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Impact of winding drum shell ribbing of a hoisting machine on its strength and manufacture costs

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Keywords: hoisting machines, winding drum, FEM strength analysis of winding drum

Słowa kluczowe: maszyny wyciągowe, bęben nawojowy, analiza wytrzymałościowa MES bębnów nawojowych

Abstract:

A strength analysis of winding drums of hoisting machines, with particular attention paid to an impact of using circumferential ribs on stresses in the drum shell, is presented in the article. The winding drum, used as rope shafting and a load–carrying element of a hoisting conveyance, hung on the rope, is a widespread, historical solution applied successfully even nowadays not only in the case of mine shaft winders but also in many other applications in the industry. Hoisting machines with a rope carrier of this type are used in single – drum and double – drum winders both in shallow shafts as well as in very deep shafts, even up to 3000 m. In the Polish mines their application has been limited significantly in mine shaft winders due to an implementation of more compact hoisting machines with a frictional transmission of motion from the rope shafting onto the rope (Koepe type systems). However, drum machines still find an application, e.g. smaller machines in auxiliary shafts, as machines for shaft inspections and repairs as well as bigger single–drum machines used for shaft–sinking a double–drum machines installed in shallow shafts operating on a few levels.

Streszczenie:

W artykule przedstawiono analizę wytrzymałości bębnów nawojowych maszyn wyciągowych ze szczególnym uwzględnieniem wpływu stosowania żeber obwodowych na naprężenia w płaszczu bębna. Bęben nawojowy stosowany jako pędnia i element nośny naczynia wyciągowego zawieszonego na linie jest rozpowszechnionym i historycznym rozwiązaniem sprawdzającym się z powodzeniem i dzisiaj nie tylko w górniczych wyciągach szybowych, ale w wielu innych zastosowaniach w przemyśle. Maszyny wyciągowe z tego typu nośnikiem liny są stosowane w maszynach wyciągowych jedno i dwubębnowych w szybach płytkich jak i bardzo głębokich, nawet do 3000 m. W polskich kopalniach ich stosowanie zostało znacznie ograniczone w górniczych wyciągach szybowych na rzecz bardziej zwartych maszyn wyciągowych z ciernym przeniesieniem ruchu z linopędni na linę (systemy typu Koepe). Maszyny bębnowe jednak nadal znajdują swoje zastosowanie np.: mniejsze maszyny w szybach pomocniczych jako maszyny do prowadzenia rewizji i naprawy szybów, jak również większe maszyny jednobębnowe stosowane przy głębieniu szybów lub maszyny dwubębnowe zabudowywane w płytkich szybach obsługujących kilka poziomów.

1. Introduction

Hoisting machines of mine shaft winders, due to the way of transmitting the rope shafting torque to the load carrying rope, on which the hoisting conveyance is hung, can be divided into winding drums (Fig.1) and those with frictional contact of the Koepe type (Fig.2).

Fig. 1. Double-drum hoisting machine
Kinga Shaft

Fig. 2. Two-rope hoisting machine
of Koepe type

Single - or double-drum hoisting machines as well as double-drum ones with a possibility of hanging the conveyance on two ropes (Blair system) are used in shallow shafts and very deep ones exceeding 3000 m (Blair type machines). The winding-drum system has been used in the underground mining industry for hundreds of years (Fig.3, Fig. 4). Drum winches have very many applications in various branches of industry. Double - drum hoisting machines with re-set drums enable an adaptation of conveyances location for servicing a few mining levels. Their disadvantage consists in a relatively big weight in relation the weight of the transported run-of-mine.

Fig. 3. Horse gear
Wieliczka Salt Mine [1]

Fig. 4. Steam double-drum hoisting machine
Museum of Bochnia Salt Mine [2]

Winding drums of hoisting machines had different design forms over the years. Their construction was often connected with the technology level related to drives of machines. Apart from typical cylindrical drums (Fig. 5) other design solutions also appeared e.g. cylindrical-conical (Fig. 6).

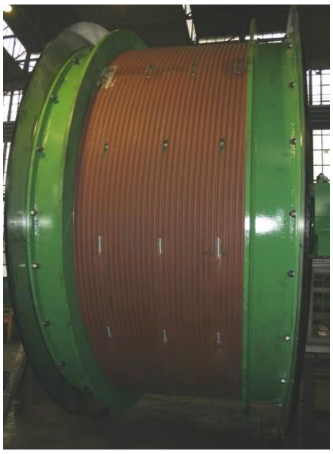
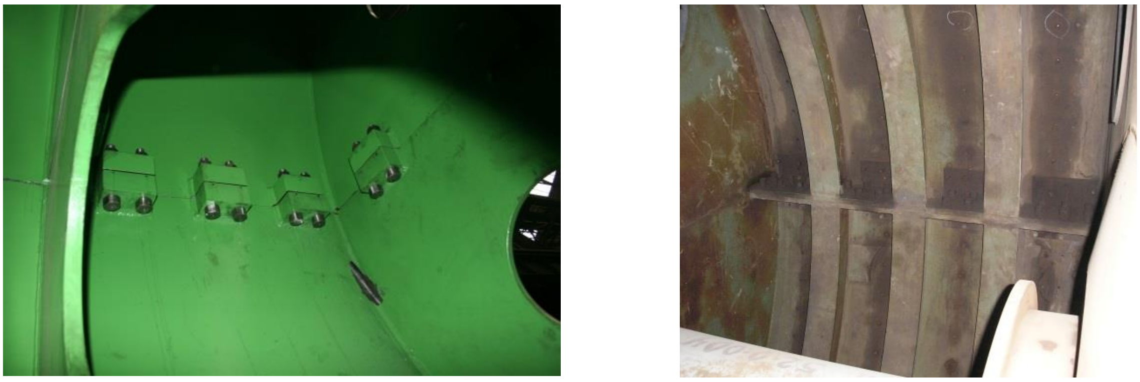


Fig. 5. Winding drum with a steel, grooved
lining installed on the drum shell

Fig. 6. Cylindrical-conical winding drum with
direct grooving on the drum shell

Winding drums are adapted to a single-layer or a multi-layer winding of rope. In the mines all over the world it is possible to find a series of different types of winding drums, produced several dozen years ago and operated up till the present time. Hoisting machines with winding drums have been and still are designed at the KOMAG Institute of Mining Technology.

One of design problems, related to the winding drum shell strength of the hoisting machines, is addressed in the article. It concerns an impact of circumferential ribs on the drum shell strength (Fig. 7) in the aspect of manufacture costs.



