excessive intensity results in reduced cutting quality, increased kerf width, and rounding of the upper edges of the material. Conversely, too low intensity initially causes metal drooping, ultimately resulting in a lack of cut.

Cutting speed determines the quality of the cut, especially in the case of manual cutting. As cutting speed increases, its quality decreases, the kerf width decreases, and — similarly to current intensity — metal drooping begins to occur, ultimately resulting in a lack of cut. On the other hand, too low cutting speed leads to an increase in kerf width (material loss) and rounding of the upper edge, as well as the formation of metal drooping at the lower edge.

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The cutting process was carried out at the Research and Didactics Service Center in the Material Bonding Laboratory of the Faculty of Mechanical Engineering and Robotics of AGH University of Krakow, Poland. The device with which the cutting was performed was a MAGNUM CUT 160 plasma cutter (Fig.1.). It is designed for manual and machine air plasma cutting. These types of cutters are used in various industrial plants, but are also used in field conditions: on construction sites, when repairing machinery and equipment in the field, such as in open-pit mines and quarries. Technical data of the cutter can be found in Table 2.

Table 2. Technical specifications of the MAGNUM CUT 160 plasma cutter

Power supply	AC 400 [V], 50 [Hz]
Required safeguards	25/C
Cutting current	30 ÷ 160 [A]
Idle voltage	288 [V]
Approximate cutting thickness for structural steel	Separating max. 40 [mm] Qualitative max. 35 [mm]
Required air pressure	5 [bar]
Air consumption	210 [l/min]
Efficiency	60%
Product protection class	IP21S

Fig. 1. MAGNUM CUT 160 plasma cutter

For cutting, a basic LT-141 plasma torch was used-air-cooled, with a Euro-type connector, designed for handheld cutting machines, with a gas distributor integrated into the body.

The technical data of the torch can be found in Table 3.

Table 3. Technical specifications of LT-141 plasma torch

Cooling	Air
Operation at 100 A	100%
Operation at 140 A	60%
Pressure	5 [bar]
Airflow rate	220 [l/min]
Max. cutting thickness at 120 A	45 [mm]
Max. cutting thickness at 140 A	55 [mm]
Connector length	6 [m]
Connection type	Euro

The plasma cutter device was equipped with an electric carriage, allowing the torch to move linearly at a set speed (Fig. 2). The speed of the carriage with the plasma torch was adjusted using a power supply and controlled by the voltage supplied to the carriage motor.

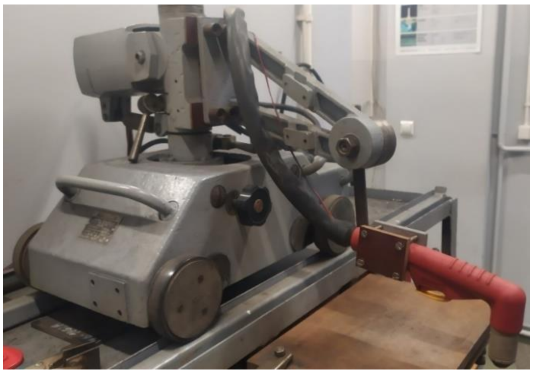

Fig. 2. Carriage with the torch

The research was conducted on a total of 10 samples: three with a thickness of 8 mm, three with a thickness of 20 mm, two with a thickness of 30 mm, and two with a thickness of 35 mm. For samples of the same thickness, the same current intensity was used, selected according to the device instructions and previous cutting trials with the plasma cutter used for the tests.

During the tests, only the cutting speed was changed within the range of 4 to 13 mm/s. A speed of 13 mm/s was applied to sheets with a thickness of 8 mm, and only a speed of 10 mm/s was used for sheets with thicknesses of 8 and 20 mm. These speeds were not used for the thickest sheets because of the inability to cut them at such speeds. The standoff distance of the torch remained unchanged throughout the experiment. The thicknesses of the samples and their corresponding parameters selected for the tests are collectively presented in Table 4.

Table 4. Set technological parameters during plasma cutting

Sample No.	Thickness	Current intensity	Cutting speed		Current to the carriage	Torch standoff distance	Gas type
	[mm]	[A]	[mm/s]	[m/min]	[V]	[mm]	[—]
1.1	8	60	7	0.42	8.53	5	Air
1.2			10	0.6	11.68		
1.3			13	0.78	14.83		
2.1	20	100	4	0.24	5.38		
2.2			7	0.42	8.53		
2.3			10	0.6	11.68		
3.1	30	130	7	0.42	8.53		
3.2			4	0.24	5.38		
4.1	35	150	4	0.24	5.38		
4.2			7	0.42	8.53		

3. Results

In Figure 3, photos of one of the samples (1.1) are shown after cutting and before and after the removal of the resulting drooping. The drooping is easily removable owing to the use of an oxidizing plasma gas, namely air.

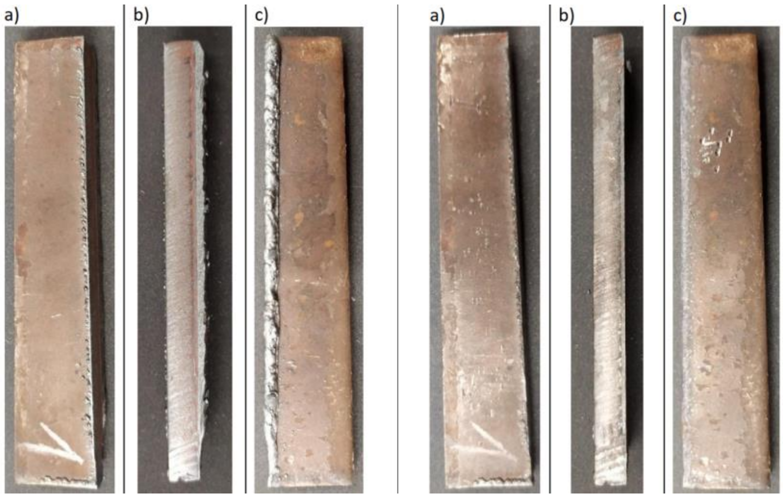

Fig. 3. Sample 1.1 after plasma cutting before and after removal of the droop: a) top view, b) cutting surface, c) bottom view

The roughness measurement was carried out using the Hommel Tester T1000E profilometer. The device was equipped with the Hommel Tester LV 15 measuring head. The measuring head was applied to the cutting surface in such a way that the measuring stylus moved in the direction of cutting. Measurements were taken at two locations: at 1/3 and 2/3 of the sheet thickness, as shown in Figure 4.

Fig. 4. Schematic of roughness measurement

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The results are presented in Table 5. Results of measurements where errors occurred are highlighted in red. These errors were caused by excessive surface irregularities, leading to incorrect readings by the measuring device. Consequently, these results were not taken into account.

Table 5. Roughness measurement results

Parameter		Measurement location	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	4.1	4.2
Ra	[μm]	1/3	4.49	6.09	5.08	11.67	8.16	7.54	8.23	7.66	7.65	8.53
		2/3	5.08	6.77	5.28	8.55	10.44	8.1	13.4	7.98	11.17	10.13
Rt		1/3	25.14	50.38	32.48	67.68	52.96	56.16	61.52	63.5	56.86	64.22
		2/3	29.06	59.06	45.24	61.38	52.88	48.08	81.88	63.1	81.88	63.7
Rm		1/3	24.58	38.76	29.16	63.46	52.2	52.6	54.32	55.1	55.8	52.2
		2/3	29.06	41.66	41.42	55.84	48.92	44.68	80.12	54.08	67.36	63.7
Rz		1/3	23.91	41.32	28.69	64.52	49.59	50.2	55.5	59.39	53.64	57.7
		2/3	28.21	33.36	38.56	54.92	49.37	43.98	76.48	54.49	74.2	56.7

For a more illustrative representation of the data, graphs were made for the more interesting roughness parameters, for *Ra*, *Rt* and *Rz*, respectively. They can be seen in Figures 5–9.

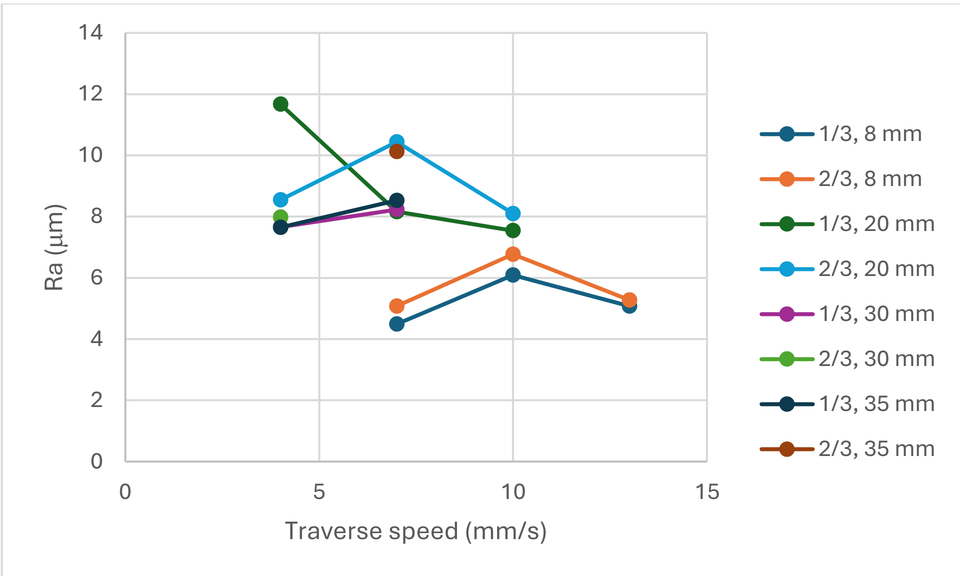

Fig. 5. The relationship between roughness *Ra* and cutting speed

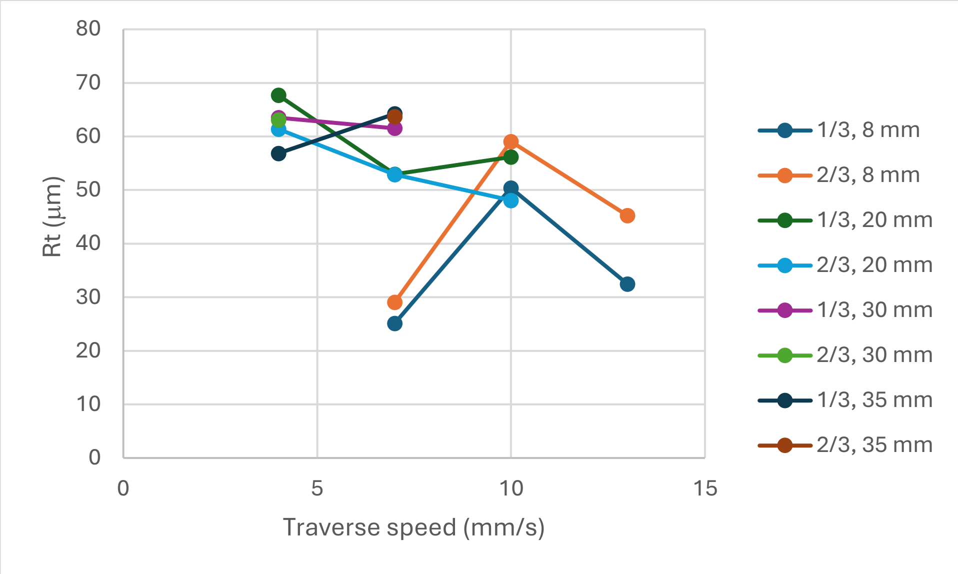

Fig. 6. The relationship between roughness *Rt* and cutting speed

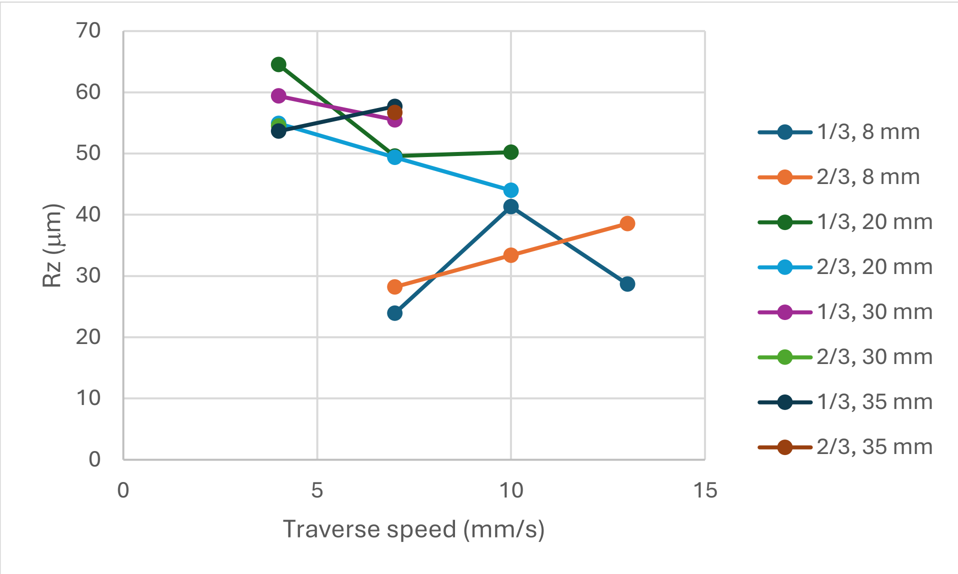

Fig. 7. The relationship between roughness *Rz* and cutting speed

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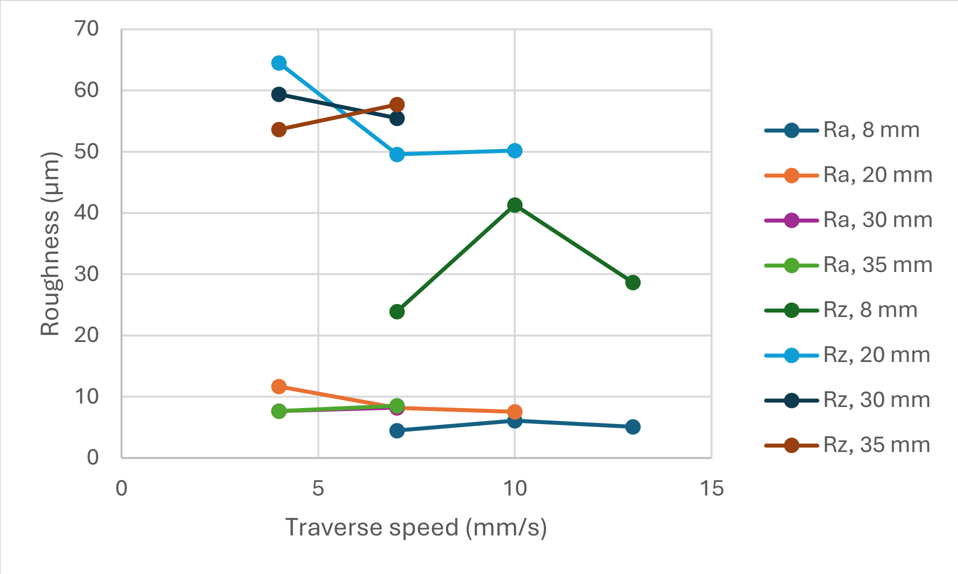

Fig. 8. The relationship between roughness *Ra* and *Rz* and traverse speed for 1/3 of the depth

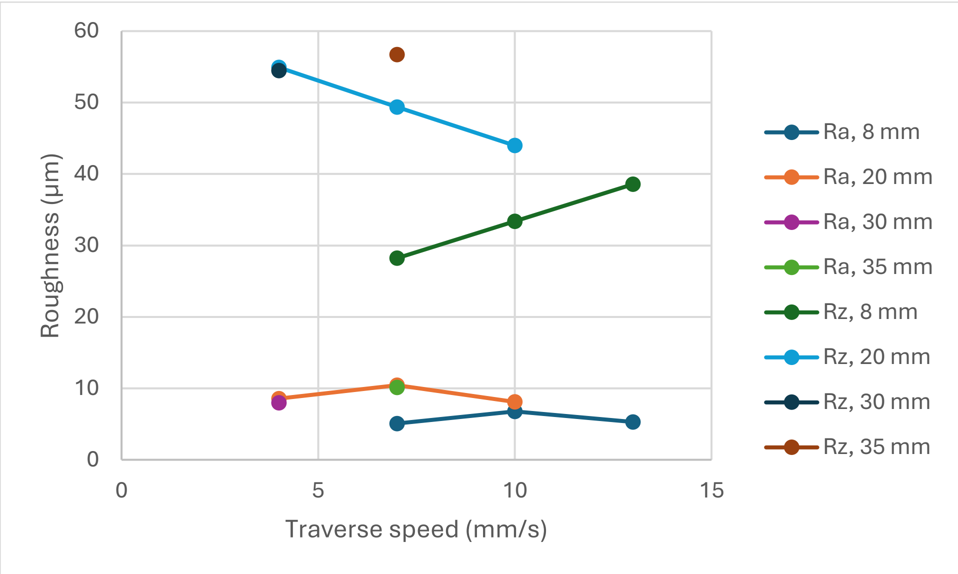

Fig. 9. The relationship between roughness *Ra* and *Rz* and traverse speed for 2/3 of the depth

From the charts, it is possible to determine at what speed, for a given thickness of sheet, the best quality of the cut surface can be achieved, as in the study, the same current intensity was set for each sample of the same thickness. The surface roughness of the cut surface is strongly dependent mainly on the cutting speed and the set current intensity.

Parameters that better illustrate the effect of parameters on surface quality in plasma cutting are the height parameters *Rz* and *Rt*, as they are much more illustrative of the change in surface roughness than the arithmetic mean parameter *Ra*, which is better suited to the study of machined surfaces owing to its widespread use in the industry. Using mean parameters such as *Ra* when measuring roughness after thermal cutting can suggest that the surface is better than even visual observation of the surface suggests—Figures 8–9.

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4. Conclusions

It can be noticed that speed has a significant impact on the quality of plasma cutting. Properly setting of the torch travel speed can improve the quality of the cut surface. At the same current intensity value, cutting speed becomes the most important technological parameter in the plasma cutting process. Therefore, during the process, close attention should be paid to the angle of molten metal ejection, as it is largely dependent on cutting speed-traces of machining after molten metal ejection are visible in Figure 3.

Analyzing the results for the sheets of different thicknesses, it can be concluded:

- For 8 mm, at a current equal to I = 60 A, the best surface quality is achieved at a speed of v = 7 mm/s.
- For 20 mm, at a current equal to I = 100 A, the best surface quality is achieved at a speed of v = 10 mm/s.
- For 30 mm, at a current equal to I = 130 A, the best surface quality is achieved at a speed of v = 4 mm/s.
- For 35 mm, at a current equal to I = 150 A, the best surface quality is achieved at a speed of v = 4 mm/s.

Depending on the intended use of the plasma-cut object, some cut materials with smaller thicknesses do not need to be further machined. However, objects made of thicker sheets require further machining processes, mainly because of high roughness, as well as the lack of perpendicularity of the surface.

Apart from the observations included above, it should also be noted that the additional value of the present research lies in the fact that there has been a scarcity of data in the subject literature for the material group here studied.