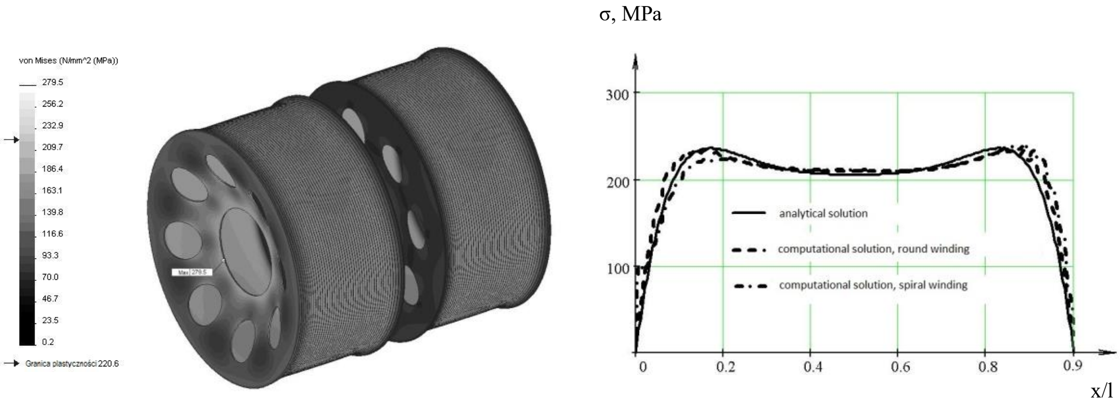
a) shell without ribs b) shell with circumferential ribs

Fig. 7. Interior of winding drum

An impact of ribbing locations and type of drum shells on the strength, in connection with manufacture costs, is discussed in this article. The discussion is concentrated on a technical justification of advantages and disadvantages of constructing winding drums shells without any ribs and with circumferential ribs.

2. Analytical model

Analytical methods (Fig. 8) [5,6,8] used to be applied for an assessment of the strength of winding drums during their designing process, but at present numerical methods, based on the Finite Element Method (Fig. 9) [3,4,7,8,9] are used.



a) FEM analysis results b) Results of analytical calculations

Fig. 8. Strength calculations of winding drum of the hoisting machine [8]

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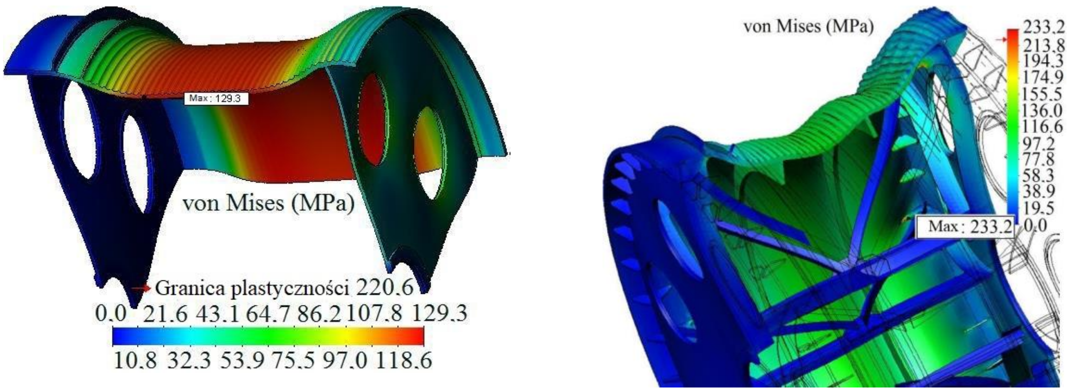
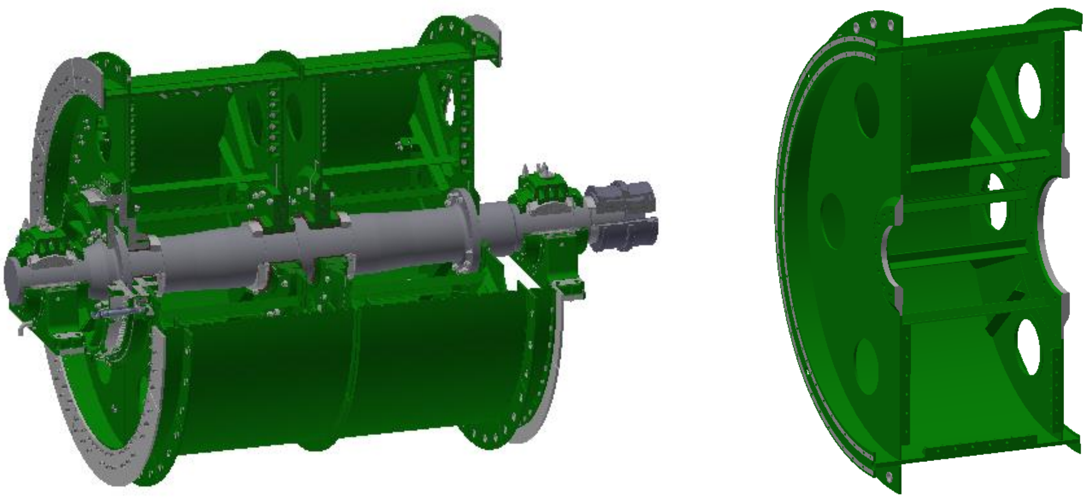


Fig. 9. Results of numerical analyses of different construction winding drums [9]

Applying the finite element methods, an analysis of the winding drum of the rope winding diameter – 7000 mm and the winding zone width – 3200 mm was constructed. The drum is adapted for a collaboration with the hoisting rope of 63mm diameter, wound in one layer. The suggested hoisting depth of the BB - 7000 machine (Fig. 10), with the drum under analysis, is about 820 m and the maximal force in the rope, loading the drum, accepted for calculations, is 580 kN.



a) main shaft assembly b) half of the winding drum

Fig. 10. Elements of BB- 7000 hoisting machine [11]

The main load of the winding drum comes from the force occurring in the hoisting rope wound onto it. Winding the rope on the drum causes a generation of an axial force, directed perpendicularly to the plane of the drum shell and expressed as the pressure exerted on the shell, determined according to the relationship (1) [6]:

$$p = \frac{S}{R \cdot s \cdot d} \tag{1}$$

where:
p – pressure exerted on the drum shell, Pa,
S – force in the rope, N,
R – radius of the drum shell, m,
s – number of layers of the wound rope,
d – rope diameter, m.

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Besides the components of force in the rope, tangential to the drum shell (Fig. 11), the component of force perpendicular to the Ssr drum axis, causing its torsion and the component of force parallel to the Spr drum causing its lateral deflection, affect the drum.

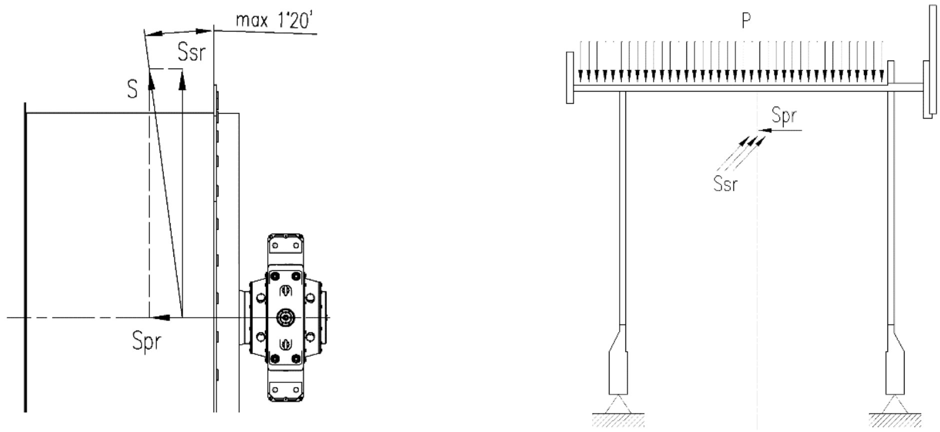


Fig. 11. Schematic diagram of the drum loading

In relation to accepted assumptions, the maximal value of the pressure exerted on the shell is about 2.5 MPa and it decreases when the rope is being wound on the drum. The weight of one-meter hoisting rope of Ø 63mm is 19 kg which causes that after winding 850 m, the force in the rope will reduce to about 420 kN, which causes a reduction of the pressure, exerted to the shell, to the value of about 1.7 MPa. To reduce the number of calculations variants, the most disadvantageous case was assumed, in which the whole drum shell is loaded with the pressure of 2.5 MPa. Strength calculations were conducted with use of the finite element method. Block elements were used for a construction of the model. The general FEM model of the drum is shown in Fig. 12.

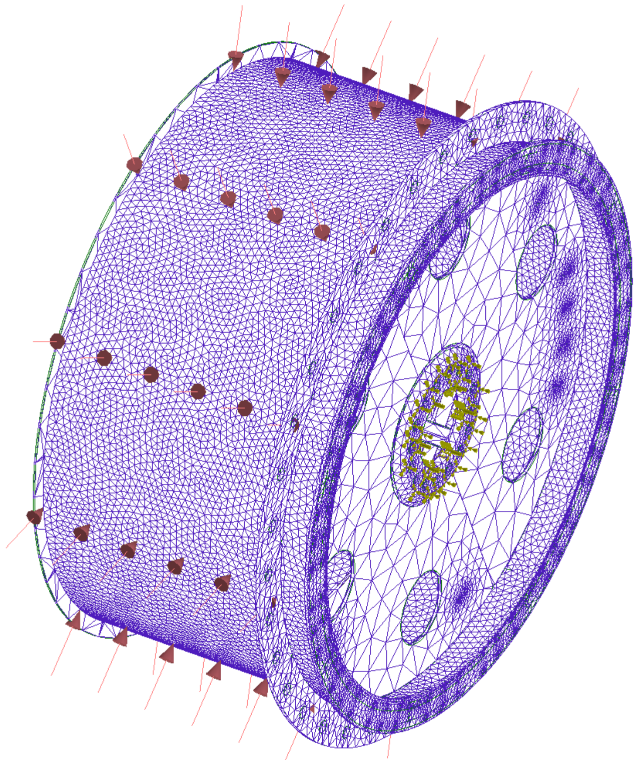
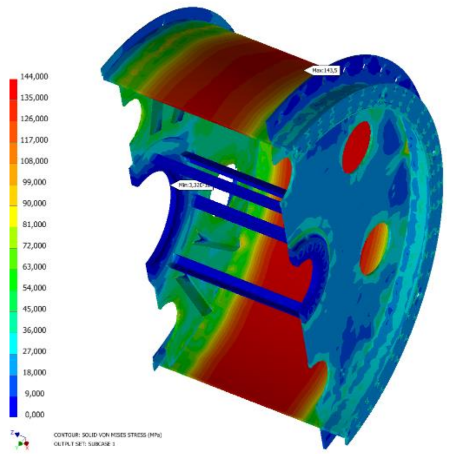


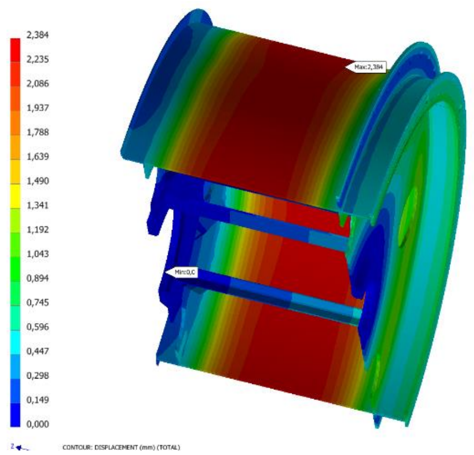
Fig. 12. Analytical model of the BB – 7000 drum

3. Result of calculations

In Fig.13 the results of the drum strength calculations are presented in a form of maps of stresses and deformations. The maximal stress value in the drum shell was about 143 MPa and the value of deformations – about 2.4 mm.



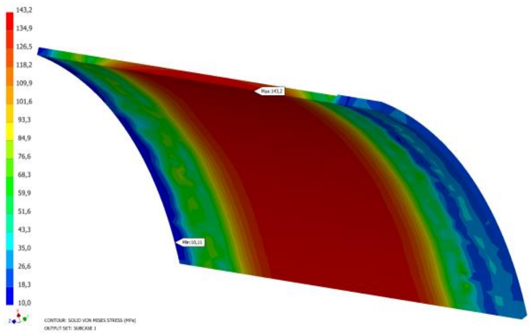
a) a map of drum reduced stresses [MPa]



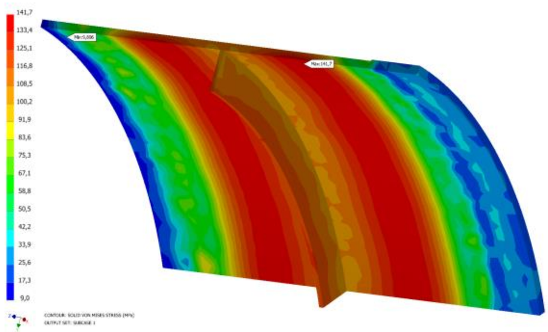
b) a map of drum global deformations [mm]

Fig. 13. Results of calculations

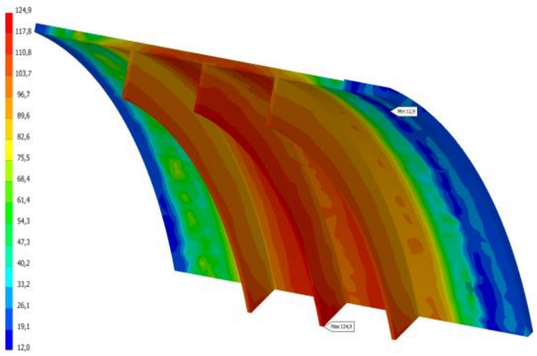
Conducting the drum strength calculations in the case of introducing circumferential ribs was the following step of analyses. It was assumed that the circumferential ribs, rings of 350 mm width and 40 mm thickness, should be analysed. Three drum variants: with one, three and five ribs, installed under the shell, were subject to an analysis. In Fig. 14 the results of calculations are presented in a form of maps of reduced stresses in the drum shell sector.