Acknowledgements

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Advance rams of longwall powered roof supports – modernization

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Abstract:

Powered roof support consists of repeatable units of support, set to load in the rock mass between the roof and the floor. Their task is a correct protection of the working, of the machines/devices and workers. Its compact design, a big extent of the roof coverage and a unit control ensure a correct and economic operation of a longwall. A walkway in front of the legs ensures safety and a big comfort for the working crew.

Supports meet all the safety and ergonomics requirements according to the PN-EN 1804-1,2,3 Standards concerning safety and ergonomics of constructions. They meet basic safety requirements for machines and components according to the 98/37/EU Directive and basic requirements for devices and protective systems to be used in the spaces where an explosion hazard occurs according to the 94/9/EU Directive as devices of Group I, M2 Category. The main objective of this article is a presentation of a repair of a powered roof support subassembly such as an advance ram.

Keywords: powered roof support, advance ram, modernization, inspection

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1. Introduction

Powered roof supports are described as units of supports started hydraulicly or mechanically. They are set to load between the roof and the floor. They must meet safety and ergonomics requirements according to the PN-EN 1804-1:2004 [1] Standards, concerning safety and ergonomics of constructions. They meet safety requirements for machines and components according to the 98/37/EU Directive [2] as well as the requirements for devices and protective systems to be used in the spaces where an explosion hazard occurs according to the 94/9/EU Directive [3] as devices from Group I, M2 Category.

The present supports use hydraulic rams as executive elements and that is why in literature they are described as hydraulic advance supports. Support units are basic components of powered roof supports and they are described as assemblies of supports.

In a powered roof support unit, the following components can be distinguished:

- basic elements,
- elements of fittings,
- additional elements.

Basic elements include all the indispensable components which transmit forces and loads. The following ones can be numbered:

- legs,
- canopies,
- floor bars,
- gob side-shields,
- bush bars,
- connecting elements,
- side shields.

Elements of fittings consist of the components indispensable for a correct operation of supports but they do not transmit loads caused by the rock mass. They include:

- advance system,
- guidance and correction systems,
- control.

Whereas additional elements include those which are indispensable for a correct operation of supports such as:

- relief elements,
- spraying devices,
- lighting.

During an operational cycle, powered roof supports must execute some determined functions. They can be defined in the following way:

- initial setting to load – it is setting to load of support unit between the roof and the floor due to an extension of legs,
- setting to load – an extension of piston rods of legs and rams due to an increase of hydraulic pressure,
- drawing off – an insertion of piston rods of legs and rams due to an action of the hydraulic system,
- yielding – extension/insertion of piston rods of legs and rams due to an action of an external force (e.g. an impact of rock mass),
- advance increment – translational motion of support in the result of advancing front of operations,
- advance – advancing of the conveyer or of the advance beam (following the extraction front) [4, 5].

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2. Materials and methods

2.1. Advance rams

The main task of advance rams consists in advancing powered roof support units to the wall and that is why they are also called rams of advance increments. They must generate the force needed for conquering frictional resistances between the supports (units) and the floor. While determining the force of advance increment the value of frictional resistances, resulting from an incomplete unloading of the unit from the roof pressure, should be taken into account. Jamming of rear parts of canopies and gob shields from the gob rocks should also be taken into consideration.

In the case of support units of single increment, the task of advance rams consists in advancing the conveyor towards the wall. However, in the case of exploitation with use of a plow, the task of advance rams is a generation of the appropriate force to press the plow head against the wall.

The value of the force which must be generated by advance rams results from:

- the weight,
- the conveyor stiffness,
- the devices connected with it,
- the local operational conditions (strength, shape of the floor),
- the size of the run-of-mine rubble in the panel,
- the pressure forces required for the cutting process.

The forces needed for a conveyor advance are in the range of 20-150 kN, whereas the pressure in advance rams can reach the value of 320 bar.

The rams used in advance rams are mainly made as rams of double action. They can also be made as:

- differential rams with a unilateral piston rod,
- differential rams with a unilateral dragged piston rod,
- rams of uniform motion with a bi-lateral piston rod [4, 5].

2.2. Types of advance increments

To execute a translational motion of a powered roof support unit (advance increment) advance rams are used. Three basic principles of advance increments are known:

- simple,
- coupled,
- follow-up.

In the case of a simple advance increment (Fig. 1), individual units of powered roof support, without any interconnections, are pushed to the armoured face conveyor or to the advance beam.

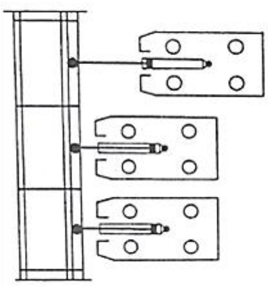

Fig. 1. Simple advance increment
Source: [4]

After having advanced the conveyor (or the advance beam) support units are advanced individually one by one. In this motion, the main spot of resistance is the conveyor supported by the units set to load. In the coupled advance increment, two or three frames situated next to one another are interconnected with hydraulic mechanisms of advance increments (Fig. 2).

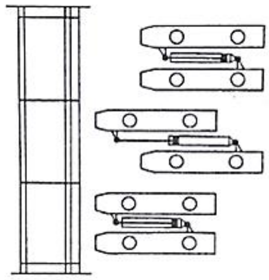

Fig. 2. Coupled advance increment
Source: [4]

Such advance increment units composed of two or three frames are called couplers. In practice two – or three-frame couplers are known.

The follow-up advance increment – the following individual units are positioned in series and they are mutually connected by mechanisms of advance increment.

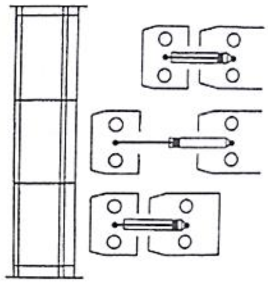

Fig. 3. Follow-up advance increment
Source: [4]

During an advance, each time one unit is lowered, whereas all the other ones are set to load. In this system the advancing unit is called a follow-up support. From the principles of advancing, described above, a simple advance increment has a dominating position. An advantage of this method is an individual mechanism of advance, at a simultaneous maintaince of distances of support units from each other. This type of advancing is simple and its resistance is significantly smaller than in the case of coupled advance increment. The support units maintain the direction of advance and the distance automaticly, when they are attached to the conveyor or to the advance beam.

Pulling of the support unit during a follow-up advance uncovers the roof between the front and the rear canopy. A roof fall can occur through such a gap. When the advance ram is not attached to the conveyor, a follow-up advance increment causes problems with maintaining the advance direction and the distance between support units.

Taking into consideration the time sequence of the conveyor transfer and of the advance increment, an operation of powered roof supports can be performed as:

1. advance increment forward,
2. advance increment backwards.

An operation of powered roof support with advance increment forward is understood as a course of the process in the longwall: cutting, conveyor transfer – support advance (Fig. 4).

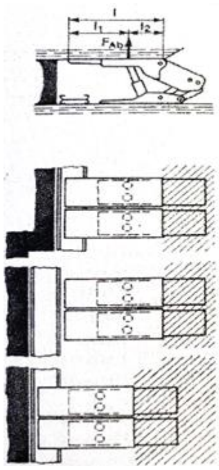

Fig. 4. System – with advance increment forward
Source: [4]

However, an operation of powered roof supports with advance increment backwards is a course of the process: cutting – pulling of supports – conveyor transfer (Fig. 5).

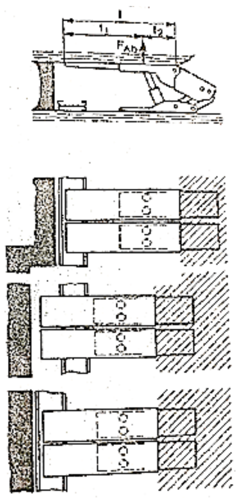

Fig. 5. System – with advance increment – backwards. Source: [4]

The time sequence of the conveyor transfer and of the supports advance has an essential impact on a unit design.

During an operation with an advance increment backwards, at the beginning of the cutting process, the support is one increment in the rear. This situation reflects a longer canopy extended towards the wall than in the case of the supports operated with advance increment forward. It is a disadvantage as regards a contact of the canopy with the roof. However, its advantage consists in a possibility of delaying an installation. In turn, an operation with advance increment forward is appropriate for the contact of canopies with the roof but inappropriate due to slowing down an installation.

Disadvantages of the aforementioned operational cycles are “softened” by proper design of support. For supports operated with the advance increment backwards, a better contact of canopies is obtained due to an application of articulated canopies (deflected canopies). However, for supports operated with the advance increment forward, a delay in installation is reduced due to an application of extended canopies. At present it lacks comparative data in the scope of roof control for these two modes of operation.

In the hard coal mining industry powered roof supports, operated with an advance increment backwards and with deflecting – extendable canopies, are in majority. Their advantages are:

- small lengths of elements – in particular essential for the transportation process,
- short delays in setting to load of supports,
- a good contact of the canopies system with the roof,
- a good roof control.

3. Results

3.1. Modernization of advance rams

An inseparable stage of extending life of mining support is its repair. After having finished a longwall extraction all the elements of supports are subject to profound inspection to indicate potential damages and then to implement repair processes adequate to damages. The main purpose of these processes consists in restoring initial technical parameters of individual elements of support unit making them useful again. There is special computer software, aiding repair processes. The software is helpful in indicating spots which require reinforcements or in particular cases a reconstruction [5, 6, 7].

A modernization of advance rams of the TAGOR-22/46-POz powered roof supports has been conducted in accordance with the scope of work required by the orderer.

A modernization of the G-2607.01.08.01.R1 (Fig. 6) advance system beam and of the G-2607.01.08.10.R2 (Fig. 7) bush bar has been conducted.

Fig. 6. Advance system beam before repair

Fig.7. Bush bars of advance system beam

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3.2. Modernization of the advance system beam

Modernization of the G-2607.01.08.01.R1 advance system beam consisted in:

1. Pad welding of worn-out surface with SG3 wire (Item **6**),
2. An exchange of elements for new ones (Items **10**, **16**, **17**),
3. Welding in an additional holder to the beam of 3-ton load capacity,
4. Regeneration of holes ϕ 62 – 2 items through pad welding and boring,
5. Pad welding and grinding of the socket insert to the basic size (Item **1** and **2**),
6. Marking according to operational manual,
7. Painting of one layer.

The advance system beam is presented in Fig. 8 where all the mentioned/repaired elements, in the drawing are marked in red. A system of forces, acting on the advance system beam during the conveyor transfer causes lifting of the beam rear part, the one among bases. Therefore, on the side walls of advance rams short guides are welded to limit this motion. However, the width of guides cannot be too big due to a necessity of installing an advance ram inside the beam. That is why additional plates are welded to the beam side walls. The main task of guides is an elimination of possibility of the beam extension above the guides (at one of bases).

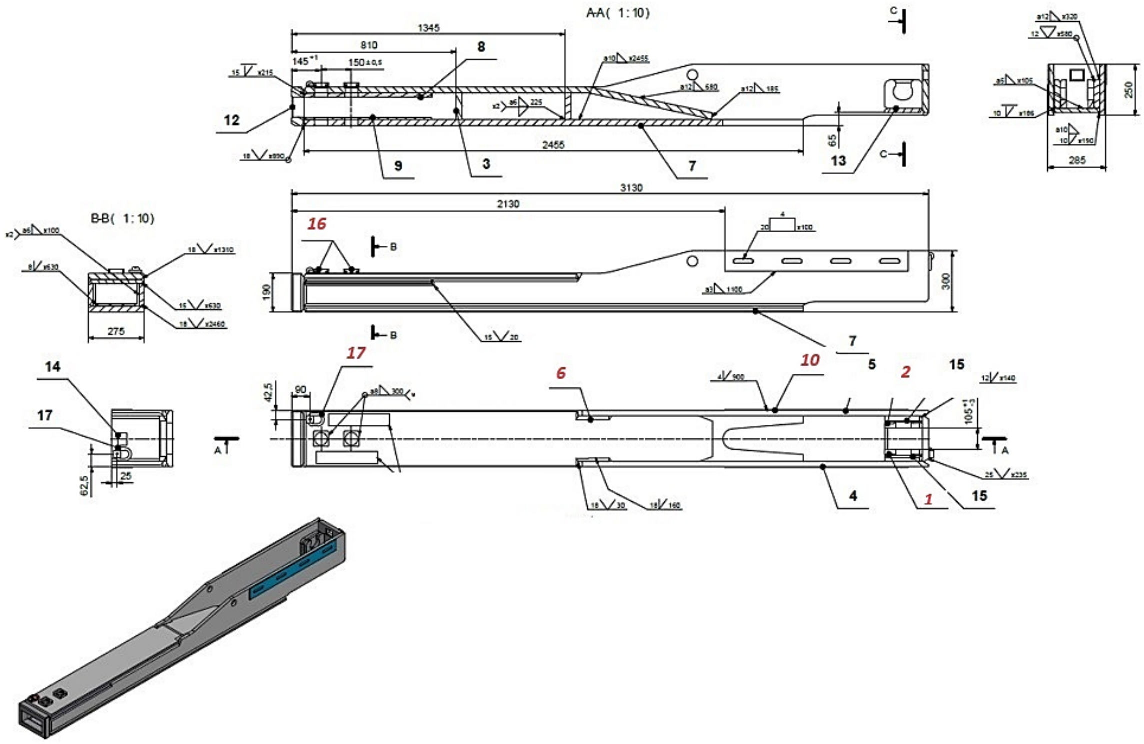

Fig. 8. Beam of the advance system

3.3. Modernization of the bush bar

Extended beams of the advance ram (bush bar) are used when due to lowering the front part of canopy at the longwall face there is a hazard of collision with the cutting drum. Then the beam is extended with pins inserted into the following holes and the support unit can stay in the rear. A modernization of the G-2607.01.08.10.R2 bush bar consisted in:

1. Straightening (Items **3** and **5**),
2. Regeneration of holes (in Items **3** and **5**) by pad welding and boring,
3. Holes from Items **3** and **5** – which preserved round shape – only cleaning,
4. Marking according to operational manual,
5. Painting of one layer.

The scope of modernization of the bush bar is presented in Fig. 9, where all the repaired/mentioned items are marked in the drawing with red.

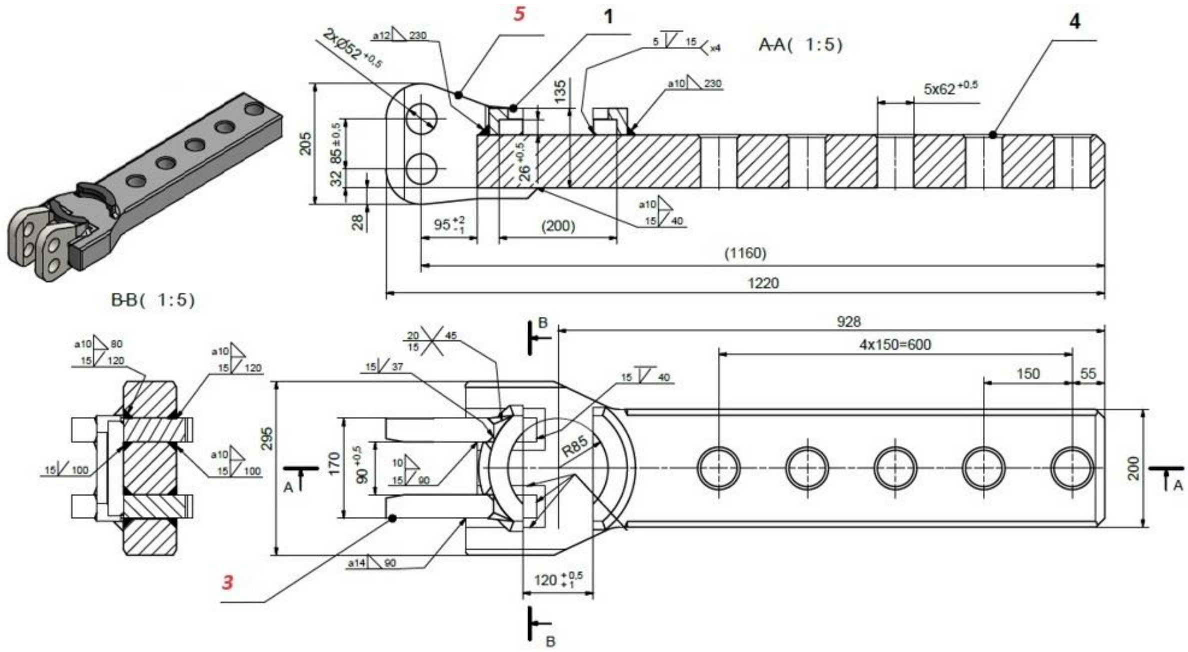

Fig. 9. Bush bar

4. Technical inspection of the repair process

The welding process of individual elements of the advance system beam was performed exactly according to the general and detailed Welding Technological Cards (Plans of Welding) and Technological Manuals of Welding, observing precisely welding parameters included in them [8]. The SG3 wire was used for welding.

A type of the bush bar, grade of basic material, method and position of welding, parameters of welding and type of additional materials – electrode wire and shielding gas were specified in the mannual. The technological process required to preheat the material initially to the temperature of 120°C. A check up of temperature took place about every 30 minutes with use of a pyrometer. Full penetration welds were made – all the welds were tested (UT). The holes, which required pad welding, were pad welded with the SG3 wire (Conformity Certificate, Fig. 10), with initial preheating to120°C.

Material	**Diameter**	**Type of spool**	**No. of melt**	**Amount [kg]**	**Date**
SG3	1.2	K300	5430492	15	13.02.2024

Chemical construction:

Melt	**C**	**Mn**	**Si**	**P**	**S**	**Cr**	**Ni**	**Cu**	**Mo**	**V**	**Al**	**Ti+Zr**
Requirements acc. to PN-EN ISO 14341 – A Standard	0.06-0.14	1.60-1.90	0.80-1.20	max 0.025	max 0.025	max 0.15	max 0.15	max 0.35	max 0.15	max 0.03	max 0.02	max 0.15
5430492	0.08	1.68	0.96	0.010	0.010	0.020	0.02	0.21	0.013	0.013	0.009	0.09

Mechanical properties of binder:

Classification/melt	**Re [MPa]**	**Rm [MPa]**	**A5 %**	**Operation of breaking KV[J] temp.-40°**	**GAS**
Requirements acc. to PN-EN ISO 14341 – A Standard	min 420	500-640	min 22	min 47	
5430492	458	545	27	101	C1
5430492	476	545	28	101	M21

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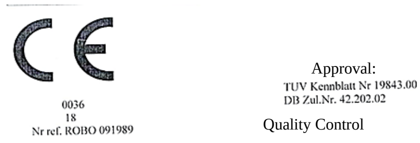

Fig. 10. Conformity Certificate - SG3 welding wire

An inspection of welds was performed based on the card of welds inspection. The welds were checked according to the requirements of PN-EN ISO 17635:2017-02 Standard [9] and kinds of non-destructive tests PN-EN ISO 17635:2010 Standard [10]. All the welds were tested visually in 100% (VT). The welds which should be tested with use of other methods are determined in the card of the welds inspection.

Before the final operation of painting the beam of advance system and bush bar were subject to final inspection. The inspection consisted in checking a correctness of repaired elements according to the delivered documentation.

The diamensions of diameters and spacing of holes as well as checking a functionality of connection of the advance system beam with the bush bar were carried out with use of gauges and control templets.

Fig. 11. Beam of advance system and bush bar after repair

Results of measurements were inscribed in the measurement card and stored in archives. Ready, repaired elements of powered roof support are presented in Fig. 11.

5. Conclusions

Powered roof supports, as basic elements of a longwall system, decide about safety of people and machines working in a longwall face. Longwall powered roof supports, qualified as devices of increased hazard risk, require a special approach before their implementation into operation.

The second essential factor concerns functional requirements determined by users of powered roof supports. A necessity of meeting the requirements in this scope has stimulated a development of design form of individual assemblies of a powered roof support unit. This requirement has led to changes in a design form of advance rams of a powered roof support unit. A design change of advance rams has been caused by inconformity of the support unit increment with a web depth of a shearer. In the result of such changes bush bars have appeared.

Due to a collaboration of different types of powered roof supports in one longwall some changes in the design form of advance system beams have been introduced. A change in the length of the advance system (in the result of applying additional bush bars), enables a correction of the width of the face roof path. However, this solution has generated big costs and that is why bush bars have been applied.

Assemblies of intermediate bush bars, facilitating both a change in the length of the advance system beam and a proper connection of the support unit with the armoured face conveyor pan, appeared.

One of available methods is a connection of the advance system beam with the armoured face conveyor pan with use of a vertical pin. Such bush bars have been subject to a repair process.

An application of bush bars enables an improvement of collaboration of different types of powered roof support units in one longwall and a collaboration with a given type of an armoured face conveyor.

Intermediate bush bars are commonly used and they constitute an element of a powered roof support unit. An application of a given support unit in the following longwall (connected with a change of configuration of its equipment), causes a necessity of using intermediate bush bars. Their length and form is usually selected individually.

An application of an adjustable beam length of the advance system is also an essential fact as in practice it eliminates a necessity of correcting the shape of the gob side shields to seal the support units from the gob side.

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HADES: Security and Monitoring System for Selected Technological Processes in Polish Underground Mining

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Abstract:

A mine cannot operate without environmental monitoring systems and basic mining machinery and equipment. In individual mines, these systems work in various configurations. Current information from these systems is visualized in the mine dispatch rooms. This article presents the basic structure of the visualization system, focusing on those most commonly used in our mines. It highlights that the diversity of monitoring systems used does not favor their unification and integration, aimed at providing the entrepreneur with essential data necessary for making crucial decisions related not only to the functioning of individual facilities within a company but, most importantly, the entire enterprise. The article introduces a new proprietary HADES visualization system program used in JSW SA mines. This program, named after the first microprocessor-based dispatching system implemented in Polish mines several decades ago, enables the entrepreneur to make key decisions regarding the operation of the entire coal company and its individual facilities.

Keywords: visualization systems in underground mines, monitoring of mining machinery and equipment

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1. Introduction

Geological and mining law, along with its implementing acts [1, 2], obligates the entrepreneur to monitor both environmental hazards and the technological processes of the mining facility. This requirement involves the necessity to monitor the operational status of essential mining machines and equipment used in the mine. Monitoring systems in the mine are not limited to observing selected areas using cameras but primarily involve cyclical measurements of many technical parameters of machines and equipment used in the workings, and presenting these results on monitors at selected observation points.

The data collected by monitoring systems in mine dispatch rooms are used not only for the diagnostics of machines and equipment but, above all, for the analysis and proper organization of the work of individual technological processes in the mine.

Different monitoring scenarios can be implemented in the dispatching system [3], the most important of which are:

- Technological: This scenario involves the control of a selected group of technologically interconnected devices.
- Territorial: Characterized by the supervision of various devices located in one area of the mine (e.g., a longwall face or heading).
- Hierarchical: A synthetic monitoring and evaluation of the state of many different processes that determine production or safety conditions throughout the entire mine.

2. Materials and Methods

2.1. General structure of the monitoring system in the mine

The general structure of the mine's dispatch monitoring system is shown in Fig. 1. [4].

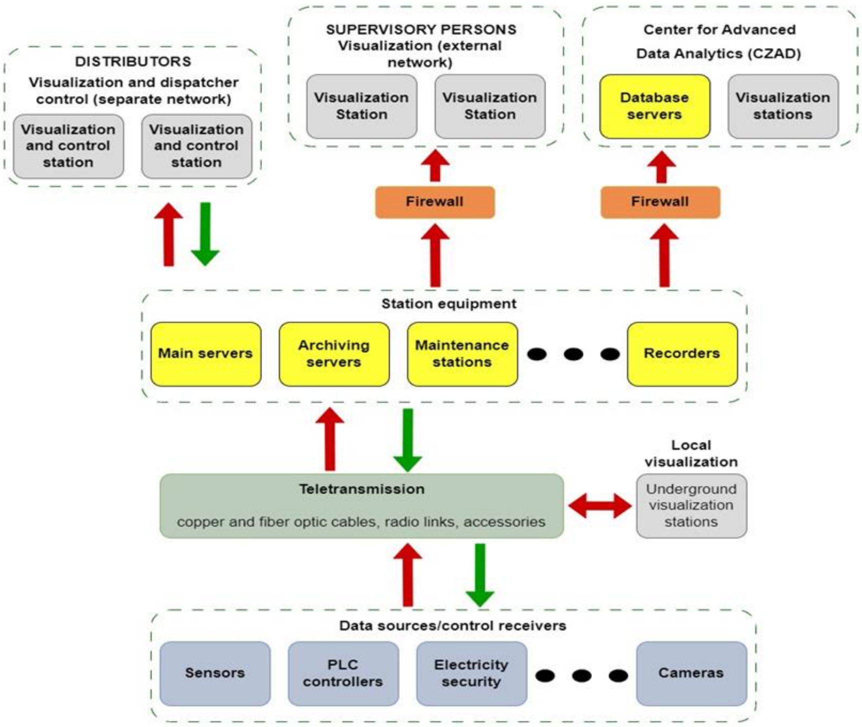

Fig. 1. Block diagram of dispatcher monitoring systems
[source: own study]

In the mine's dispatch system, three main layers can be distinguished:

- Data sources: PLC controllers, local stations, protections in electrical devices, cameras, and other end devices (sensors, signalling and executive devices).
- Telecommunication networks: Copper and fiber optic networks along with accompanying devices.
- Station devices: Such as central units, servers, control stations, visualization stations, maintenance stations, video recorders, etc.

In certain situations, it is possible to control underground devices (e.g., switching on and off switches in the power network). Data from the servers is also transmitted to visualization stations in the mine's general network (the so-called external network) using appropriate measures for protection against cyberattacks.

3. Computerized systems for monitoring technological processes operated in JSW SA mines

Initially, due to technical capabilities, so-called binary state visualization systems for mine technological processes were constructed. In 1980, at the Moszczenica mine, based on the PRS-4 industrial microcomputer, the so-called Modular Dispatch System type MSD-80 was launched. One of its modules was a system for controlling production parameters and selected safety parameters, commonly known as HADES [5].

It was intended for:

- Binary control of the operation of machines and equipment forming technological sequences (longwall faces, main haulage).
- Balancing of the extracted material (at loading points and shafts).
- Control of the operation of machines and equipment not linked in technological sequences, such as development faces, pumps, compressors, scales, fans, seals, water levels, water pressure in fire pipelines, etc.

By the late 1980s, this system was replaced by the upgraded MSD-90 system, which featured a new production control module called microHADES (μHADES) [6]. It allowed the processing of signals from approximately 2000 binary and counter inputs, serving as an intermediary for their visualization.

The advancement in computer technologies also enabled the development of so-called dynamic synoptic tables (DTS-1), which used semi-graphic monitors (typically with a resolution of 25 lines of 80 characters each). DTS-1 was implemented from the late 1980s. Information about the technological process in the mine was most commonly displayed on screens of six 23-inch graphic monitors.

In the 1990s, the ZEFIR system became widespread. It was the first dispatch visualization system utilizing IBM PC-class personal computers running under the DOS operating system. This system, after numerous technical and software modifications, is still in operation in most mines today, setting many informal standards for the functioning of computerized visualization systems in mines [7].

As the development of computer-based monitoring systems for machines and equipment progressed, manufacturers began offering their own (proprietary) software for visualizing individual technological processes. This made the integration of monitoring systems more difficult. Developers of universal visualization tool software had to coordinate data exchange protocols with the manufacturers of transmission systems.

An analysis of the current state revealed that several different visualization systems are used concurrently in every Polish underground mine. Some are used by the main dispatcher, others by the methane monitoring dispatcher, and still others in energy-mechanical dispatch centers or transport control centers. Table 1 presents examples of visualization systems used in Polish mines [7, 8].

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Table 1. Examples of monitoring, control and visualization systems used in Polish mines

System	Company Name	Description
DEMKop	SOMAR Katowice	This system is used for visualization and generation of reports from the data which is obtained from machines and devices. This is dedicated to the control rooms of hard coal mines. SMok is used as a hardware solutions
e-kopalnia	FAMUR Katowice	This is a mining machinery supervision system that consists of a set of ICT solutions, hardware, and measuring tools. The main elements of this system are machine control devices (e.g. FAMAC: MRS, OPTI, DMP), IT systems (like servers, LS local station, MPC I computer), hardware, and software diagnostic systems
EMAC	ENERGO TEST	A system which is used for the industrial facilities and this is dedicated to power grids. it cooperates with PLC controllers of these devices and protections equipped with an open communication protocol
eSPiM CSBiRE	WINUEL Wrocław	eSPiM is used for the Electronic energy metering and billing system and CSBiRE is used for the Central Energy Balancing and Settlement System. These systems are used for the visualization, reporting, and management of electricity consumption; used in KGHM.
MonSteer-D	Tranz-Tel Kobiór	FOD-900 is a Dispatch supervision system that is designed to gather and transmit information from the underground mine. This is also used for the plant operations and safety dispatcher
SAURON	RedNT (RNT) Cieszyn	The SAURON visualization system which is used for Control, Traffic Automation and Supervision. This system is used for communication with the IEDs of mining equipment and dedicated software applications (which is known as modules) such as: Pumping Stations, 6 kV Network, Haulage, Walls, Faces, Skips, Loading, Air Conditioning, ZPMW
SD-2000	EMAG	This is a Dispatching visualization system - Utility software.
SmartWall	Elgór+ Hansen Chorzów	Integrated system which is used for control, visualization and monitoring of mining machines and equipment. The system has proprietary hardware components (e.g. flameproof computer EH-O/06, control panel EH-O/01, separator EH-O/03) and software components for visualization and control (e.g. KESSA-ATON, EH-WallView, EH-MineView)
SP3	HASO Tychy	This is the Abbreviation of the words: "Industrial process presentation system" Utility software
SWµP	HASO Tychy	The Computer support system work as methanometry dispatcher; Utility software
SYNDIS (RV)	MIKRONIKA Poznań	This is Supervision, Consulting and Control System used for Industrial Installations. This system is used for monitoring and controlling the operation of the mine's power system; is used in KGHM
THOR	SEVITEL Katowice	This is a Dispatch system which is used for visualization, monitoring, archiving, generating reports and control. Utility software
WIZAS	Becker Warkop	Visualization system which is used for longwall machines with dedicated BECKER controllers
WIZCON Supervisor	Wizcon	This is a Dispatch system which consist of WIZCON visualization module; popular SCADA software that allows you to manage processes using a web browser
ZEFIR ZEFIR/NT	PRUNELLA Katowice	This is the first dispatcher visualization system used in many mines. This is used for the first time in 1991 in the Andalusia mine

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4. Genesis of the HADES system implementation

In the European Union (EU), coking coal mined by JSW SA is classified as a critical raw material because it is essential for steel production. Poland supplies only 25% of the total demand for coking coal in the EU. Considering this, a few years ago, the management of JSW SA prepared a new business strategy that significantly incorporates the ongoing digital transformation in the mines towards the development of the so-called intelligent mine JSW 4.0. One of the tasks of this transformation was the establishment of a specialized IT unit at the enterprise level, IT Systems JSW SA, whose primary tasks included the creation of the Advanced Data Analytics Center (Polish abbreviated name: CZAD JSW 4.0) and, in the area of monitoring, the Central Technological Data Server (Polish abbreviated name: CSDT). CZAD was a fundamental element of a comprehensive plan to increase production management efficiency, standardize the broad area of automation, telecommunication, and IT systems supporting JSW SA's production processes [9].

Data on the operation of key machines and equipment, describing the course of production processes, are dispersed across the various technological systems of the mines. Integration of data from different areas, considering the functionality and performance of dedicated SCADA systems in the mining industry (Table 1), is limited and has not yet been conducted at the enterprise level.

Addressing this issue, in 2018, the JSW SA capital group began implementing the "Standardization of Data and SCADA Systems" project. As part of this project, JSW ITS Systems launched a new proprietary SCADA system named HADES, based on the Asix Evo platform by Askom. The name of the new SCADA system refers to the history and launch of the first microcomputer production parameter control system in the MSD-80 modular dispatch system at the Moszczenica mine over 40 years ago.

For better cooperation with the individual units of the JSW SA Group (Polish abbreviated name: GK) in the various mines (facilities), automation departments (Polish abbreviated name: EDA) were established independently of the communication departments (Polish abbreviated name: EDŁ).

The establishment of new, multi-kilometer fiber optic networks at both the enterprise level (GK JSW SA) and in the workings of individual mines enabled the real-time transmission of a large amount of data to CZAD and the central CSDT server in IT Systems JSW SA [10].

The expansion of CSDT with new reporting methods, the use of artificial intelligence in expanding the knowledge base about the course of mining operations, and the utilization of the PI System (*The PI System is a solution for managing very large amounts of data generated in an industrial environment; it is a tool that collects, archives, manages, and analyzes vast amounts of sensor data. It provides online distribution of this data to users and applications that need it at any given moment*) in HADES allows the creation of specific reports for the company's management and key personnel. These reports, in the form of dashboards (*A dashboard is a specific type of report where the most important information and indicators related to the company's objectives are presented in a visual format. This information is displayed on a single screen (large-format panel*), contain essential production data and selected economic indicators of the entire enterprise or specific technological sequences in individual facilities, all displayed on a single screen.

5. Construction and modules of the HADES Visualization System

The HADES system includes [11]:

A virtual machine used as an application server with Asix software and Microsoft SQL Server installed. A virtual machine used as a terminal server with Asix software installed, equipped with a Remote Desktop Services (RDS) license.

User (and administrator) workstations, i.e., computer stations connected to the network infrastructure, providing access to the HADES system via the Internet Explorer web browser or the RemoteApp service.

The architecture of the HADES system is shown in Fig. 2.

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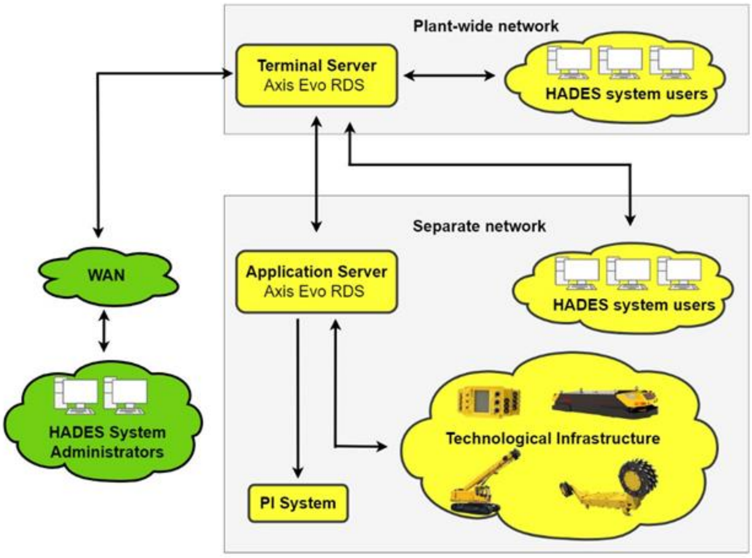

Fig. 2. Architecture of the HADES system
[source: 11]

The HADES system, developed for the needs of JSW SA mining facilities, performs the following functions:

- Acquisition of measurement data from other devices and monitoring systems operating in various JSW SA mines (Table 1).
- Visualization and control of selected technological processes.
- Alarm notifications about dangerous events, data archiving, and analysis of archived data, including reporting.
- Data transmission to MES, ERP systems, and business analysis tools.
- Data sharing with MS Office suite (MS Excel).

The HADES system has a modular structure, allowing for the successive connection of additional devices or entire installations, visualization of their operation, and control of devices and processes. The modules of this system developed so far are usually named after the primary service performed by the module:

- Visualization and control of switches and transformers.
- Control of 6 kV electrical substations.
- Central reactive power compensation system.
- Energy media measurement and billing module.
- Methane balance. Monitoring of the underground methane drainage network.
- Visualization and control of methane drainage stations.
- Media monitoring. Visualization and control of pumping stations.
- Visualization and control of reduction and filtration stations.
- Visualization and control of shaft heaters.
- Visualization of central air conditioning.
- Visualization of the operation of main ventilation fans.
- Monitoring of nitrogen generators.
- Scales and analyzers.
- Supervisory system for ZPMW.
- Visualization of longwall complexes.

Network communication is required to acquire data from devices located in individual mining facilities, which are the sources of measurements, for further processing, archiving, and making process

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data available for visualization and control. Control of automation actuators is possible via serial communication or through Ethernet networks using protocols implemented in the HADES system.

Data acquisition from devices is performed by software installed on the application server. Communication is carried out through the LAN using industrial automation protocols, such as OPC DA or UA, Modbus TCP/IP, S7 Communication, or Profinet, as well as other native protocols available in the HADES system. For industrial automation protocols based on TCP/IP, the plant network or JSW WAN networks are used. Data acquisition from end devices in the case of serial communication is conducted via media converters or converters of the appropriate protocols.

Data exchange between user workstations and the application server is carried out indirectly through the RDS terminal server using various protocols (e.g., HTTPS, Asix Network, RDP) and ports (e.g., ports 443 (*Port 443 is a virtual endpoint through which all data transmissions are sent and received. It is communicated via the transport layer protocol TCP, which helps in directing network traffic to the endpoint*), 6000 (*Port 6000 can use a defined protocol for communication depending on the application; it is a set of formalized rules that govern how data is transmitted over the network to ensure the communication is most efficient*), etc.). Data flow between user workstations in the general plant network is filtered by a firewall. The HADES system has the capability to transmit data to the PI System in CZAD for further process data analysis. Depending on the required exchange protocol, the application server configuration provides process data to the PI System via the OPC UA or Modbus TCP/IP protocol.

Using the HADES system requires user authentication (confirmation of identity by providing a password associated with an account) and access to appropriate resources and the ability to perform certain operations requires authorization, which is the verification of the authenticated user's permissions. Authorization is related to assigning the user an appropriate role. The following roles are defined in the system [11]:

- Observer: Ability to view application screens.
- Operator: Ability to view application screens, alarms, and blocks, and change descriptions.
- Local Administrator: Ability to view application screens, control devices, clear alarms and blocks, change descriptions, and edit users and their permissions.
- Administrator: Ability to view application screens, control devices, clear alarms and blocks, change descriptions, edit users and their permissions, edit visualization screens, variable databases, and add additional devices.

In the HADES system, backups of servers are performed daily, weekly, and monthly. Daily backups are executed cyclically during nighttime hours and are retained for a period of two weeks. Weekly backups are performed on weekends and are retained for a period of one month. Monthly backups are performed on the first weekend of the month and are retained for a period of three months.