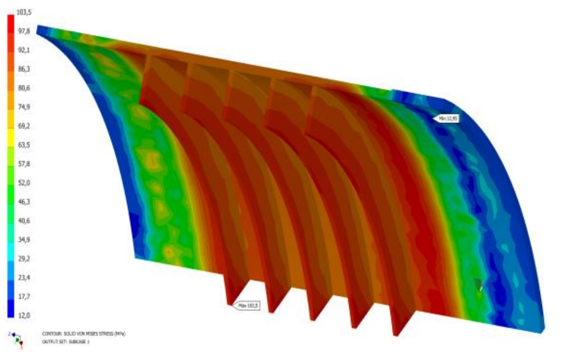
a) without ribs



b) one rib



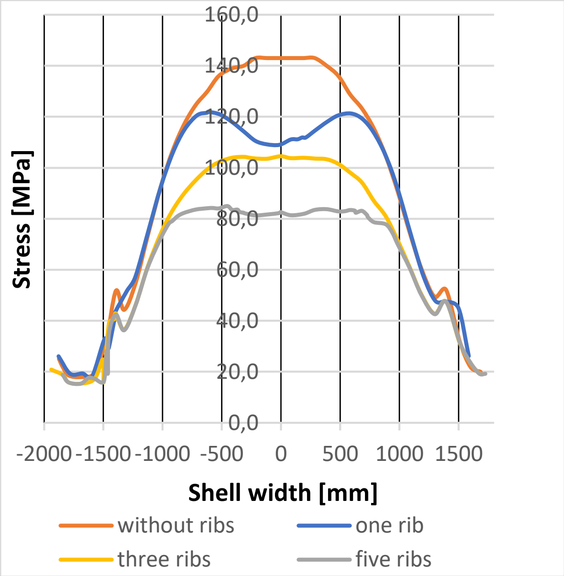
c) three ribs



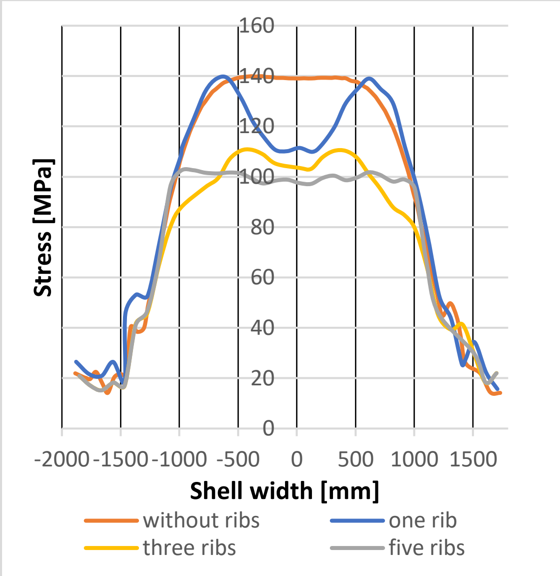
c) five ribs

Fig. 14. Reduced stresses in the drum shell and circumferential ribs

To compare the obtained results of calculations, in Fig. 15 the results are listed in a form of graphs of the stresses distribution along the shell width in relation to the number of applied circumferential ribs. An impact of the ribs, causing a reduction of stresses in relation to a smooth shell (without ribs) can be seen on the graphs. An implementation of three ribs caused a reduction of stresses in the drum shell of about 13%, but an introduction of five ribs – a reduction of stresses of about 28% in comparison with the smooth shell. An application of one rib reduced the stresses in the central part of the shell of about 16%, however it had no impact on the rest of the shell, where the stresses were similar as in the case of the shell without ribs.



a) shell external side



b) shell internal side

Fig. 15. Stresses in the drum shell in relation to a various number of circumferential ribs

An introduction of circumferential ribs caused a reduction of stresses in the drum shell at the cost of the stresses in the ribs themselves. In Fig. 16 maximal stresses in the ribs, in the case of the analysed variants with a different number of ribs, are presented. The obtained results indicate that the biggest stresses in the ribs occur for the variant with one rib, i.e. 127.6 MPa and the smallest ones when five ribs are applied, i.e. 103.5 MPa. The biggest difference of stresses between the rib and the shell occurs in relation to the variant with one rib and it reaches about 14 MPa, whereas in the other cases the stresses in the shell and in the ribs are comparable.

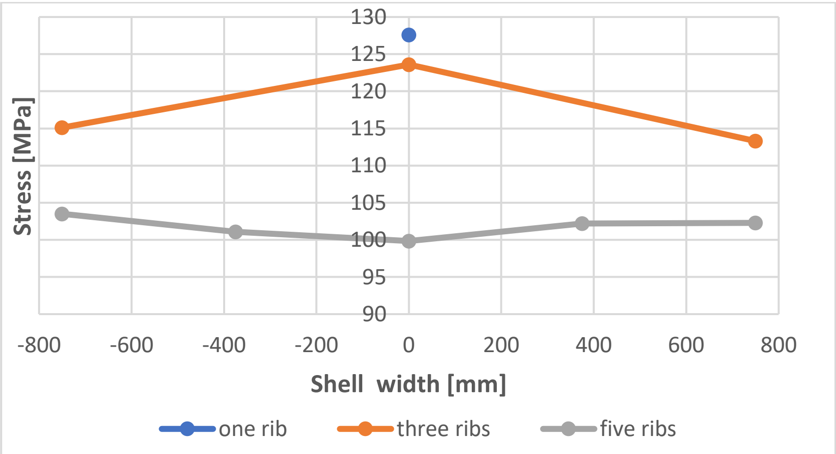


Fig. 16. Maximal stresses in ribs

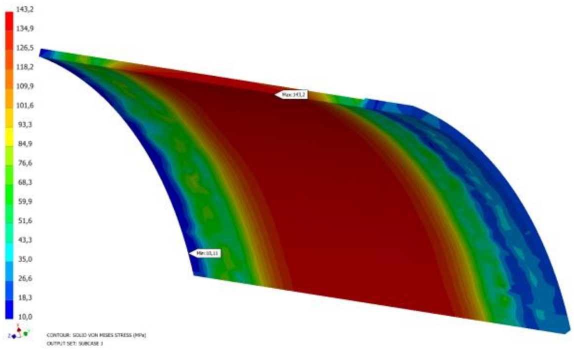
A comparison of the values of stresses, occurring in the shell of the constant thickness and in the drum ribs for a different number of ribs, is shown in Table 1.

Table 1. Values of maximal stresses in the shell of 65 mm thickness equipped with ribs in relation to the drum with a different number of ribs.