6. Example visualization screens of the HADES System

As mentioned in the previous chapter, the HADES visualization system can activate many monitoring modules for selected technological processes. These modules are also available in the SCADA systems currently operated in the mines (Table 1). In the plant dispatch rooms, longwall and development faces, belt conveyors, and shaft operations are most commonly monitored (in binary systems: working/stopped, open/closed, etc.). Methane monitoring dispatchers monitor gasometry systems, fans, and seals. In the energy-mechanical dispatch rooms, 6 kV power substations and selected electrical parameters of key machines and equipment responsible for material extraction are monitored. Many publications have presented selected screens from these modules, for example, from the ZEFIR, THOR, SAURON SmartWall systems [8, 11].

Since all JSW SA mines are highly methane-prone, the creators of the Hermes visualization system have implemented four modules related to this hazard in addition to the aforementioned modules. These are the modules: methane balance, monitoring of the underground methane drainage network, visualization and control of methane drainage stations, and the energy media measurement and billing module.

Methane drainage systems are operated in JSW SA mines. JSW supplies (sells) this methane to the Jastrzębie Energy Company (SEJ SA). Visualization and mutual settlements between the seller and the buyer are carried out using the HADES system.

Figure 3 [11] shows an example screen fragment from the Methane Balance module in the HADES system.

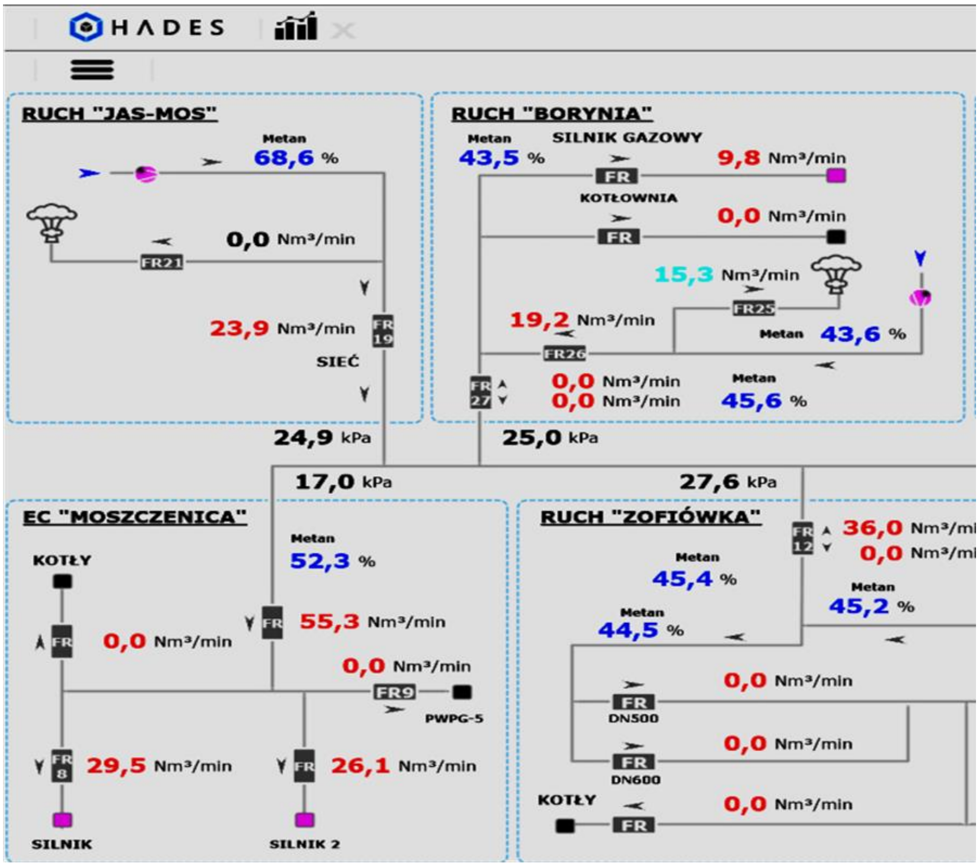

Fig. 3. Screen fragment of the gas network from the Methane Balance module in the HADES system [source: own study]

The visualization screen shows normalized flows, gas concentrations, and pressures at the measurement points of the methane drainage network. JSW SA mines have also initiated a project involving the construction of a measurement system for the underground main methane drainage networks using sensors and the CST-40 teletransmission system by HASO. For this application, the Methane Drainage visualization module was launched in the HADES system. In each JSW mine, points were selected in the underground main methane drainage networks where measurement systems should be installed. A measurement point included, among other things, a differential pressure transmitter, a methane meter adapted to measure methane concentration in the pipeline, and a pressure and temperature transmitter. Figure 4 shows a screen fragment from the Methane Drainage module for the Szczygłowice movement [11].

The screen shows values of normalized flow, methane content, pressure, and temperature at the individual measurement points of the underground methane drainage network. All JSW mines are covered by such a measurement system.

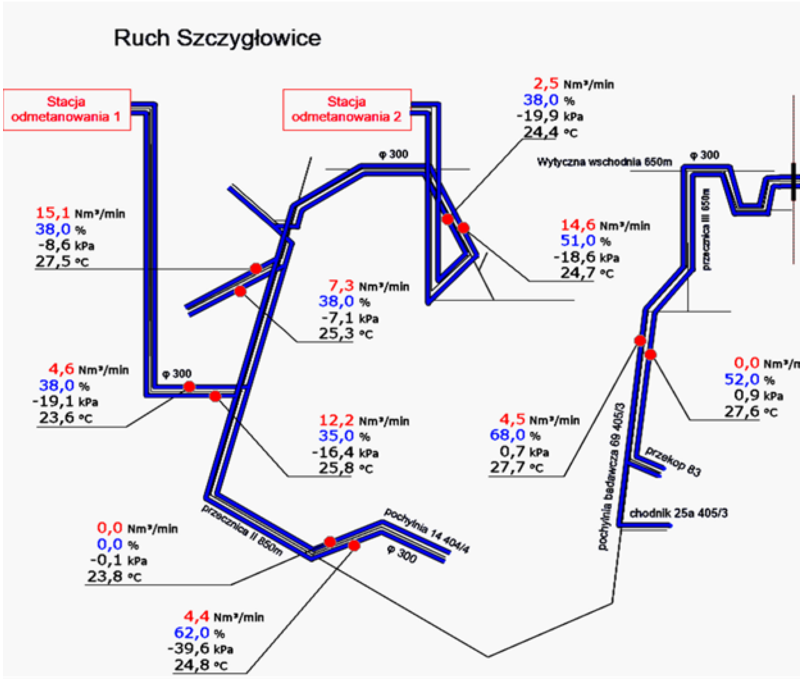

Fig. 4. Example screen fragment from the Methane Drainage module for the underground part of the Szczygłowice movement
[source: own study]

7. Conclusions

Increasing productivity in a mine can be achieved in several ways. In addition to costly replacements of existing technical equipment with new ones, one of the cheapest ways to achieve this goal is:

- increasing the effective working time of electrical machinery and equipment used in the mining plant,
- minimization of downtime, time wasted on uncontrolled failures of machines and equipment and shortening of interoperational activities (e.g. machine spacers).

These objectives can be achieved by introducing modern monitoring and visualization systems for technological processes in mines, particularly for essential mining machines and equipment. Unforeseen breakdowns should not occur in mines. Therefore, great emphasis should be placed on the continuous monitoring of electrical equipment, primarily for the early detection of irregularities in their operation and the proper preparation of planned maintenance.

The HADES system not only supports the dispatching of production processes but also aids the management in making key decisions at the level of the JSW SA Management Board.

Coal mines are considered "operators of essential services" and therefore must comply with the requirements of the National Cybersecurity System Act [12]. Ensuring cybersecurity in IT/OT networks is crucial due to the necessity of continuous operation of the mine's communication, alarm, and gasometry systems. This task is carried out by the specialized unit of the company, IT Systems JSW SA, which integrates and standardizes the teleinformatics systems operating in individual mining facilities.

The teleinformatics systems integrated into the HADES visualization system belong to the OT (Operational Technology) area, which includes both hardware and software designed for monitoring and/or controlling physical variables using executive devices in technological processes.

OT systems are most often integrated with the IT (Information Technology) area, which is essential for the operational (business) management of the mining enterprise, as these are the methods and means of operation related to information processing [9].

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Cybersecurity of IT/OT systems in key functional areas of a mining plant operating on the basis of the idea of INDUSTRY 4.0

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Abstract:

The article is based on practical experience and research, presenting the author's concept of applying the principles of cybersecurity of IT/OT systems in key functional areas of a mining plant operating based on the idea of INDUSTRY 4.0.
In recent years, cyberspace has become a new security environment, which has introduced significant changes in both the practical, and legal and organizational aspects of the operation of global security systems. In this context, it is particularly important to understand the dynamics of this environmental change (both in the provisions of the NIS 2 directive and the KSC Act) [1]. Building a legal system as a national response to the opportunities and challenges related to its presence in cyberspace was an extremely complex task. This results not only from the pace of technological change, but also from the specificity of the environment and its "interactivity". The trend in international law that has emerged during COVID-19 and the current geopolitical situation is to treat organizations from the mining and energy sector as one of the important actors in national and international relations [2].
The new regulations introduce and expand international cooperation between individual entities and regulate security strategies and policies, which should take into account the recommendations of the Ministry of Climate and Environment, with particular emphasis on, among others, ensuring the continuity of system operation, handling security incidents and constantly increasing awareness of cybersecurity and cyber threats. It should not be forgotten that threats in cyberspace represent a different class of organizational challenges, largely similar to those posed by other asymmetric threats such as terrorism. Their common feature is that they require less hierarchical and more flexible solutions on state structures. Cybersecurity, both socially and technologically, with all its consequences, emerges as one of the most important concepts of the security paradigm at the national and international level [3].

Keywords: Industry 4.0, mining, IT/OT, cybersecurity, data processing, AI in mining, economic parameters.

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1. Introduction

The second decade of the 21st century brought the events that led to a re-evaluation of the current thinking about security management in many domains, brutally verified additionally by the COVID-19 pandemic and the outbreak of the war in Ukraine.

Both of these events are equally important, considering that the armed conflict in Ukraine continues to negatively affect the level of security in neighboring countries, which have automatically become an arena of hybrid operations. This applies in particular to the Baltic states and Poland. As Microsoft reports show, in the contemporary hybrid war model, information influence operations based on social engineering techniques and supported by digital technology are becoming particularly important. Various events, including those taking place in the country, show that information operations can be as effective as complex attacks on industrial infrastructure, while being much cheaper. Currently, false information introduced into public space can be used to cause disruptions in the functioning of a sector that is important from the point of view of the security of an organization, community or state. For example, effective disruptions in the fuel sector can be achieved by causing social hysteria by introducing false information into the media about a significant increase in fuel prices or its limited stocks. A society susceptible to disinformation, subject to panic, will destabilize the situation on the fuel market. Such an operation will be much cheaper than the sophisticated actions of highly respected hackers. Examples of this type of activities make us look at the security of office computers, mobile devices, as well as industrial automation in a broader context [4].

The pandemic forced ICT system administrators to use solutions enabling remote work and learning in those areas where it was possible. A side effect of these then desirable actions was the emergence of new types of risk, related to the level of digital skills of the user who is outside the secure company network and uses important company data as part of his professional activity. In these circumstances, the issue of identity protection and the philosophy of authentication of IT system users become particularly important. During the epidemic, a similar situation was observed in industry. Pandemic restrictions on the movement of personnel, including service technicians, forced many companies to compromise in the area of OT security by allowing remote service and maintenance activities. Unfortunately, this meant additional system vulnerabilities and a potential threat to the continuity of operation of the infrastructure. As a result of these changes, certain risks have moved from the business layer to lower layers, exposing OT to threats in a greater extent than before [5].

Cyberspace protection has become one of the most frequently discussed security topics. Countries, international organizations and other non-state entities understand that the stable functioning and development of the global information society depends on an open, reliable and, above all, safe cyberspace. The growing awareness in this area goes hand in hand with a sharp increase in the number of computer incidents and the emergence of new types of threats.

Poland faces technological, environmental, but also social challenges related to the supply of raw materials that underlie our industrial activities. The civilizational transformation of our economy cannot take place without ensuring the monitoring and safety of industrial processes, these processes cannot be supervised without efficient exchange of information and access to the latest technologies, ICT, automation and control systems, the construction and operation of which is already the subject of routine activities of specialized services [3].

Analyzes of events and vulnerabilities - both reported by the energy sector to the competent authority and included in subsequent reports of consulting and auditing companies, show that a new approach to managing security, resilience and business continuity is needed. This is expressed, among others, by: recent legislative work at the European Union forum, as part of which, on December 27, 2022, amendments to two key directives were published, regarding the resilience of critical entities and measures for a common level of cybersecurity within the territory of the European Union.

The European legislative offensive, which cumulated at the end of 2022, led to the creation of a package of new directives and regulations that are extremely important for the regulated market that

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makes extensive use of digital technology. This is particularly important in the case of the NIS 2 Directive (Directive on measures for a high common level of cybersecurity across the EU) and the CER Directive (Critical Entity Resilience Directive). Both directives were created in response to new types of risks in cyberspace, which are based not only on events such as the pandemic or the war in Ukraine, but in particular on the models of functioning of modern supply chains. Nowadays, simple sequences of business processes are becoming less common. Modern supply chains are often complicated connections of smaller or larger sub-processes, the interruption of which may lead to a cascading effect and pose negative consequences unknown in advance. This prompts us to re-examine the areas that should be protected, what protection model should be used and whether an object-oriented or process approach should be used [3].

Unlike the existing legal solutions, the need to cover an entity with the NIS 2 directive will not be signaled by a notification or the issuance of an administrative decision - the interested entrepreneur himself should check whether the subjective scope of the regulation applies to him. The obligations that will be associated with the implementation of directives into national law will mainly concern the application of an approach to security based on risk analysis and the design of risk mitigating measures based on the zero-trust rule. In practice, this will mean giving up on the current principle according to which all resources should be locked in a safe network in favor of protecting these resources under one central policy. This approach significantly hinders the penetration of company resources, typical of today's attack vectors, by obtaining subsequent credentials as part of the so-called lateral movements. The resources that should be constantly protected include identity, data, applications, networks, devices and digital infrastructure. Effective strengthening of resilience in this area is only possible with the involvement of all possible stakeholders - from the management board and administrators to serial users of end devices.

2. Cybersecurity system in key functional areas of the JSW Group is a means to ensure business continuity

In the JSW Capital Group, a systemic approach to managing the security of IT/OT systems began to be created in mid-2017, when the "Strategy for the development of IT/OT systems of the JSW Group" was developed, in which the " Cybersecurity Program " was established. The next stage of strengthening the cybersecurity system being built was the adoption on March 6, 2018 by the Management Board of JSW SA of the "Model for management and supervision of the IT/OT area" in the Group, containing a security strategy along with a roadmap for further work [6]. These activities were intensified with the recognition of the JSW Group as a Key Service Operator in accordance with the provisions of the Act of 5/07/2018 (Dz.U. 2018, poz. 1560) on the national cybersecurity system [7], which led to JSW IT Systems launching on October 10, 2019 a support for JSW Group in implementing the obligations arising from the Act on the national cybersecurity system by introducing the "Model of management and supervision over the IT/OT area" adopted in 2018 and implementing [6]:

- antivirus system with the EDR module to detect and respond to suspicious activities on end devices; thanks to advanced technology that detects cyber-attacks at an early stage, it is an effective weapon against hackers, detecting suspicious activities at their initial stage,
- MDM class system combining the functionality of comprehensive security and the Enterprise Mobility Management (EMM) tool, including traditional mobile application management (MAM) and a mobile content management tool (MCM),
- Log Management system for centralized storage, monitoring, visualization and analysis of server/application/machine logs.

These activities preceded the decision on November 27, 2019 by the JSW Group to launch a strategic project entitled: "Expansion of IT/OT cybersecurity systems in key functional areas."

The historical context of the creation and supervision of the systemic security management of IT/OT systems by the author, along with the idea of establishing the Cybersecurity Information

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Exchange and Analysis Center for the mining sector, over the years 2017÷2023, is presented in Figure 1 [3].

The above-mentioned Act of 5/07/2018 on the national cybersecurity system-imposed obligations on operators of essential services [8]:

- systematically assessing the risk of incidents and managing this risk,
- implementation of appropriate technical and organizational measures proportional to the assessed risk, taking into account the latest state of knowledge,
- collecting information about cybersecurity threats and vulnerabilities to information system incidents,
- incydent management,
- applying measures to prevent and limit the impact of incidents on the security of the information system,
- using means of communication enabling correct and safe communication in within the national cybersecurity system.

Taking the above into account, in November 2020, the Company performed a security audit of information systems used to provide the Key Service - mineral extraction. Its aim was to confirm the compliance of the security of the information system used to provide Key Services with the requirements of the Act on the National Cybersecurity System [3].

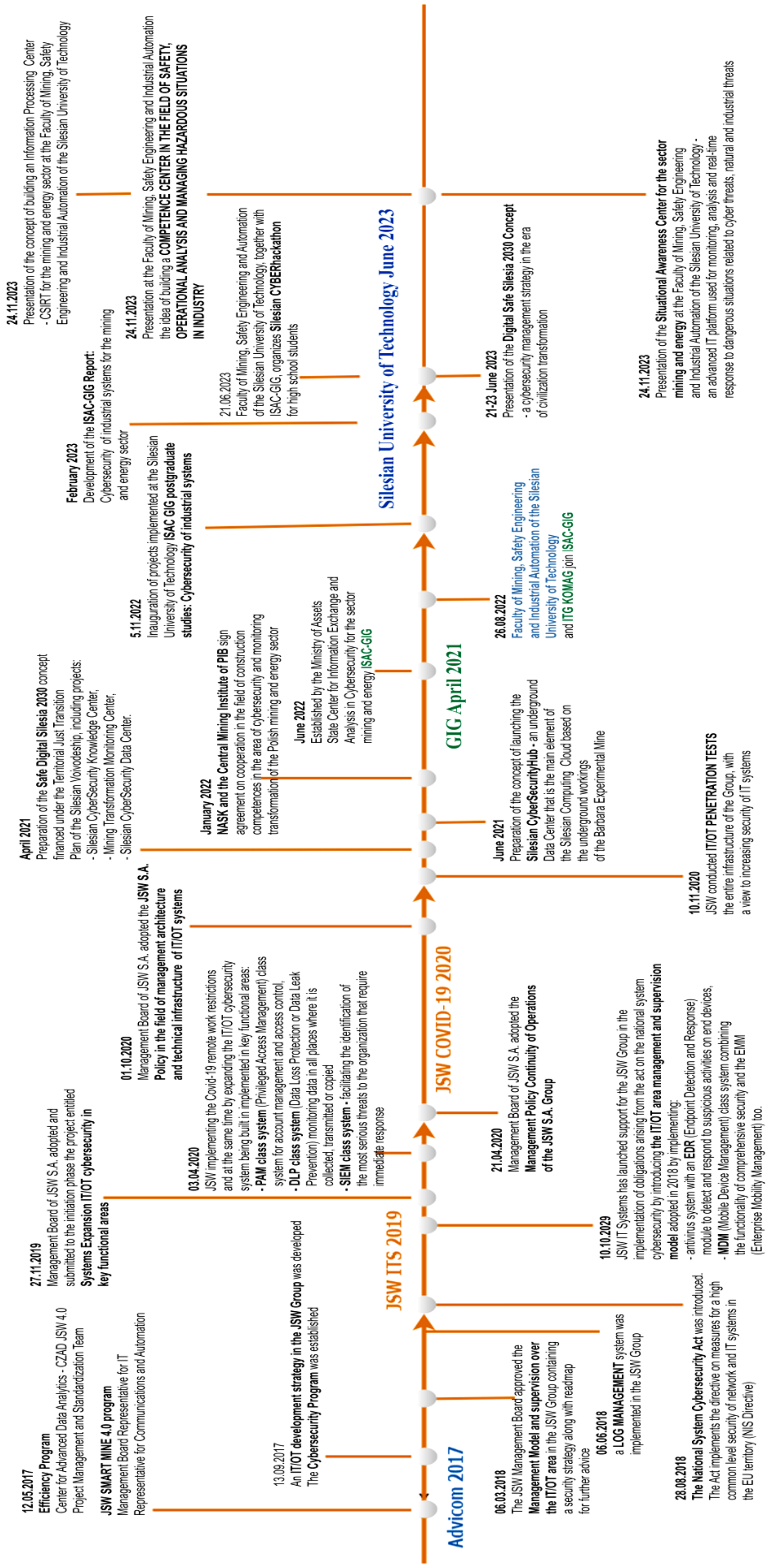

Fig. 1. Historical context of the author's creation and supervision of the systemic security management of IT/OT systems in the JSW Group, along with the development of the idea of establishing the Cybersecurity Information Exchange and Analysis Center for the mining sector, over the years 2017÷2023 [3]

The audit consisted of sampling the implementation of system maintenance processes with the support of external suppliers (including software updates, change management, vulnerability testing, system monitoring, ensuring the continuity of system operation, making backup copies and testing their correctness, controlling access to systems, documenting service activities, etc.). The scope of work included:

- understanding the context of the organization's operation, including the impact of IT and OT Systems (SI_OUK) on Key Services;
- confirmation of the fulfillment of the obligations of the Key Service Operator in accordance with articles 8-16 of the Act on the National Cybersecurity System;
- analysis of documentation regarding cybersecurity of the information system used to provide Key Services;
- tests of the effectiveness of control mechanisms;
- preparation of a report containing a description of identified non-compliances along with recommendations;
- presenting the results of the Audit to the Top Management.

The results of the audit allowed for the issuance of a positive opinion and the identification of a number of recommendations, the most important of which included the implementation of the following tools in the Company:

- PAM class for managing privileged accounts, which allows for effective monitoring of activities carried out using accounts with "super user" rights, e.g. admin, root, accounts with elevated rights in databases, servers, etc. (Fig. 2) [9].

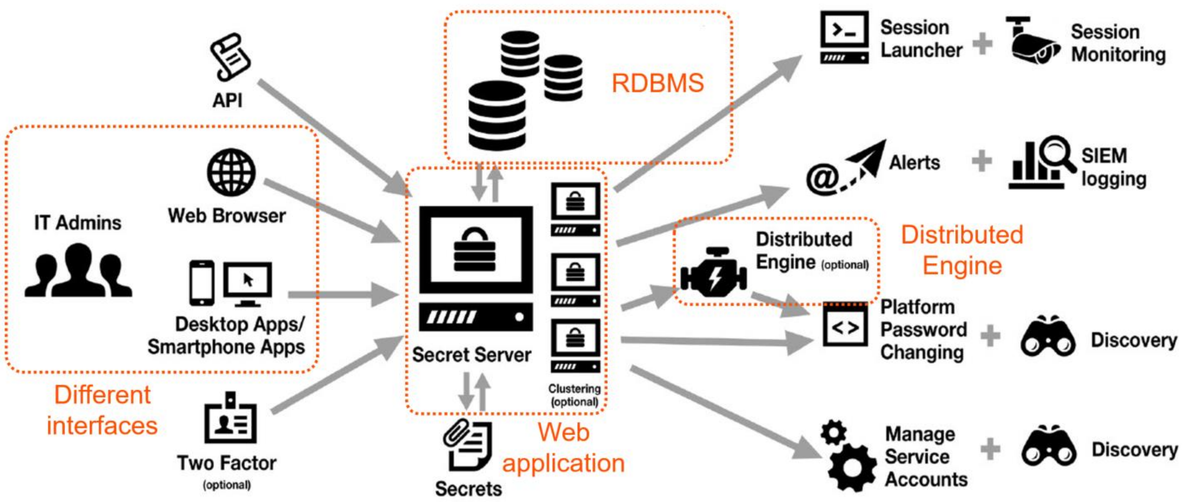

Fig. 2. Sample Privileged Access Management (PAM) System Architecture [9]

- SIEM systems provide comprehensive insight into what is happening on the network in real time and help IT teams actively fight threats. The uniqueness of SIEM solutions lies in the combination of security incident management with information management about the monitored environment (Fig. 3) [10].

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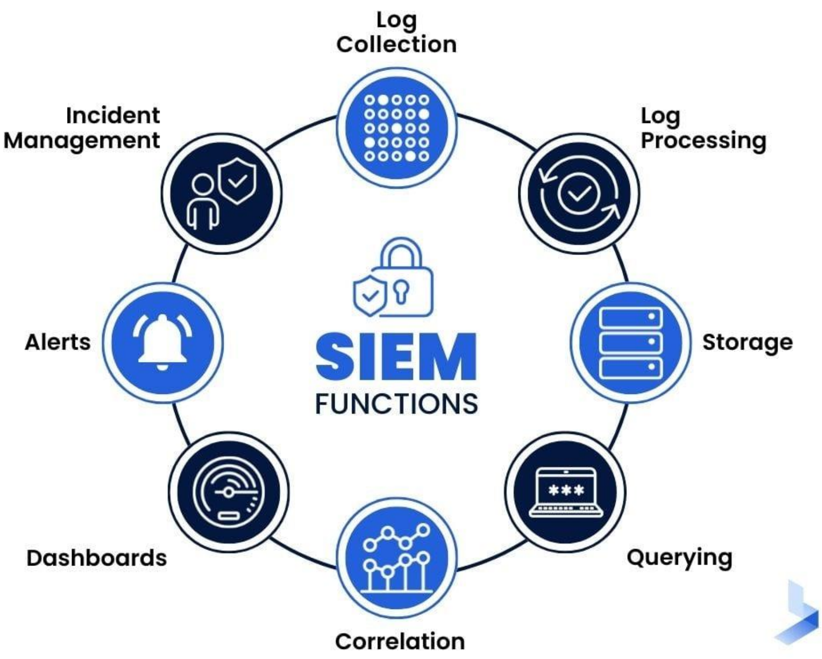

Fig. 3. Features of security information and event management (SIEM) systems, which are platforms that provide insight into the company's IT environment and help detect and respond to threats [10]

The tools used as a result of the implementation of the audit recommendations allowed the Company to provide a level of security adequate to the requirements and risk, ensuring that the protection of processed data is maintained at the highest possible level. They also allowed us to develop an optimal model of cooperation between the Privileged Access Management and Security Information and Event Management systems (Fig. 4 and Fig. 5) [3].

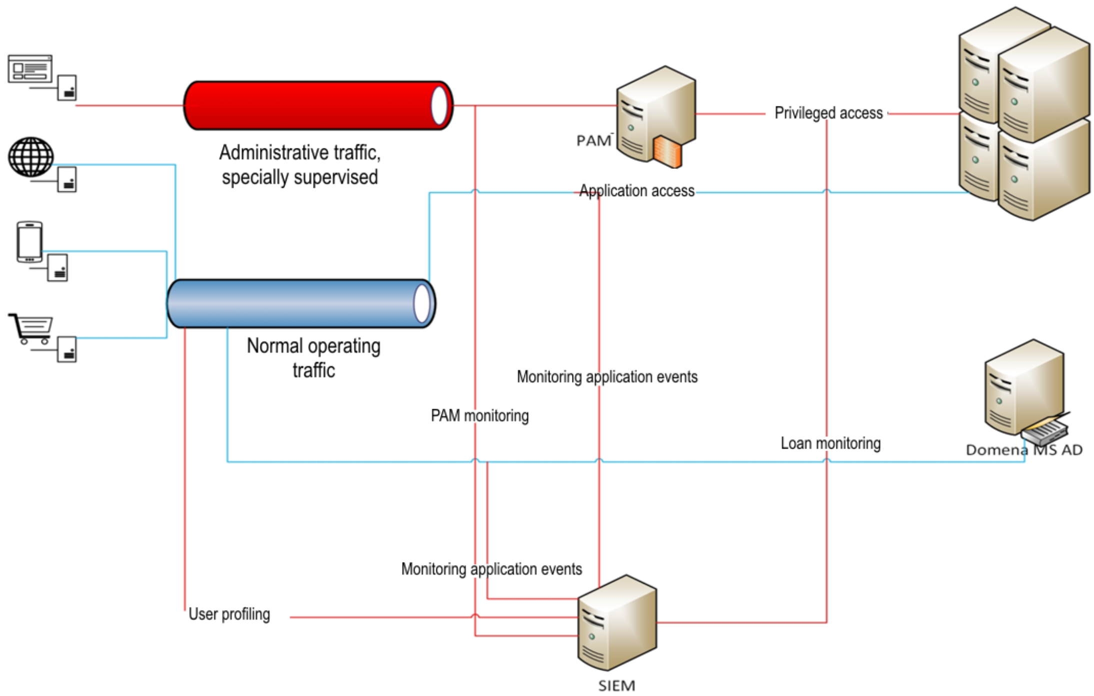

Fig. 4. Model approach for cooperation between SIEM and PAM class systems [3]

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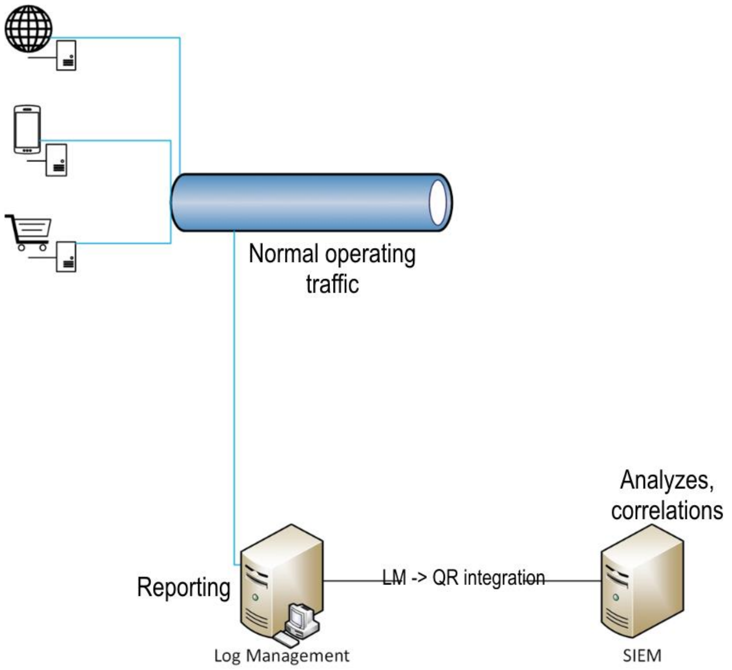

Fig. 5. Log Management SIEM model approach [3]

– DLP class system - monitoring data, searching data patterns, and in the event of an attempt to send or copy documents containing sensitive data (defined by the DLP System Administrator), blocking this action and notifying the administrator about irregularities. It is a tool that was created to tighten the information processing processes in the company. They effectively support business and security departments in understanding how, where and by whom critical data is processed - Fig. 6 [11].

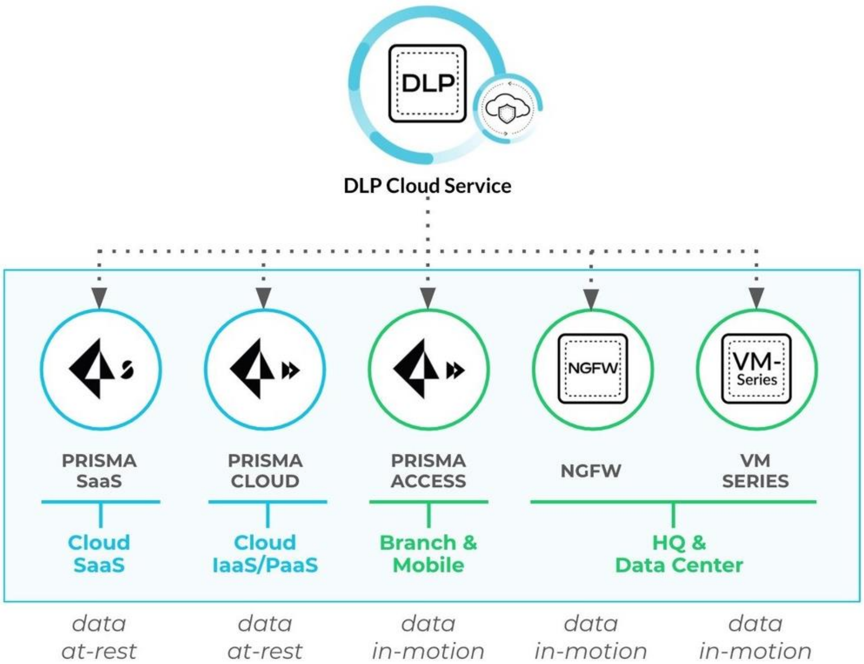

Fig. 6. Sample architecture of the Data Loss class system Protection DLP by Palo Alto Networks [11]

IT/OT cybersecurity system built in the years 2017÷2020 in key functional areas of the JSW Group allowed in 2020 alone to block approximately 900 domains that regularly harass the Company's IT network with phishing attacks, at the same time, the farms of JSW SA anti-spam and anti-phishing systems scanned and rejected approximately 1.3 million messages. Phishing currently accounts for approximately 49% of all cyberattacks and is sometimes difficult for an employee to identify. That is why it is so important to raise awareness and constantly train employees.

The year 2020 will always be associated with the COVID-19 pandemic. The Crisis Team at Jastrzębska Spółka Węglowa, established in March of that year, decided to start remote work for a significant number of employees, which created new challenges for the IT and OT services in the Company, forcing increased protection of the Company's IT infrastructure and blocking numerous attempts to infect workstations. Suffice it to say that in the second half of 2020 alone, JSW SA recorded approximately 8,000. domains showing "Malware behavior" and over 10,000 attempts to inject malicious code into workstations. These attacks were treated very seriously, bearing in mind the experience from December 2019, when the Ostrava-Karviná mines (OKD) were attacked by hackers, as a result of which, for security reasons, the entire OKD Company was interrupted in mining for almost a month. As it turned out, the hackers skillfully infiltrated the OT networks of Czech mines from the office network, using unsecured and infected end-user workstations for this purpose. The experience of the Czech OKD mines had a significant impact on the preparation of Polish mines for face attacks related to the CYBER area. An important activity was to conduct a continuous inventory of resources, IT/OT architecture, identify areas susceptible to threats and appropriate security. An essential element was to conduct cybersecurity training, which allowed a wide group of employees to be aware of the threats on the one hand and, on the other hand, allow us to operate in accordance with the adopted standards and Security Policies [3].

Currently, JSW SA together with JSW IT Systems is conducting a number of projects and implementations of systems that increase safety at work. The foundation of these projects is to increase the level of safety of crews and IT/OT processes and technologies. The cybersecurity strategy developed by JSW IT Systems in 2016÷2020 is based on stopping attacks (prevention), monitoring and determining undesirable events (detection), as well as implementing corrective actions (reaction). This is considered in relation to resources identified in the prism of protection of an extensive maturity model, extending the requirements of ISO 27001. Projects are implemented in cooperation with technological leaders in the field of IT/OT security on the market. The activities carried out strengthen the technical area of prevention by hardening the environment, controlling the tasks performed by employees and limiting the propagation of vulnerabilities in the internal network. In order to properly manage this infrastructure, the JSW SA Automation and IT Office was established at the Company's Headquarters, reporting directly to the President of the Management Board for Technical and Operational Affairs, which included the Automation and Teletransmission Team and the Advanced Data Analytics Team, closely cooperating with JSW IT Systems. This allowed the development and implementation on April 21, 2020 of the "Business Continuity Management Policy of JSW SA" and on October 1, 2020 of the "Policy of Jastrzębska Spółka Węglowa SA regarding the management of the architecture and technical infrastructure of IT/OT systems", including: "Conditions of access to separate networks in JSW SA plants" and "Guidelines for IT/OT solutions for the created Specifications of Essential Procurement Terms at JSW SA".

3. Ensuring business continuity

From the point of view of mining companies, it is critical to maintain business continuity and rebuild service continuity after a failure. Therefore, it is recommended to follow the Recommendations on actions aimed at strengthening cybersecurity in the energy sector and the sectoral guidelines on reporting incidents prepared by the Ministry of Climate and Environment in the field of cybersecurity for the Polish energy sector. Business continuity management is an activity whose aim is, among others, to: ensuring the operation of a given entity by protecting critical, key processes against the effects of incidents in the technological process area, as well as protecting information assets necessary to implement these processes. Business continuity itself can be defined as the ability of an

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enterprise to anticipate and respond to business process disruptions in order to maintain its operations at an acceptable, established level. Business continuity management should be a priority for every company. Therefore, it is recommended that the organization develops methodologies for maintaining business continuity, taking into account aspects that, according to the organizational specificity of a given enterprise, may affect this continuity, understood as maintaining key processes enabling the provision of a key service. It is recommended that a business continuity plan be developed for each type of threat that may occur according to the risk analysis, as shown in Figure 7 [12].

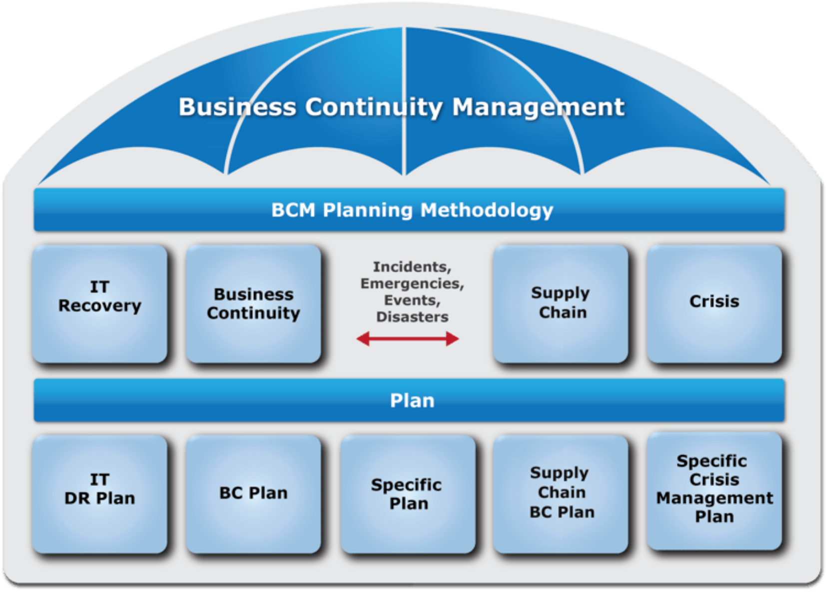

Fig. 7. Methodology for planning and managing business continuity in an enterprise according to the Business Continuity Management Institute [12]

Business continuity management is a holistic management process aimed at identifying the potential effects of threats and developing response plans. The key goal here is to increase the organization's resilience to business disruptions and minimize their effects. The definition of business continuity management includes not only business continuity (BC), but also crisis management (CM), crisis communication (CC), IT disaster recovery planning (DRP) and operational resilience (OR).