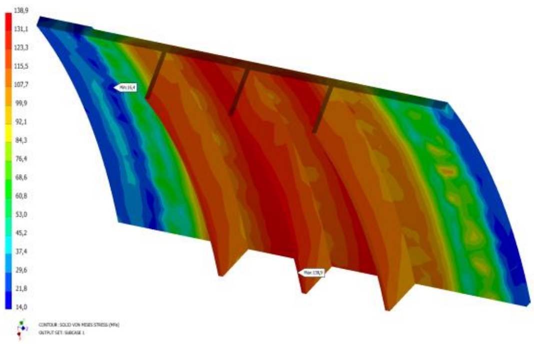
Number of ribs	0	1	3	5
Shell [MPa]	143.2	141.7	116.3	103.5
Rib [MPa]	0	127.6	124.9	103.5

An introduction of the following ribs gives a measurable effect in a form of lower and lower values of stress in the shell and in the ribs, however it generates additional costs of the drum manufacture. One of the reasons of introducing circumferential ribs includes technological limitations connected with a necessity of coiling very thick sheets or also due to the overall dimensions of the drum shell and its weight. In the other cases ribbing can be thereby unjustified economically.

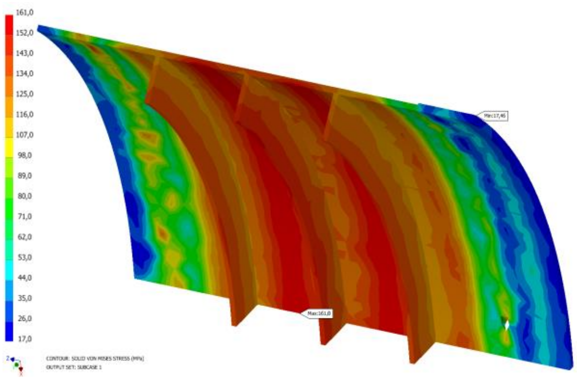
In the following analyses an attempt was undertaken to show how an introduction of circumferential ribs would enable to reduce the drum shell thickness, at keeping the stresses on the level as in the case of the drum with the shell without ribs. This analysis was conducted at an assumption of introducing three circumferential ribs of geometry and parameters of the drum shell loading as before. The thicknesses of shells or calculations were as follows: 32.5 mm, 45 mm and 55 mm. In Fig. 17 the results of calculations are presented in a form of maps of reduced stresses.



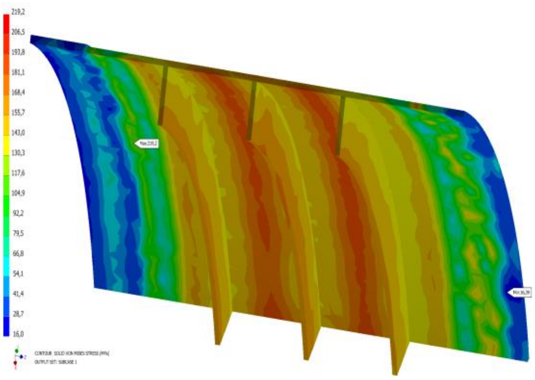
a) without ribs - shell thickness: 65mm



b) shell thickness: 55 mm



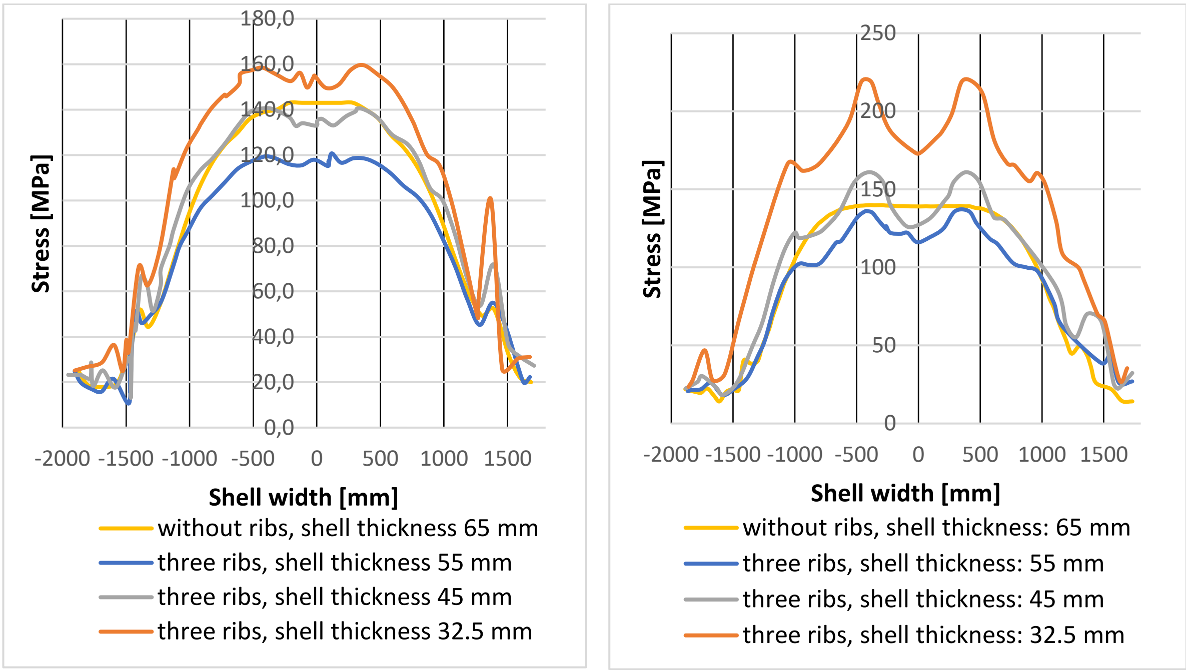
c) shell thickness: 45mm



d) shell thickness: 32.5 mm

Fig. 17. Reduced stresses in relation to different thicknesses of shells

The obtained results of stresses values in the shells of different thicknesses, equipped with three ribs, were compared with the stresses in the shell without ribs, of the thickness: 65 mm (Fig. 18).



a) shell external side b) shell internal side

Fig. 18. Stresses in drum shell with three circumferential ribs in relation to different thicknesses of shells

The obtained results indicated that a reduction of the shell thickness by 50% (i.e. 32.5 mm) caused an increase of stresses by 53% in relation to the smooth drum of the shell thickness 65 mm, but a reduction of the shell thickness by 30% (i.e. 45mm) caused an increase by 13%. The most optimal variant concerned the shell thickness of 55 mm. In this case a reduction of the shell thickness by 15% in relation to the basic thickness (65 mm) enabled to obtain the stresses in the shell on the level of about 137 MPa. These values are close to the stresses in the shell without ribs of the thickness 65 mm (143.2 MPa). To get a full image of the stresses level in the construction, the stresses in circumferential ribs for different thicknesses of drum shells, are presented in Fig. 19.