In the Jastrzębie mines, the "Business Continuity Management Policy of JSW SA" was adopted on April 21, 2020. It is generally a set of procedures and information developed to assess risk and plan business continuity in the event of any business disruptions and minimize their effects to an acceptable level [13].

The primary goal of business continuity management in the JSW Group is to protect the Company as effectively as possible against the negative consequences of critical events and to enable the restoration of original efficiency in the shortest possible time. By implementing the principles described in the Policy, the Company's Management Board expected to achieve the following goals:

– integration and coherence of contingency plans in the event of catastrophic disruptions in Critical Business Processes,
– ensuring supervision over the effectiveness and adequacy of maintained emergency plans,
– providing policies and tools to support BCP Plan Owners in their development and maintenance.

The policy applies to all issues related to the identification, analysis and development of rules of conduct in the events that have a strong impact on the course of Critical Business Processes. Business continuity management is presented in two perspectives: the efficiency of the Company's Critical Business Processes and the passage of time counted from the occurrence of events that result in a critical drop in this efficiency. The principles of conduct adopted in the Policy enable the

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development of effective response plans to the occurrence of an Extraordinary Event. The business continuity management model in the JSW SA Group is presented in Figure 8 [13].

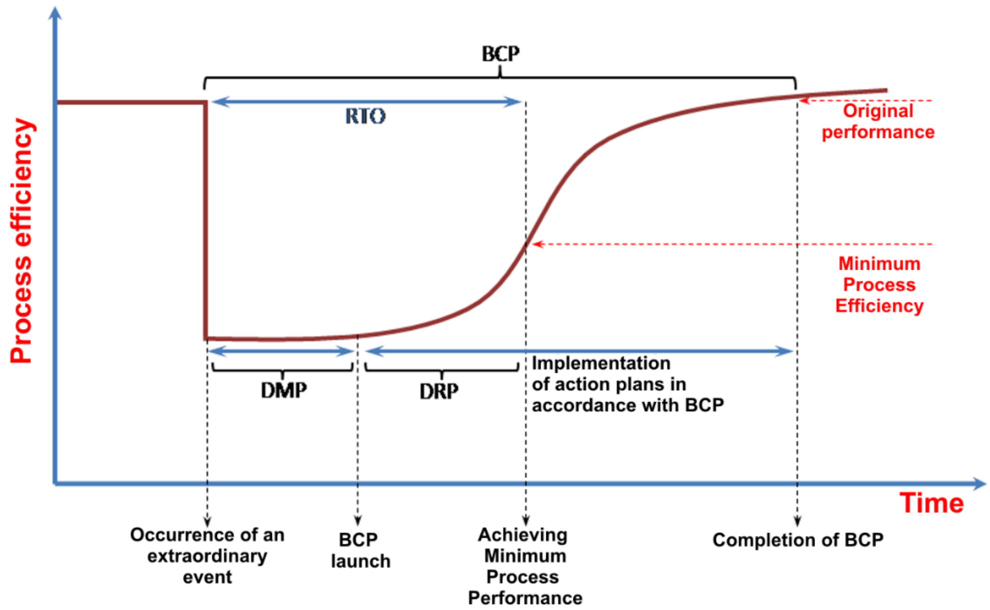

Fig. 8. Procedure diagram and main elements of the business continuity management system in the JSW Group [13]

The occurrence of an event that is considered in the context of loss of business continuity causes a sharp decline in the efficiency of the entire process. In order to be able to restore the lost efficiency in an optimal time, it is necessary to plan actions that will be taken immediately after the occurrence of an Extraordinary Event. The procedure is divided into three stages:

– activities from the moment of occurrence of an Emergency Event to the moment of formal establishment of a business continuity plan (DMP),

– activities undertaken as part of the announced and applicable business continuity plan and leading to the restoration of the minimum expected efficiency of interrupted Critical Business Processes (DRP), or the introduction of a maintenance mode,

– activities undertaken as part of the announced and applicable business continuity plan leading to the restoration of lost performance (BCP).

The first step after an Emergency Event occurs is to take steps to formally announce and implement the BCP. The procedure defined as DMP is described directly in the BCP plan. The essence of DMP is to use the shortest possible communication and decision path so that it is possible to effectively take actions aimed at maintaining Critical Business Processes.

After establishing the BCP, which includes a course of action taking into account assigned roles, rights and responsibilities, the Company begins to operate in an emergency mode. The first actions are aimed at achieving the minimum efficiency of interrupted processes that will enable it to survive, or establishing a maintenance mode. The activities that are performed at this stage are described in the DRP, which is part of the BCP plan. DRP is constructed taking into account the critical time during which the lost efficiency must be partially restored, thus enabling the company to maintain its operations. The time counted from the moment of occurrence of an Extraordinary Event to the moment of achieving minimum survival efficiency is defined as RTO.

After the Company achieves efficiency at a level that guarantees the resumption of Critical Business Processes or the introduction of the maintenance mode, activities related to restoring the state before the Extraordinary Event are carried out. In special cases, the nature of the disruption or the effectiveness of the solutions used so far justify making changes and restoring the lost functionality by using other methods.

After the loss of efficiency is achieved, the BCP operation is terminated, which is equivalent to the cancellation of the emergency mode. As in the case of introducing the BCP, in accordance with the described DMP procedure, the procedure for its cancellation must result from specific and described rules. The rules for canceling the BCP are described in each of the BCP plans prepared and adopted for use.

In the years 2020÷2023, Polish Ministry of Climate and Environment recommended mining enterprises to develop procedures for dealing with emergency situations, including [3]:

– action plans in the event of a sudden loss of operational capabilities caused by the unavailability of a large number of employees at one time,
– establishing methods of communication between people involved,
– developing procedures for training employees with similar competences and transferring them, if necessary, to provide higher priority services, the aim of which should be to maintain the provision of the key service.
– developing shift work mechanisms, maintaining continuous monitoring of key systems,
– developing mechanisms for notifying key employees in the event of a serious failure or event related to CRP alert levels,
– developing remote work mechanisms, purchasing equipment enabling remote work and delegating employees (who can perform this type of work) to perform it at their place of residence,
– limiting access to the organization's headquarters by third parties, taking into account exceptions, such as people from CSIRT-type teams,
– controlling and monitoring third parties supporting the operation of key systems.

Integral to an organization’s ability to maintain business continuity is the development of Disaster Recovery Plan (DRP). Developing such a plan is the process of formulating a strategy detailing the key actions required to restore IT services within the established recovery goals to be achieved following business interruption due to a disaster.

For the key services provided, dependent on information systems, it is extremely important to include these systems in the post-disaster reconstruction plan. Taking the above into account, the possible threats leading to a disaster in their context include [3]:

– criminal activity/cyber-attack/abuse,
– wiretapping/intercepting the session,
– physical attack,
– accidental damage (accident),
– malfunction/failure,
– interruption in supply (e.g. electricity),
– legal threats,
– natural disasters.

An important recommendation is also to raise awareness of employees in the field of cybersecurity, continuous training and education in the field of service continuity, and above all, OT/IT cybersecurity, with particular emphasis on the layering of security and implemented systems. One of the best means of protecting an organization's assets are employees who are aware of the threats and the importance of the information processed. An employee who is not fully aware of the consequences, such as disclosing certain information, may inadvertently take actions that negatively impact the organization. The process of periodic awareness and training can be a mean of creating preventive protection against such events. Training for new and existing employees should include at least relevant information on information security within the organization, as well as information specific to a particular job position. It is advisable to organize the training itself in a form that is interesting for the listener, which will not only enable passive acquisition of knowledge in a given area, but will also provide an opportunity for discussion. Additionally, where possible, examples of violations should be provided along with an indication of the consequences that occurred or could occur.

4. Responding to incidents

With the increasing likelihood of incidents and attacks on small and large organizations in the mining and energy sectors, it is essential to prepare the organization's ability to respond to incidents in order to secure the provision of services that are crucial to maintaining critical social or economic activities. Cybersecurity regulations, including: The Act on the National Cybersecurity System enforces the requirement to be able to respond to incidents.

Incident response requires thorough preparation as well as the ability to identify, contain and recover from cyberattacks. There are standards and guidelines for responding to incidents, e.g. ISO 27035:2016, SANS Incident Response in a Security Operation Center and NIST 800-61 Rev. 2 Computer Security Incident Handling Guide. The ISO 27035 standard proposes five phases of the incident management process. These are [3]:

1. Planning and preparation.
2. Detection and reporting.
3. Assessment and decision.
4. Reaction.
5. Drawing conclusions.

NIST Guideline 800-61 Rev. 2, are one of the most detailed publicly available standards that describe in detail the process of responding to IT security incidents. According to the NIST document, there are four main steps in incident response:

1. Preparation.
2. Detection and analysis.
3. Reduction, elimination and recovery.
4. Post-incident actions.

In 2022, the Report "Cybersecurity in mining - 2022" prepared by the Faculty of Mining, Safety Engineering and Industrial Automation of the Silesian University of Technology, ISAC-GIG Information Exchange and Analysis Center for the mining and energy sector proposed the necessary guidelines and supplements to improve cybersecurity conditions in 2023 (Fig. 9) [14].

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Fig. 9. Principles influencing the improvement of enterprise cybersecurity conditions developed basing on the experience of the JSW IT Systems Ltd. [14]

Incident response requires a holistic approach to analyzing the situation and mitigating hostile actions taken against organizational assets. Threat analysis helps you realize how important it is to maintain constant dialogue and cooperation between IT and OT departments, cybersecurity and physical security experts, market entities and auditors. Therefore, in order to support active, early warning and rapid response to critical incidents, it is recommended to create a permanent and multidisciplinary task force within the organization, which must be able to select an appropriate strategy to mitigate the effects of incidents in order to minimize the impact on the continuity of key service.

To achieve this goal, the multidisciplinary task force should include:

- operational business line experts who know the consequences of shutting down a system or communication channel,
- IT/OT experts who know the business continuity specifications of the organization's infrastructure and who are in contact with suppliers and other partners during major incidents,
- incident response experts who are responsible for making decisions regarding actions determining the level of severity,
- analysts who can understand attack patterns and malware behavior, who should identify possible countermeasures.

Current practice shows that an incident may be various events, but in order for them to be considered a serious or critical incident, they must meet appropriate conditions. The Polish government regulated the issue of recognizing a given incident as serious by specifying these premises by way of a regulation on the thresholds for recognizing an incident as serious, according to the types of events in individual sectors and subsectors specified in Annex No. 1 to the KSC Act. Based on the thresholds indicated in this document relating to the effects that a given incident may cause, the following are listed [15]:

- the number of users affected by the disruption of the provision of an essential service,
- time of impact of the incident on the key service provided,
- geographical scope of the area affected by the incident, other factors specific to a given subsector, i.e. circumstances such as: death of a person, serious damage to health, other serious damage to the health of more than one-person, financial losses exceeding PLN 250,000. zloty.

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The key service operator classifies the incident as serious and then, no later than within 24 hours from its detection, reports its occurrence to the appropriate CSIRT MON, CSIRT NASK or CSIRT GOV. When an incident occurs, the responsibility for appropriately classifying the incident as serious rests with the operator of the essential service. It should appropriately analyze the thresholds contained in the relevant regulation for a given essential service and, on this basis, submit the notification to the appropriate national level CSIRT.

5. Information Sharing and Analysis Center (ISAC) in the mining and energy sector

Information Sharing and Analysis Center (ISAC) are non-profit organizations that provide the opportunity to exchange information about threats in the CYBER area. They enable the exchange of information on threats and vulnerabilities of IT systems and automation between enterprises, research institutes and local government units. This is especially important now that there is an armed conflict so close to our country’s borders and the use of IT systems and the Internet in enterprises and offices has significantly increased as a result of the COVID-19 pandemic. It is the greater use of IT in the operation of industrial enterprises that has translated into a very large increase in related risks [3].

In counteracting CYBER threats, the key issue is access to expert knowledge. Therefore, enabling the exchange of experiences between people dealing with cybersecurity in different enterprises is particularly important and valuable, especially today, when there is such a shortage of specialists in this field. Cooperation within ISAC provides this opportunity and enables the education of new specialists, contributing to increasing resistance to all types of threats related to IT and automation systems.

The first Center for the exchange of knowledge and experience regarding cybersecurity incidents (ISAC) was established in the 1990s after the terrorist attacks in New York and Oklahoma City, when President Bill Clinton established the Presidential Commission for Securing Critical Infrastructure. The commission's task was to prepare a report recommending actions to secure American critical infrastructure in the future. In the report, the committee indicated the Internet and ICT systems as one of the greatest threats. The experts primarily recommended strengthening cooperation between government agencies and critical infrastructure operators and sharing information on potential threats. This recommendation was to be implemented through the establishment of the ISAC Center for the exchange of knowledge and experience regarding cybersecurity incidents. The Commission also emphasized the need to invest in research and development of modern technologies. In response to the Commission's recommendations, the first ISAC centers were created, and two years later, in accordance with the presidential recommendation, the obligation to create ISACs in each critical infrastructure sector was passed. The organization bringing together ISAC teams from all sectors in the USA is the National Council of ISACs. Its responsibilities include strengthening cooperation and exchanging cross-sectoral information [3].

There are currently over 20 ISAC organizations in the United States. In Europe, the first ISACs were established in the financial and energy sectors. It is worth emphasizing that European organizations have different specifics than their American counterparts. They were created later, were built on a different cultural basis and are much more focused on government support, not just sector cooperation. This results from the belief deeply rooted in European culture that the state should ensure the security of both the public and private sectors.

European ISACs, compared to their American counterparts, are much more formalized, mainly due to the greater influence of government bodies on their functioning. They focus primarily on building partnership and trust. According to the nomenclature adopted by the European Network and Information Security Agency (ENISA), there are three ISAC models in Europe: national, sectoral and international. Each of these models has its own characteristics and specifics. Currently, there are over 20 ISACs operating in Europe, including: in Spain, Portugal, Poland, the Netherlands, Lithuania, Hungary, Greece, Ireland, France, Estonia, Austria, Belgium. ISAC-GIG is the first center for the exchange of information, experience and knowledge in the field of cybersecurity in the mining and energy sector in Poland and even in Europe.

The rapid development of technologies used in the energy and mining industries has increased the number of dangers that may disrupt its smooth functioning. Effective cooperation, based on mutual trust between the public and private sectors, is necessary to ensure effective protection against new threats.

The idea of building an ISAC Center for the Exchange of Knowledge and Experience regarding cybersecurity incidents for the mining and energy sector appeared for the first time in March 2020 during consultations between the heads of the crisis teams of JSW SA, Artur Dyczko, author of this exempt, and of KGHM Polska Miedź SA, Radosław Stach, vice-president responsible for copper production. Crisis teams were established to prevent, counteract and combat the threat of the SARS-CoV-2 virus. The editor of this monograph, organizing the work of the crisis team, which he then headed until March 2021, appointed as the team member, in addition to the directors of key production plants of the JSW Group, the President of JSW IT SYSTEMS Ltd., providing comprehensive IT services for Jastrzębie mines. It is this fact that led to intensive discussions until June 2020 at the level of the JSW SA and KGHM Polska Miedź SA crisis teams on the necessary procedures to ensure the Business Continuity of the Mining Plants, also requiring the construction of the Knowledge and Experience Exchange Center regarding ISAC cybersecurity incidents [14].

It should be emphasized that the idea of creating ISAC, formulated in March 2020, during the work of the JSW SA Crisis Team for the mining and energy sector was born from the need to exchange knowledge, information, experience, but above all, good practices in securing the Business Continuity of Mining Plants. The past three years have clearly demonstrated the relevance and reasonableness of our idea. Today, no one disputes the thesis that cybersecurity of the entire mining and energy sector depends on the security of individual entities, especially the smallest ones.

Currently, ISACs are becoming an increasingly popular cooperation model because they help improve the competences of operators in key sectors and build trust between the stakeholders of the cybersecurity system. Learning from each other, reducing costs and improving the level of cybersecurity - these are just some of the benefits of launching ISAC. Such knowledge exchange centers are built around various sectors of the economy (e.g. financial, aviation or energy). Their main task is to bring together institutions and enable an exchange of experiences about threats. ISAC is a form of public-private partnership (PPP) that is particularly effective in the area of cybersecurity. Operators of key services are private or public enterprises, and ICT threats rarely concern only one institution or even one sector. Therefore, good cooperation and proper exchange of knowledge can significantly increase the level of cybersecurity. The data collected by ENISA shows that the creation of ISAC significantly contributed to increasing the level of knowledge about threats in a given country and to increasing the competence of companies and institutions in counteracting these threats.

As life has shown, despite several attempts and interventions of the Ministry of Climate, establishing the Knowledge and Experience Exchange Center regarding ISAC cybersecurity incidents by the State Treasury companies themselves was extremely difficult and fraught with the risk of divergent strategic goals - which consequently causes economically strong companies to operate alone, not taking advantage of the opportunities offered by working in a group, generating at the same time the costs of lost development opportunities that could be achieved by using the available resources more effectively. Not being discouraged by these problems, the author of this monograph, after almost a year of objective difficulties, in April 2021, together with several enthusiasts of the topic, proposed the organization of the Knowledge and Experience Exchange Center regarding ISAC cybersecurity incidents for the mining and energy sector at the Central Mining Institute (GIG), where the Institute's management, with great enthusiasm and ingenuity, took to create the necessary formal ISAC structures.

Formally, the agreements between the Central Mining Institute and most representatives of State Treasury companies, playing a key role in the Polish mining sector, were signed in January 2022, while the ceremonial signing of the declaration of launching ISAC-GIG took place on June 3, 2022 at the Ministry of State Assets (Fig. 10) [17].

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Fig. 10. Signing of an agreement between the Central Mining Institute and representatives of most State Treasury companies that play a key role in the Polish mining sector. Piotr Toś from JSW SA was appointed as the first Managing Director of ISAC-GIG. – Warsaw June 3, 2022 [17]

The signatories of the agreement on cooperation within ISAC-GIG are currently [17]:

- Central Mining Institute,
- Jastrzębska Spółka Węglowa SA,
- JSW IT Systems Sp. z o. o.,
- KGHM Polska Miedź SA,
- TAURON Polska Energia SA,
- TAURON Wydobycie SA,
- Polska Grupa Górnicza SA,
- Lubelski Węgiel "Bogdanka" SA,
- Węglokoks Kraj SA,
- ITG KOMAG,
- Silesian University of Technology, Faculty of Mining, Safety Engineering and Industrial Automation of the Silesian University of Technology.

In August 2022, in the presence of the Undersecretary of State at the Ministry of State Assets, Minister Piotr Pyzik, the Faculty of Mining, Safety Engineering and Industrial Automation of the Silesian University of Technology and ITG KOMAG solemnly signed an agreement on joining the Information Exchange and Analysis Center in the field of cybersecurity for the mining and energy sector ISAC - GiG. The accession of ITG KOMAG and the Faculty of Mining, Safety Engineering and Industrial Automation of the Silesian University of Technology to ISAC GIG is the next step after the launch of elite postgraduate studies at the Faculty of Mining, Safety Engineering and Industrial

Automation from October 2022 together with ITG KOMAG entitled: "Cybersecurity of industrial systems" (Fig. 11) [16].

Fig. 11. Accession of the Faculty of Mining, Safety Engineering and Industrial Automation of the Silesian University of Technology and ITG KOMAG to ISAC- GiG – Gliwice, August 2022 [16]

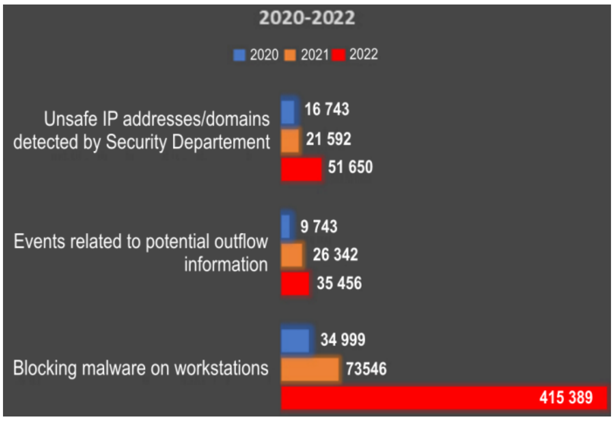
ISAC-GIG is one of the first projects of this type in the country, the first to bring together companies that play a key role in energy security. So far, only two such centers have been launched in Poland, i.e. ISAC-Kolej in the railway sector and the Reputation Center for Electronic Communications (ISAC-UKE) in the telecommunications sector. The idea of creating ISAC-GIG was born from the need to exchange knowledge, information, experience and good practices in the use of IT system security. The aim of ISAC-GIG Center is to, in accordance with the adopted principles, develop and promote standards and recommendations for the mining and energy sector, as well as cooperate in handling security incidents and cyberattacks affecting entities in this sector.

The joint effort of each participant is to constantly analyze and share information about threats and incidents that occur in cyberspace. The main tasks of ISAC-GIG include:

- exchange and analysis of threat data in real time,
- creating reports on security incidents,
- exchange of technical and operational experiences along with the solutions used,
- sharing conclusions and experiences from incidents and threats.

One of ISAC-GIG's cyclical initiatives is the preparation of the Report " Cybersecurity of industrial systems for the mining and energy sector for 2022". This document is an element of the Center's larger strategy related to conducting postgraduate studies entitled " Cybersecurity of industrial systems" at the Silesian University of Technology by the Faculty of Mining, Safety Engineering and Industrial Automation together with the KOMAG Institute of Mining Technology (Fig. 13, Fig. 12) [16].

Fig. 12. The architects of the creation of postgraduate studies entitled: " Cybersecurity of industrial systems" at the Silesian University of Technology, Dean of the Faculty of Mining, Safety Engineering and Industrial Automation, prof. Franciszek Plewa PhD Eng. and the head of ISAC GIG, the CEO of JSW ITS Sp. z o.o. Piotr Toś – Gliwice, October 2022 [16]



Increased threat of cyberattacks - source: JSW IT Systems Sp. z o. o

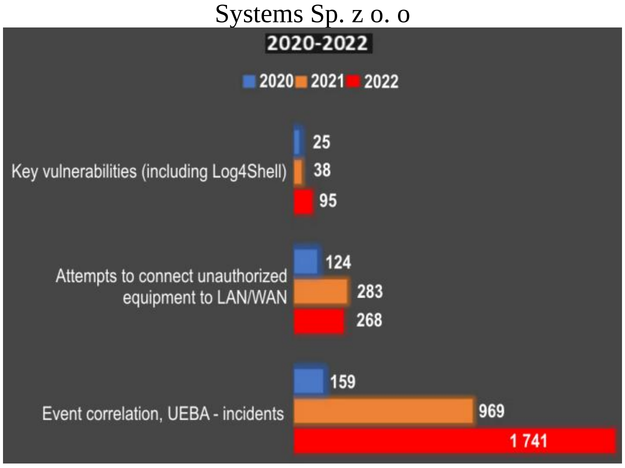


Fig. 13. Report " Cybersecurity of industrial systems for the mining and energy sector for 2022" [17]

The report (Fig. 13) is ultimately intended to be an important element of ISAC-GIG's activities in the field of promoting and developing cooperation in the area of cybersecurity between science and business, constituting a kind of alliance of innovative projects and research programs, disseminating their results in order to raise awareness of the management of the entire cybersecurity ecosystem for mining and energy sector [17].

Learning from each other, reducing costs and improving the level of cybersecurity - these are just some of the benefits that come from reading the document, which will allow you to turn the data, observations and recommendations contained therein into actions that can ultimately improve security, among others, by building a new potential and capabilities in the area of the national cybersecurity system. The report, presenting the achieved goals and improvements that have been developed as part of developing a higher level of maturity and resilience of cybersecurity in the mining and energy sector, also includes the effects of the amendment to the KSC Act, as well as proposals for the NIS 2 Directive introducing a number of challenges for entities of the national cybersecurity system in all sectors [15].

6. Silesians CyberSecurity Hub - a new way to build digital awareness and develop cybersecurity competences

As mentioned above, the idea of building the ISAC Center for the Exchange of Knowledge and Experience regarding cybersecurity incidents for the mining and energy sector appeared for the first time in March 2020 during consultations of the heads of the JSW SA and KGHM Polska Miedź SA crisis teams. A little later, in April 2021. As a result of developing this idea, the main assumptions of the strategic research program entitled "Safe Digital Silesia 2030" were developed, an extremely ambitious initiative aimed at ensuring digital security for the inhabitants of Silesia in the era of civilization transformation [3].

The entire concept was based on the assumption that the primary goal of the "Safe Digital Silesia 2030" program will be the construction, in the "Barbara" Experimental Mine in Mikołów, belonging to the Central Mining Institute, of the Center for the Development of Innovative Digital Competencies, whose task in the coming years will be:

– creation of the Center for the Exchange and Analysis of Information on vulnerabilities, threats and incidents to support entities of the national cybersecurity system, currently ISAC GIG,
– development of digital competences, especially in the field of cybersecurity, of local government units, large, small and medium-sized enterprises, construction of a training base in the field of cybersecurity, along with the launch of a program for discovering and training the most talented students of Cybersecurity Talent Identification and Assessment Program - CTIAP
– creating technological security measures ensuring the continuity of operation of industrial IT/OT systems, enabling coordination and active response to incidents in cyberspace, creation of the Regional Transformation Monitoring Center based on obtaining source production and environmental data from mines undergoing the transformation process.

All this so that ISAC GIG, thanks to published reports, analyzes and training, becomes an opinion leader and creator of ecosystems that increase resistance to cyberattacks.

All the author's ideas were strongly confronted with the prose of life, and especially with the financial reality of Polish science, in order to finally discuss the assumptions of the program with the Marshal's Office, which, after familiarizing itself with the proposed concept, included them in the Territorial Plan for the Just Transformation of the Silesian Voivodeship up to 2030, supporting activities aimed at increasing the level of innovation of the economy, developing new competences related to the need to adapt employees in the mining and mining-related industries to ongoing changes, and an effective and socially responsible transformation management system.

The finally prepared projects constituting the "Safe Digital Silesia 2030" research program were incorporated into the Territorial Just Transformation Plan of the Silesian Voivodeship, forming three main pillars (Fig. 14.) [3]:

– Digital competence center – Silesian CyberSecurity Knowledge Center,

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– Regional transformation monitoring center – Mining Transformation Monitoring Center,
– Technological security center – Silesian CyberSecurity Data Center.

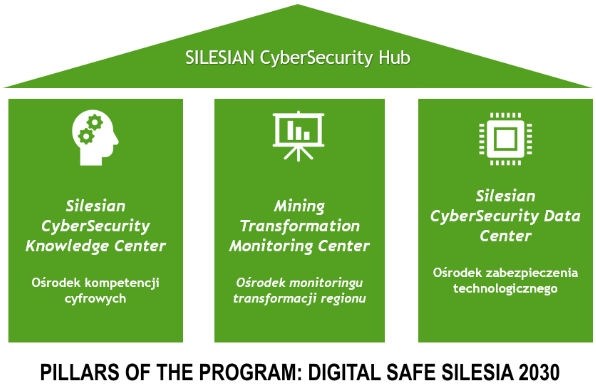

Fig. 14. The idea of transforming the Barbara Experimental Mine into Silesian CyberSecurity Hub [17]

The process of transforming the "Barbara" Experimental Mine, which had conducted normal mining activities in the past, into a modern IT center with a modern data processing center located underground, which will become a good example of the digital transformation not only of Silesia, but of the entire raw materials industry, has already been planned and financed in the National Reconstruction Plan of the Silesian Voivodeship.

The main advantage of locating the Data Center in underground mines is maintaining a high degree of security of stored data in an easier way than when using traditional server rooms. Data center customers demand server reliability and full availability. All IT and support devices located underground are not exposed to bad weather conditions or other random situations, not to mention war.

Internet service providers around the world have been cooperating with underground data processing centers for years. The most energy-efficient server room in Europe is located in Lefdal, Norway. It is located 150 m underground, in the workings of a former olivine mine, and has been operating since 2017 (Fig. 15) [18].

Fig. 15. The most energy-efficient server room in Europe located in the Norwegian Lefdal olivine mine 150 m underground [18]

In the American city of Springfield, Missouri, in an old underground limestone mine, approximately 25 m underground, a data processing center with an area of over 7 500 m^2 was located. Similar underground server rooms operate in Pennsylvania and Kansas City. The Kansas City center is located 34 m below the surface and the Pennsylvania center is located 70 m below the ground (Figure 16) [10].

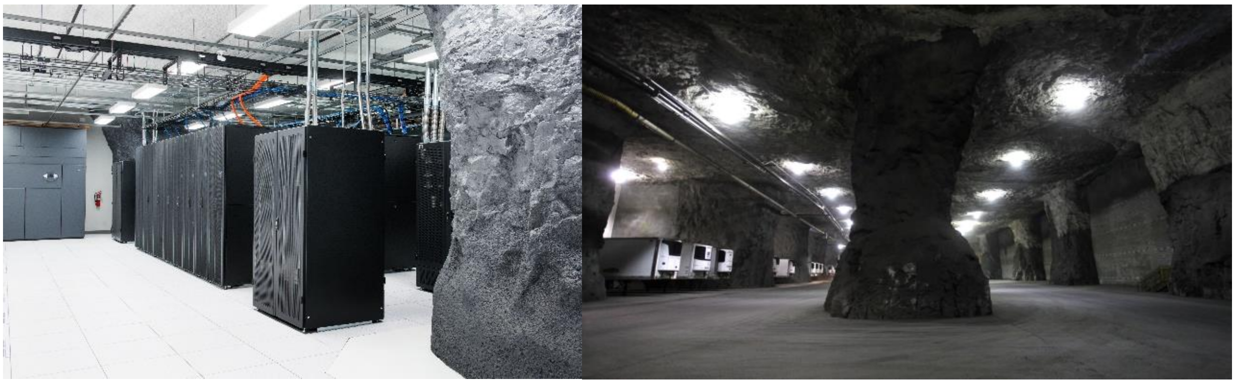

Fig. 16. Data processing center in the American Springfield, Missouri in an old underground limestone mine - DATA CENTER COMPANY EXPANDS UNDERGROUND IN MISSOURI [10]

Data Center KD Barbara, through the use of existing underground workings, will help reduce the costs of data processing center operators, as it will not be necessary to build an entire server room building or rent expensive space. There will also be no huge costs associated with cooling the devices, because there is no sunlight underground and the temperature and air humidity are constant there.

According to the author of this chapter of the monograph, who is one of the creators of the concept of "Safe Digital Silesia 2030", Silesian CyberSecurity Hub can not only be an element of the Silesian Computing Cloud built, among others, based on the KD "Barbara" Data Center, but ultimately it should become an important element of the Government Computing Cloud in the area of monitoring the transformation of the national mining and energy sector [17].

Fig. 17. A modern IT center in the "Barbara" Experimental Mine [17]

As the reality around us shows, the "Safe Digital Silesia 2030" program prepared in April 2021 has not lost any of its attractiveness and relevance, and the war in Ukraine only confirmed the validity of the theses formulated by the authors a year before its outbreak, giving them additional meaning.

7. Conclusion

The past is in our heads and the future is in our hands - as folk wisdom says, the truth of these words was clearly confirmed by the past year 2022. This was the first year of operation of the Information Exchange and Analysis Center for the mining and energy sector (ISAC GIG).

ISAC GIG works actively, integrating the entire environment of the Polish raw materials sector to raise awareness and digital responsibility, which is the foundation of the new face of the mining and energy industry in our country.

The writer of these words is particularly pleased that currently Silesian CyberSecurity Hub is not only GIG and the idea of building a Center for the Development of Innovative Digital Competencies in the "Barbara" Experimental Mine with the only modern server room in Poland located in underground mines. Today, after a year of operation, ISAC GIG, Silesian CyberSecurity Hub is primarily an ALLIANCE between the Faculty of Mining, Safety Engineering and Industrial Automation of the Silesian University of Technology, the Central Mining Institute and the KOMAG Institute of Mining Technology for the benefit of State Treasury companies playing a key role in the Polish mining and energy sector.

Today Silesian CyberSecurity Hub is also, and perhaps above all, an agreement between the worlds of science and industry - an industry that is exceptionally important for the security of our country's functioning - to permanently secure an elementary node of concentration of the main data streams of our critical infrastructure in many fields. As Piotr Toś, Chairman of the Management Committee of the Information Exchange and Analysis Center ISAC-GIG, said: *"... today Silesian CyberSecurity Hub is working to create a training base to support all existing and emerging new ISACs throughout Poland. We have experience and great achievements in building efficiently operating Information Exchange and Analysis Centers in the field of cybersecurity, we want to become an important element of the Government Computing Cloud in the area of monitoring the transformation of the Polish energy industry, we want to launch, together with the Silesian University of Technology, a program for searching and training the most talented students Cybersecurity Talent Identification and Assessment Program - CTIAP, we want, together with the KOMAG Institute, to build a fast certification path in the field of cybersecurity of IT/OT products that will be recognized in Europe. I believe that our cooperation in Silesia will bring a new quality. There is no doubt that we play as one team, and our team is not a group of people who just work together! Our team is a group of people who trust each other in the context of science, new and innovative ideas, research projects and initiatives that are aimed at developing and modernizing the Polish scientific sector...* " [16].

THE ALLIANCE of the Faculty of Mining, Safety Engineering and Industrial Automation of the Silesian University of Technology, the Central Mining Institute and the KOMAG Institute of Mining Technology breathed life into the idea of building Silesian CyberSecurity Hub! Through organized postgraduate studies, training and information exchange, as well as ensuring an appropriate response to emerging threats, it has made it possible to build and develop new competences in the field of cybersecurity for State Treasury Companies, Local Government Units and other participants of the National Cybersecurity System.

This alliance also focused the efforts of the Faculty of Mining, Safety Engineering and Industrial Automation of the Silesian University of Technology around the idea proposed by the Author to launch six laboratories at the Faculty by 2025, constituting a COMPETENCE CENTER IN THE FIELD OF SAFETY, OPERATIONAL ANALYTICS AND MANAGING HAZARDOUS SITUATIONS IN INDUSTRY [16].

The Alliance for building a DIGITAL ECONOMY as a factor in the technological development of the mineral resources sector and a fair energy transformation of Silesia was established on December 11, 2023 in Gliwice.

The Silesian University of Technology and the Mineral and Energy Economy Research Institute of the Polish Academy of Sciences from Krakow have concluded an agreement on cooperation in the implementation of research programs, project initiatives and commissioned works aimed at improving innovation, technical and economic efficiency of the mineral resources management in Europe.

The agreement was solemnly signed by the Silesian University of Technology - Vice-Rector for Science and Development, prof. Eng. Marek Pawełczyk PhD, and on the part of the Mineral and Energy Economy Research Institute of the Polish Academy of Sciences - Prof. eng. Krzysztof Galos PhD, Director of the Institute (Fig. 18) [16].

Fig. 18. Signing an agreement on cooperation between the Silesian University of Technology and the Mineral and Energy Economy Research Institute of the Polish Academy of Sciences in Krakow by the Vice-Rector for Science and Development, prof. Eng. Marek Pawełczyk PhD and prof. Eng. Krzysztof Galos PhD, Director of the Institute [16]

The CENTER, based on the latest achievements in automation and IT using artificial intelligence, will enable simulation of industrial and technological processes and crisis situations, as well as connecting distributed monitoring, control and security systems responsible for the operation of the enterprise (Fig. 18) [16].

Fig.19. The construction of the CENTER will be managed by the Dean, prof. Eng Franciszek Plewa PhD and Dr. Eng. Artur Dyczko [16]

AI, OPERATIONAL ANALYTICS AND INFORMATION PROCESSING Laboratory - will constitute the heart of the CENTER being built, serving as a research ground for ensuring the security and cybersecurity of industrial automation systems in the mining and energy sector. This will fill the gap in testing the cyber resistance of automation systems and devices used in industry. A complement to the activities presented by the Author, originator and initiator of activities aimed at involving the Faculty of Mining, Safety Engineering and Industrial Automation of the Silesian University of Technology around the idea of: Digital Economy as a Factor in the Technological Development of the Mineral Sector, will be the creation of a SITUATIONAL AWARENESS SYSTEM - constituting, as it were, the brain of the CENTER being built. The situational awareness system for industry is an advanced platform for real-time monitoring, analysis and response in an industrial environment. The main assumptions of this system include, among others, the integration of data from various sources, such as sensors, monitoring systems, databases and measuring devices, which will allow to obtain a comprehensive picture of the situation. This knowledge provides the opportunity to counteract and respond appropriately to emergency situations [16].

The author of this chapter of the monograph believes that the COMPETENCE CENTER IN THE FIELD OF SAFETY, OPERATIONAL ANALYTICS AND MANAGEMENT OF HAZARDOUS SITUATIONS IN INDUSTRIES being built at the Faculty of Mining, Safety Engineering and Industrial Automation of the Silesian University of Technology will be an excellent development and complement to the Silesian concept of CyberSecurity Hub, at the same time becoming a new quality on a European scale in the field of research and training, using simulation and virtualization in laboratory conditions of dangerous situations related to cyber threats, natural and industrial threats.

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Extraction of methane from the closed mine "Moszczenica”

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Abstract:

Closed methane hard coal mines may become a source of methane used in the energy industry. There are many unliquidated tunnel workings left, they contain lot of workings with a large capacity of free space, and a network of cracks formed in the rock mass. Release of methane to the atmosphere is practically reduced to zero. Closed mines can be a source of methane used to produce energy. This article presents the example of the "Moszczenica" mine as a source of methane, which is captured and converted into electricity and heat.

Keywords: methane mine, methane drainage station, methane intake, electricity generation

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1. Introduction

Hard coal seams in many Polish mines are accompanied by methane, which is treated as an accompanying mineral. Methane, like carbon dioxide, is classified as a greenhouse gas. There are statements in the literature that the greenhouse effect caused by the methane is 21 to 30 times greater than that caused by the carbon dioxide. According to [1], there are 1000 times more carbon dioxide (CO_2) in the Earth's atmosphere than methane (CH_4), and due to the increase in emissions [2], increase in CO_2 concentration in the rate of intensification of the greenhouse effect is almost three times higher than that caused by increase in CH_4 concentration.