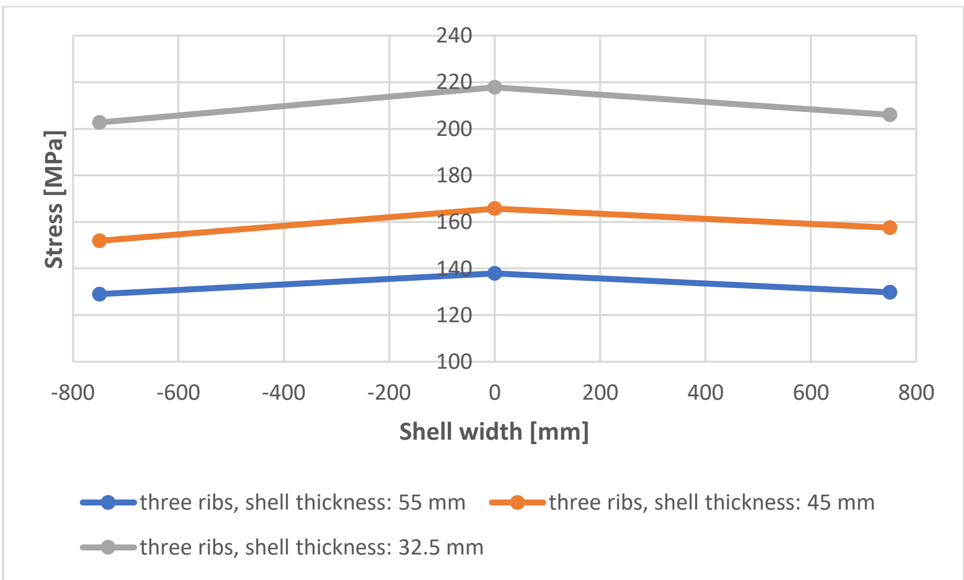


Fig. 19. Maximal stresses in ribs

The results of calculations are presented in Table 2 for drums of different shell thicknesses equipped with three ribs.

Table 2. Stresses in drum shells and in ribs in the case of different shell thicknesses and three circumferential ribs.

Shell thickness [mm]	Drum without ribs [MPa]	Drum with ribs	
		Shell [MPa]	Rib [MPa]
65	**143.2**	116.3	124.9
55	-------	**136.6**	**138.9**
45	-------	161.0	154.5
32.5	-------	219.2	172.0

4. Summary

The presented results of strength calculations of the winding drum of the hoisting machine indicated that an installation of circumferential ribs under the shell gives measurable advantages in a form of reduced stresses. It is achieved at the cost of additional technological machining i.e. a manufacture of rings and then their welding to the drum shell. An introduction of circumferential ribs enables to reduce the shell thickness. A correlation between the drum weight, in the case of the shell thickness change and a number of introduced ribs, is shown in Table 3.

Tabela 3. Drum weight for different shell thicknesses and a different number of circumferential ribs.

Shell thickness [%]	Drum without ribs [kg]	Drum with one rib [kg]	Drum with three ribs [kg]	Drum with five ribs [kg]
65.0	**76800**	**79020**	**83460**	**87900**
55.0	70650	72870	77310	81750
45.0	64500	66720	71160	75600
32.5	56800	59020	63460	67900

An approximate weight of the drum without circumferential ribs, with the shell of 65mm thickness, subject to an analysis, is about 76800 kg. It can be assumed that from the strength point of view (Table 2) a drum with the shell of 55 mm thickness and three ribs will be an equivalent of a drum with the shell of 65 mm thickness without ribs. Therefore, keeping the same level of stresses in the drum with the shell without ribs and with three ribs, it was not possible to obtain any advantages in the aspect of an essential reduction of the drum weight-an increase of weight below 1%.

An installation of circumferential ribs under the shell requires a series of additional technological operations. A comparative tabulation of operations for a manufacture of a drum with the shell without ribs and with circumferential ribs is presented in Table 4.

Special attention should be paid to the fact that an efficiency of ribs can be achieved exclusively in the case of their exact fitting to the drum shell and their good connection by welded joints.

An introduction of circumferential ribs can be justified in the case of drum shells of very big thicknesses e.g. above 150 mm, big overall dimensions and a big weight, when a reduction of these parameters turns out to be indispensable.

Table 4. A comparison of manufacturing technologies of a shell with ribs and of a shell without ribs.

Name of technology	Shell without ribs	Shell with ribs	Comments
Bending of shell sheet	**yes**	**yes**	Bending of shell sheets from 20 to 120 mm does not cause any technological problems. With an increase of thickness of the sheets subject to bending, a number of companies which can do this operation, decreases.
Machining of shell from inside	no	**yes**	A need of machining some parts of shell to obtain a round surface for fitting the ribs (rings) may occur.
Manufacture of ribs	no	**yes**	Rings made of segments, then welded with each other. Edges must be prepared for an execution of welds.
Welding of ribs to shell	no	**yes**	In the case, under analysis, about 3x21m=63m of K-weld (estimated about 40h). An additional hazard is a deformation of shell sheet rolling due to an introduction of heat during welding.
Tests of welds	no	**yes**	Magnetic-powder method or ultrasounds

The results of the FEM numerical calculations, presented in the article, are the result of research and development projects realized at the KOMAG Institute. These calculations were conducted with use of the Autodesk Inventor Nastran Software.

5. Conclusions

While designing rope shaftings of hoisting machines in the system with winding drums and with the frictional contact, ribbing of shells is avoided. An introduction of ribs, under the shell, parallel to the drum axis should be avoided firmly [10] as they are components which have no impact on the strength increase of the drum shell.

Circumferential ribs, which are correctly chosen according to the drum design as regards their number and geometry, give positive strength effects – a reduction of stresses in the construction. However, it should be borne in mind that in most cases their introduction causes an increase of the drum manufacture costs.

The conclusions, presented above, are related exclusively to the drum under analysis and they show some possibilities of a construction optimization as regards the strength and production costs. Due to a big variety of constructions and loading conditions, each winding drum is different and it should be designed individually.

Literature

[1] http://muzeum.wieliczka.pl/kierat [accessed: 28.10.2020]

[2] http://kopalnia-bochnia.pl [accessed: 28.10.2020]

[3] Bućko S., Trzebicki M.: Wpływ wybranych parametrów konstrukcyjnych na poziom wytężenia płaszcza bębna nawojowego. Transport Szybowy 2007, Instytut Techniki Górniczej KOMAG, Gliwice 2007, tom II s. 119-130.

[4] Bućko S., Trzebicki M.: Wytrzymałościowo-konstrukcyjne problemy projektowania bębnów maszyn wyciągowych. Transport Szybowy, Instytut Techniki Górniczej KOMAG, Gliwice 2009, s. 207-229.

[5] Dawydow B.Ł.: Obliczenia i konstruowanie górniczych maszyn wyciągowych. Uglietiehizdat 1949 s. 82-112.

[6] Popowicz O.: Górnictwo tom IX, Transport Kopalniany Część 4, Wyciągi szybowe, Wydawnictwo Górniczo-Hutnicze, Katowice 1957 ss. 627.

[7] Narkar K. M., Patil. D. D.: Design and finite element analysis of rope drum and drum shaft for lifted material loading condition. International Engineering Research Journal (IERJ) Special Issue 2 Page 2034-2040, 2015, ISSN 2395-1621.

[8] Rutkowski M. A.: Prawidłowe przygotowanie osiowo - symetrycznych modeli do obliczeń cylindrycznych bębnów spiralnych. UDK 622.673.1.

[9] Zabalotny K. S., Panczenko E. B.: Zastosowanie MES w projektowaniu cienkościennych elementów konstrukcji maszyn. UDK 622.673.1:621.778.27.

[10] Zmysłowski T.: Górnicze maszyny wyciągowe. Część mechaniczna. „Śląsk” Sp. z o.o. Wydawnictwo Naukowe, Katowice 2004.

[11] Dokumentacja techniczna maszyny wyciągowej 2Ц-7,0×3,2 – MWM Elektro/ITG KOMAG (unpublished).

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Research on the assessment of flow and pressure pulses in oscillating hydraulic intensifiers

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Keywords: low-pressure pumping unit, generation of high pressure, oscillating pressure intensifiers, miniBOOSTER Hydraulics, flow and pressure pulses

Słowa kluczowe: zespół pompowy niskiego ciśnienia, wytwarzanie wysokiego ciśnienia, oscylacyjne wzmacniacze ciśnienia, MiniBOOSTER Hydraulics, pulsacja przepływu i ciśnienia

Abstract:

Some mining activities, such as interventions in the event of accidents, are carried out in narrow spaces, using small (single- or double-acting) hydraulic cylinders to obtain high static (press and squeeze) or dynamic (push and pull) forces. The opposite load of these forces can occur: at the end of the advance stroke; on the entire advance stroke; on both directions. There are two types of pumping units for these cylinders: units with positive displacement pumps and high-pressure hydraulic components, units with positive displacement pumps and low-pressure hydraulic components, plus oscillating pressure intensifiers (miniboosters). The second type, which generates high pressures with low-pressure systems, has the following advantages: lower price, higher energy efficiency and operational safety. The manufacturers of miniboosters do not specify the amplitude and frequency of pulses of pressure oscillators. In order to use these hydraulic pressure intensifiers in dynamic applications specific to mining activities, under conditions of maximum safety, the authors propose a solution for a test stand on which one can determine: flow and pressure pulse characteristics, their influence on the uniform displacement of the load of hydraulic cylinders supplied by pumping units equipped with miniboosters, functional characteristics, in dynamic and stationary modes, of pumping units with embedded miniboosters.

Streszczenie:

Niektóre prace górnicze, takie jak akcja ratunkowa, są wykonywane w wąskich przestrzeniach, przy użyciu małych siłowników hydraulicznych (jednostronnego lub dwustronnego działania), w celu uzyskania dużych sił statycznych (naciskających i ściskających) lub dynamicznych (pchających i ciągnących). Przeciwny zwrot tych sił może wystąpić: po całkowitym wysunięciu tłoczyska; przy dowolnym wysunięciu tłoczyska przy przemieszczaniu tłoczyska w obu kierunkach. Istnieją dwa typy zespołów pompujących dla tych siłowników: z pompami wyporowymi i wysokociśnieniowymi elementami hydraulicznymi, z pompami wyporowymi i niskociśnieniowymi komponentami hydraulicznymi oraz oscylacyjnymi wzmacniaczami ciśnienia (miniboostery). Drugi typ, który generuje wysokie ciśnienia za pomocą systemów niskociśnieniowych, ma następujące zalety: niższa cena, wyższa efektywność energetyczna i bezpieczeństwo eksploatacji. Producenci minibosterów nie określają amplitudy i częstotliwości impulsów oscylatorów ciśnienia. Aby zastosować te hydrauliczne wzmacniacze ciśnienia w dynamicznych zastosowaniach specyficznych dla działalności górniczej, w warunkach maksymalnego bezpieczeństwa, autorzy proponują koncepcję stanowiska badawczego, na którym można określić: charakterystyki pulsacji przepływu i ciśnienia, ich wpływ na równomierny rozkład obciążenia siłowników hydraulicznych zasilanych przez agregaty pompowe wyposażone w minibostery, charakterystykę funkcjonalną w trybie dynamicznym i stacjonarnym zespołów pompowych z wbudowanymi miniboosterami.

1. Introduction

The main research issues are related to experimental testing of stationary and dynamic operation of hydraulic pumping units that integrate in their structure oscillating hydraulic pressure intensifiers, minibooster type. The aim is to create a test stand that includes a test cylinder supplied by a pumping unit with embedded minibooster and a load cylinder supplied by a low-pressure pumping unit with proportional pressure valve, which will allow to determine: the stationary flow rate /pressure characteristic in the secondary circuit of the booster, to linear variation of the load of the hydraulic test cylinder, performed by a ramp signal applied to the proportional valve within the supply unit of the load cylinder; the booster response to a pressure step signal applied to the proportional valve within the supply unit of the load cylinder; the amplitude/frequency of flow pulses in the secondary circuit of the booster, and their impact on the uniform displacement of the test cylinder, at constant load, over the entire stroke.

The main objective of the work is to expand the technical applications of hydraulic cylinders with small dimensions and high forces to mining activity, under conditions of maximum safety.

The methodology used in solving the problems specific to this objective comprises six stages, of which the last two will be the topic of a future paper; they are: documentation on the structure and operation of minibooster type oscillating hydraulic pressure intensifiers; preliminary numerical simulation of pulses generated by a minibooster; selecting a minibooster in order to integrate it into a low-pressure pumping unit (LPPU); determining the functional hydraulic schematic diagram of the stand on which one conducts experimental tests on a LPPU; *determining the test methodology for a LPPU (future task); developing the stand, performing experimental tests on the LPPU and completing the numerical simulation model (future task)*.

2. Structure and operation of oscillating hydraulic pressure intensifiers

Hydraulic pressure amplifiers with oscillating pistons [1, 2, 3, 4, 5, 6, 7, 8, 9, 10] are known in the literature under several names: oscillating hydraulic pressure amplifiers, oscillating pumping units, pressure intensifiers, boosters, miniboosters (miniBOOSTER Hydraulics).

The oscillating hydraulic pressure intensifier (OHPI) is used to generate higher pressure using a low-pressure hydraulic power source. Considering the high-pressure flow pulses, OHPIs can be single-acting, SAOHPIs (higher pulsations; they pump on a single direction of piston movement) or double-acting, DAOHPIs (lower pulsations; they pump on both directions of piston movement).

The basic structure of an SAOHPI, Fig. 1.a, includes: an assembly of two pistons of different diameters, connected by a rod; a bistable piston distribution valve (Piston Control Valve), PCV; two Check Valves, CV1 and CV2; a Pilot Operated check Valve, POV. The position of the pistons will determine, at the end of each stroke, a signal S to the PCV, which will cause a change in the direction of piston travel. This "pulsating" cycle of piston movement, with a maximum frequency of 20 Hz [11], lasts until the end pressure is reached, after which the pistons stop. Further, they will only move to maintain the end pressure.