According to [3], one ton of CH_4 heats our planet as much as 86 tons of CO_2.

In the USA [4, 5, 6, 7, 8, 9, 10], methane is extracted by drilling the earth's surface. They are most often performed before the coal seam is mined. This type of extraction is possible when the seam is not very deep.

In deep mines in the USA, underground methane drainage is used [11, 12], and drainage holes are drilled from near-wall preparatory workings (similarly to Poland) or from specially made roadways above the mined seam.

Methane in coal seams appears as sorbed methane (bound by van der Waals forces to the internal surface of the coal) and free methane (in mesopores, macropores and cracks), and in the rocks accompanying coal seams. During coal mining and drilling the roadways, free methane flows under its own pressure from the surrounding rocks (coal, sandstones, mudstones, claystone) into the workings. After the end of exploitation, release of methane into the dammed workings and into the voids associated with many years of coal extraction. As a result, free methane accumulates in the rock mass of closed mines. Methane from closed mines can be extracted through an unliquidated methane drainage system connected to a methane drainage station on the surface or connected to the methane drainage system of an active, neighboring mine.

The hard coal deposit in the area included this research work had a high content of methane in the coal, which was released into the mine workings. To maintain the permissible methane content (below 2%) specified in safety regulations, large amounts of air were fed to active mine workings.

To secure work safety in mines (limiting methane emissions to mine workings), the technology for methane removal from the rock mass (coal and surrounding rocks) is used, which includes drilling holes into the rock mass from mine workings or to the surface and removing the gas (methane with air) under the impact of the negative pressure generated by blowers located in mine workings or on the mine surface.

Methane captured from Polish mines was usually used as a fuel in the energy industry.

During mining the hard coal deposits in the Rybnik Coal District, with high methane capacity in the range 20 - 25 m^3 of methane per Mg of pure coal, the methane drainage system was used in mine workings. The first installation was built in the 1 Maja coal mine (launched in 1960), and the next ones in the Jastrzębie mine (launched in 1962) and Moszczenica mine (launched in 1965).

2. Materials and testing methods

2.1. Mine methane drainage station

In the years 1962 - 1997, the Jastrzębie and Moszczenica mines had the separate methane drainage networks. The Jastrzębie mine had methane drainage stations near the shaft
Jas-VI, and the Moszczenica mine had two methane drainage stations:

- at the Mos-VI shaft - for the main shaft area,
- at the Mos-VII shaft – for the western shaft area.

Both the Jas-VI shaft and the Mos-VII and Mos-VI shafts were closed.

Due to liquidation of the western shafts of the "Moszczenica" mine in 1994 and undertaken operation of the western shaft pillar, the methane drainage station at the shaft Mos-VII was closed. In turn, in connection with the liquidation of the main shafts of the Moszczenica mine in 1997, the methane drainage station at the Mos-VI shaft was closed.

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Currently, the only active methane drainage station is the station located near the closed down Jas-VI shaft, which captures methane from the western part of the mining area of the former Moszczenica mine.

Figures 1 to 4 show the equipment of the methane drainage station located at Jas-VI shaft.

Fig. 1. The building of the methane drainage station

On the left side of the photo, you can see the pipeline supplying methane from the mine to the methane drainage station. Visible metal chimneys (three on the left side of the building and one on the front side) they discharge methane into the atmosphere in the event of a failure at the methane drainage station or in the event of no methane collection. The metal columns next to the building are lightning conductors.

Fig. 2. Equipment of the methane drainage station at the methane inlet

The visible "canisters" between the lower and upper pipes are fire arresters, preventing the transfer of an explosion in the methane drainage station to underground equipment. They are filled with washed gravel with appropriate granulation to ensure fire extinguishment. The standing column plays a role dehydrator of captured methane.

Fig. 3. Pumping unit

The pipe on the left side of the photo supplies gas from the steam trap to the pump (suction side), and the pipe on the right side (discharge side) discharges the compressed gas to the recipient. The pump is driven by an electric motor connected to the pump by a clutch.

Fig. 4. Outlet pipe arrangement

The upper pipe, visible in Figure 4, during normal operation of the methane drainage station, leads to the lower pipe, which discharges methane to the recipient. The central pipe, during normal operation of the station, discharges excess gas to the atmosphere (through the chimney shown in Figure 1). The top tube is connected to the atmosphere. This connection is poorly visible in the photo where the pipe connects outlet with a pipe discharging methane from the first pumping unit. In case of methane explosion, the membrane in the pipe connecting to the atmosphere is ruptured on the discharge side, what prevents the explosion from spreading to the pipeline connecting the methane flow to a recipient. The methane drainage station operates under constant supervision of the people employed there.

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3. Results

3.1. Analysis of methane intake from December 2017 to November 2023

In order to determine the variability of methane intake from the mining area of the closed Moszczenica mine, monthly data relating to the period from December 2017 to November 2023 were analysed. These data are presented in the table below.

Table 1. Development of the gas mixture and methane intake in from December 2017 to November 2023

Date	Gas mixture intake, m^3/min	Methane intake, m^3/min	Intake of other gases, m^3/min
12-2017	26.83	16.53	10.30
01-2018	26.64	16.54	10.10
02-2018	27.30	16.5	10.80
03-2018	25.77	16.79	8.98
04-2018	26.15	16.63	9.52
05-2018	26.03	16.29	9.74
06-2018	26.32	16.61	9.71
07-2018	25.81	16.53	9.28
08-2018	25.97	16.68	9.29
09-2018	26.43	16.72	9.71
10-2018	26.80	16.65	10.15
11-2018	26.18	16.67	9.51
12-2018	25.48	16.77	8.71
01-2019	25.32	17.02	8.30
02-2019	25.25	16.89	8.36
03-2019	25.01	16.92	8.09
04-2019	24.91	16.86	8.05
05-2019	24.35	16.93	7.42
06-2019	24.45	16.62	7.83
07-2019	24.38	16.92	7.46
08-2019	24.49	16.8	7.69
09-2019	26.38	16.8	9.58
10-2019	25.78	16.88	8.90
11-2019	25.32	16.96	8.36
12-2019	25.16	16.81	8.35
01-2020	26.22	16.55	9.67
02-2020	24.57	16.79	7.78
03-2020	24.07	16.58	7.49
04-2020	24.53	16.72	7.81
05-2020	23.94	16.79	7.15
06-2020	23.92	17.03	6.89
07-2020	23.11	16.62	6.49
08-2020	22.98	16.54	6.44
09-2020	23.03	16.67	6.36
10-2020	23.12	16.69	6.43
11-2020	23.41	16.65	6.76
12-2020	23.52	16.61	6.91
01-2021	23.10	16.6	6.50
02-2021	21.87	15.99	5.88
03-2021	23.14	16.62	6.52
04-2021	23.81	16.77	7.04

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05-2021	23.81	16.66	7.15
06-2021	23.93	16.65	7.28
07-2021	23.62	16.54	7.08
08-2021	24.08	17.08	7.00
09-2021	23.93	16.83	7.10
10-2021	23.72	16.61	7.11
11-2021	24.11	17.07	7.04
12-2021	23.28	16.29	6.99
01-2022	24.50	16.85	7.65
02-2022	24.46	16.77	7.69
03-2022	24.54	16.53	8.01
04-2022	24.63	16.74	7.89
05-2022	24.24	16.54	7.70
06-2022	24.67	16.92	7.75
07-2022	23.47	16.07	7.40
08-2022	24.65	16.85	7.80
09-2022	24.02	16.34	7.68
10-2022	24.43	16.57	7.86
11-2022	25.24	16.77	8.47
12-2022	24.76	16.69	8.07
01-2023	24.79	17.11	7.68
02-2023	24.28	16.42	7.86
03-2023	23.54	16.48	7.06
04-2023	23.58	17.04	6.54
05-2023	23.79	17.01	6.78
06-2023	23.76	16.83	6.93
07-2023	23.71	16.98	6.73
08-2023	23.35	16.92	6.43
09-2023	23.20	16.57	6.63
10-2023	22.98	16.23	6.75
11-2023	23.52	17.1	6.42

Observation period was 72 months. The amount of the captured gas mixture ranged from 21.87 m^3/min to 27.30 m^3/min. The calculated average value of the mixture one minute intake in the observed period was 24.52 m^3/min. The mixture intake was of low variability, as the standard deviation was 1.15 and the coefficient of variation was 4.70%. The mixture variability range was 5.43 m^3/min.

The amount of captured methane ranged from 15.99 m3/min to 17.11 m^3/min. The calculated average value of the minute methane intake in the period under study was 16.70 m^3/min. The mixture treatment was characterized by very low variability, as the standard deviation was 0.23 and the coefficient of variation was 1.38%. The methane intake was also had a very small variability range of 1.12 m^3/min.

Total flowrate of captured gases other than methane ranged from 5.88 m^3/min to 10.80 m^3/min, with the average value 7.82 m^3/min. The standard deviation was 1.15, which was equal to the standard deviation of the gas mixture. However, the coefficient of variation of 14.69% was much higher than for the mixture and methane. The range of variability of the amount of components other than methane was 4.92, which is a value close to the range of variability of the mixture. The variability of the gas mixture and pure methane during the observation period is presented in Fig. 5

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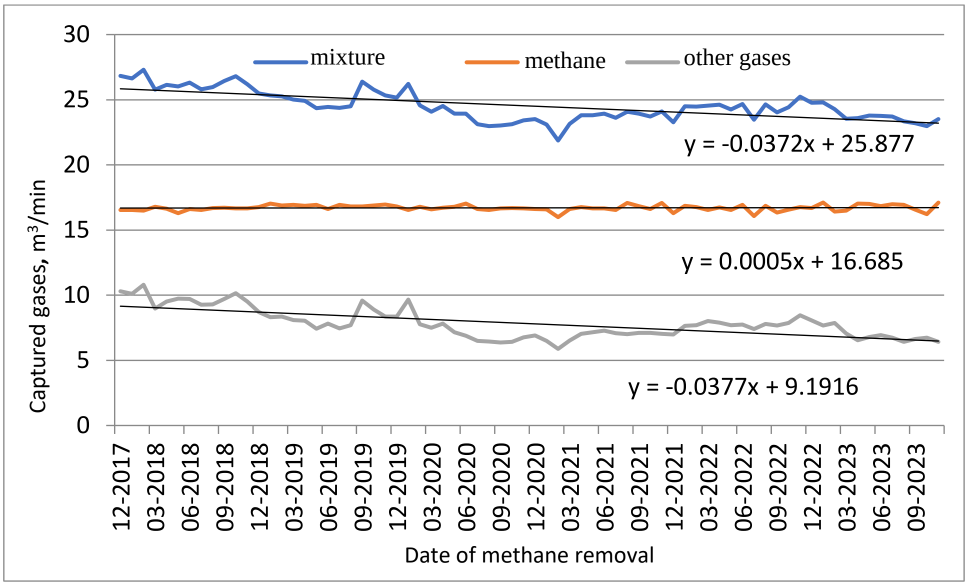

Fig. 5. Curves of the gas mixture and methane intake in the analyzed period

The amount of the gas mixture captured in the observed period showed a decreasing tendency. This is evidenced by the negative angular coefficient of the approximation line (-0.0372).

The amount of methane captured within the observed period was almost constant, independent of the amount of the captured gas mixture, evidenced by very small angular coefficient of the approximation line of 0.0005 (Fig. 5).

Figure 6 shows the relationship between the methane intake and the gas mixture intake.

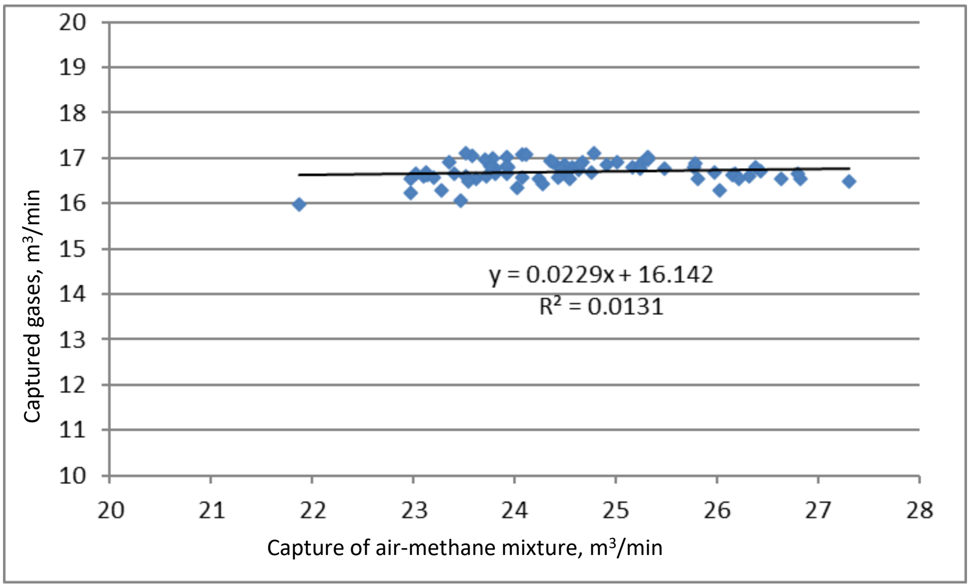

Fig. 6. Relationship between the methane intake and the gas mixture intake

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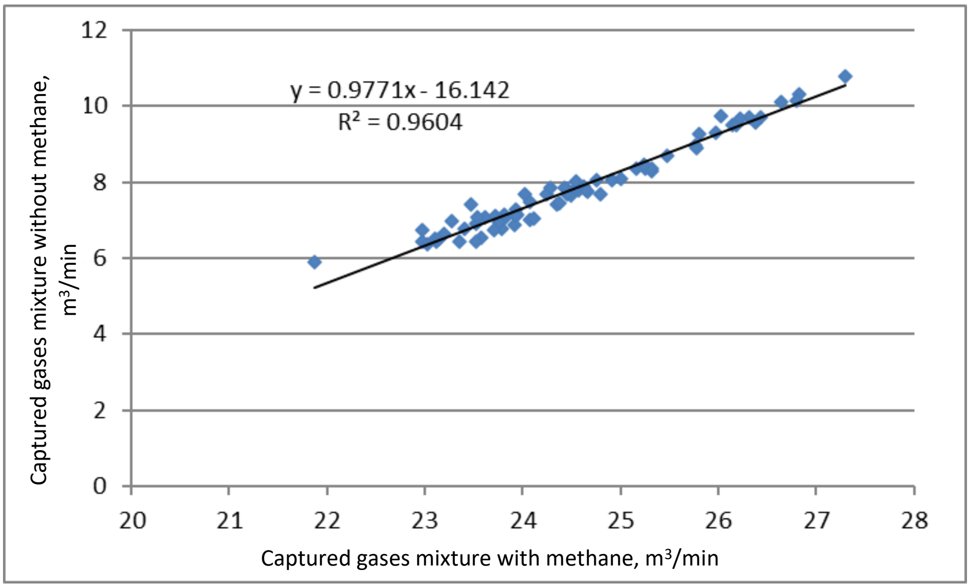

Fig. 7. Curves of the amount of captured components of the gas mixture without methane

The methane intake ranges from about 16% to about 17%.

It is not possible to determine what part of the methane is captured directly from the roadway and what part is taken from not liquidated drainage holes. The approximation line is almost horizontal (Fig. 6). The slope of the approximation line is 0.0229. The coefficient of determination R^2 = 0.013, which is very low, what indicates for very small dependence of the methane intake on the amount of the collected gas mixture.

However, there is a very strong correlation between the remaining gas components in the captured mixture (Fig. 7). The slope coefficient of the line showing the dependence of the intake amount of gases other than methane on the intake of the gas mixture with methane is 0.9771, i.e. the line is inclined almost at an angle of 450 in relation to the horizontal coordinate. The coefficient of determination R^2 = 0.9604 indicates for almost functional relationship between the intake of a gas mixture without methane and the intake of a gas mixture with methane. From the above it results that the intake of the air-methane mixture at the level of 23 m^3/min gives the best gas mixture relating the energy content.

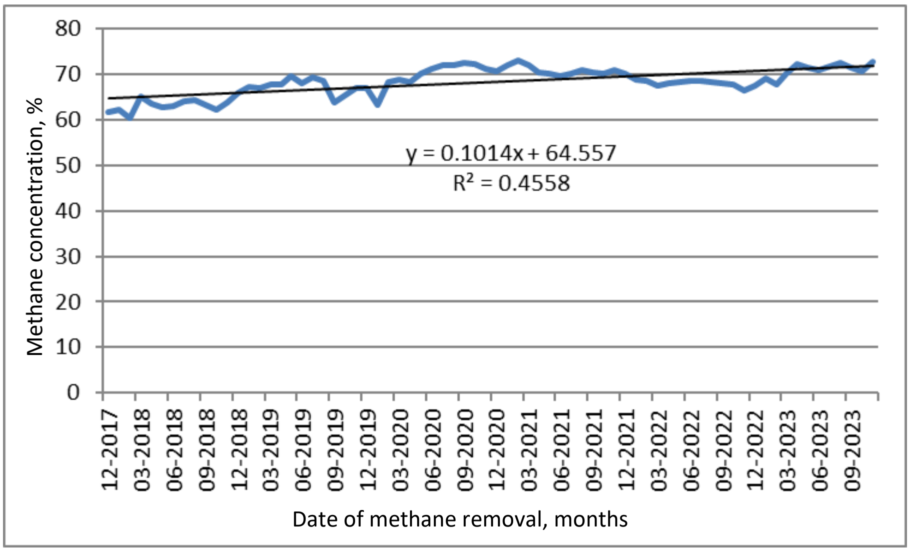

Fig. 8. Curve of methane concentration in the gas captured in the methane removal system

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Figure 8 shows that the methane concentration in the mixture captured by the methane drainage system has an increasing tendency. This is because there are gases in the treated mixture from the atmospheric air remaining in the working. After damming the workings, the amount of incoming air decreased significantly, and in a result, methane concentration increased.

4. Conclusions

The article presents an analysis of methane capture from the closed Jas-Mos Ruch "Moszczenica" mine in from December 2017 to November 2023.

The analysis shows that:

- methane intake through the methane drainage system was almost unchanged throughout the entire observation period and was independent of the air-methane mixture intake amount. The slope coefficient of the line approximating the methane intake amount was 0.0005,
- intake of the air-methane mixture varied over time and had a decreasing tendency
- intake of the air-methane mixture had greater variability than the intake of methane,
- the intake of gases other than methane showed a decreasing trend. The slope coefficient of the approximation lines for the intake of the air-methane mixture and the non-methane gas mixture was almost identical. They differ by the value -0.0005,
- methane concentration in the captured air-methane mixture had an increasing tendency. The approximation line has a slope of 0.1014. It can be expected that as a result of cutting off the mine workings from the external atmosphere, the methane concentration will slowly increase.

Recovery of methane from closed mines reduces the risk of its uncontrolled release to the atmosphere, thus limiting the greenhouse effect. The methane captured by the methane removal system is used to produce electricity and heat.

Currently, excess of the captured methane is released to atmosphere. This practice will be subject to high penalties within three years. Injecting excess gas into a closed mine will allow it to be stored and used later.

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