The operating principle of an SAOHPI, Fig. 1a), is as follows: a large fluid volume and low pressure pushes a large diameter piston, which is in contact with another piston, of small diameter; as an effect of this action, the small diameter piston will push a small volume of fluid, with high pressure, HP, equal to the low pressure amplified by the ratio of piston surfaces. The high pressure, HP, will always be proportional to the supply pressure of the large piston.

The flow rate / pressure characteristic of an SAOHPI, Fig. 1b), includes two areas: area I ($p=p_{min}...p_{max}/i$; i=intensification factor), in which the fluid coming out of the pump, with high flow and low pressure, continuously supplies the consumer hydraulic motor through the secondary side of the amplifier, allowing it to operate quickly in the desired direction; area II ($p=p_{max}/i...p_{max}$), in which the consumer hydraulic motor will be supplied with low pulsating flow, by means of the high-pressure piston, until the maximum pressure of the intensifier, HP, is reached.

An SAOHPI (minibooster), embedded in a low-pressure hydraulic pumping unit, can supply a single-acting or double-acting hydraulic cylinder type consumer, Fig. 1c), or a rotary hydraulic motor (not shown in the figure). It comprises: a low-pressure piston, LP; a high-pressure piston, HP; a bistable distribution valve, BV1, with hydraulic control through the pilot channels 1 and 2, intended to change the direction of travel of the pistons; a deblockable check valve (optional), DV, controlled through the pilot channel 3, intended to discharge the high-pressure oil from the consumer chamber.

In the simplified functional diagram of the minibooster, the pistons LP and HP along with the bistable distribution valve BV1 are included in the simplified symbol of the pressure oscillator OP.

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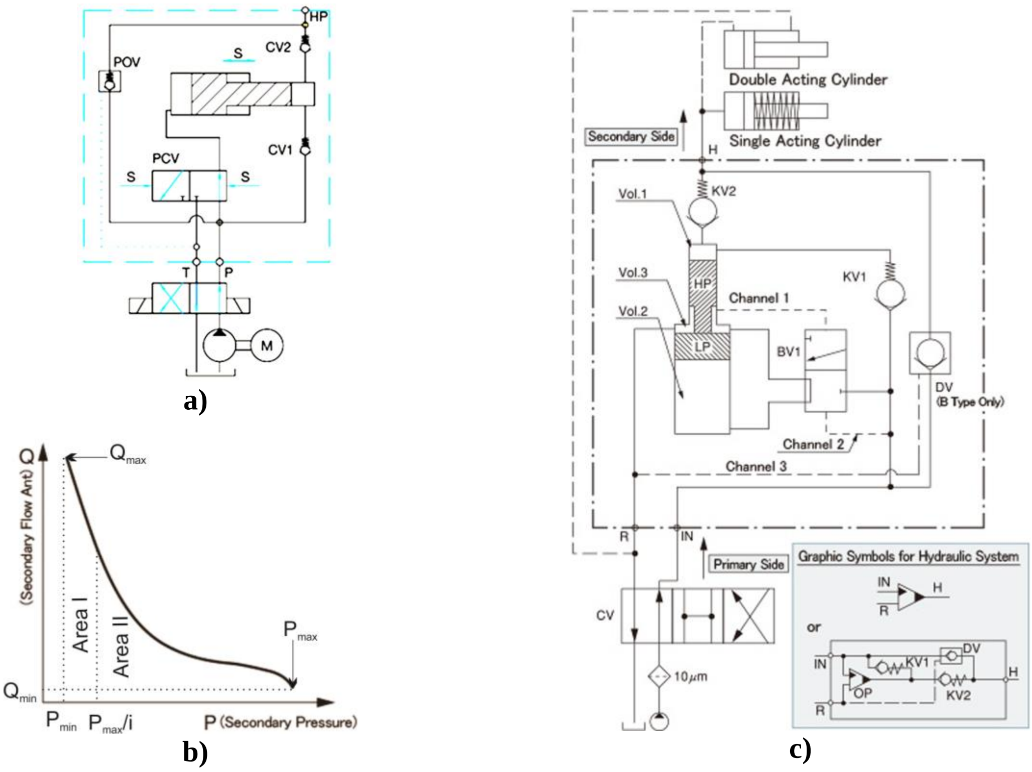


Fig. 1. Structure and operation of the SAOHPI: a) operating principle [12]; b) flow rate / pressure characteristic [13, 14]; **c)** functional diagram of a pumping unit equipped with SAOHPI [13, 14]

In operating phase I, the low-pressure pump sends the hydraulic fluid, at system pressure, to the port IN; the liquid flows freely through the valves KV1, KV2, DV and the port H. All pump flow passes through the port H, and the cylinder supplied by the SAOHPI moves fast forward.

In phase II, the load of the hydraulic cylinder equals the force given by the pump pressure; the valves KV2 and DV close, and the fluid is directed to volume 1. The bistable valve BV1 discharges volume 2 to the tank through volume 3. As the pump pressure is applied to volume 1, the pistons move downwards.

When the pistons have completely moved downwards, the pilot channel 1 is supplied with pressure, and the bistable valve BV1 changes its position; as a result, the pump will discharge fluid under low pressure in volume 2, and the small piston, pushed by the large one, will move upwards, delivering high-pressure fluid to the consumer.

Once the high-pressure piston HP has moved upwards, the pilot channel 1 connects to the tank, and the bistable valve BV1 returns to its original position. The cycle is repeated until the maximum pressure required for the hydraulic cylinder (the supply pressure amplified by the ratio of piston surfaces) is reached at port H.

The end pressure from the consumer can be discharged through the deblockable check valve DV. To do this, one shall connect port R to the pump supply pressure and port IN to the tank; the pilot channel 3 will be pressurized, allowing the fluid from the high-pressure side of the amplifier, H, to flow back into the tank.

The directional control valve CV in Fig. 1.c, four-port three-position (4/3), controls the direction of travel of the driven cylinder (left position = advance; right position = retraction; center position = stationary).

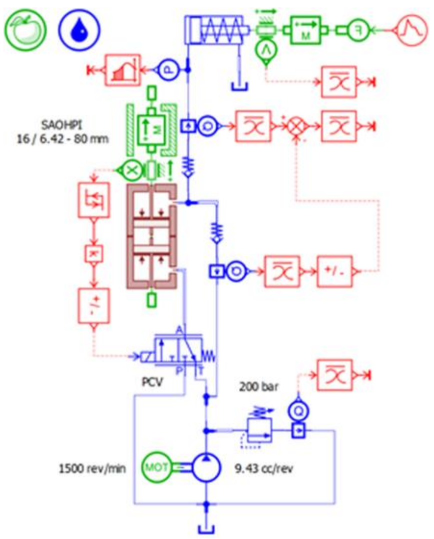
3. Preliminary numerical simulation of pulses generated by a minibooster

The numerical simulation model in Fig. 2 has the following components:

- a low-pressure pumping unit, with 9.43 cc / rev and 1500 rev / min fixed-displacement pump, pressure-control valve, with maximum opening pressure set to 20 MPa;

- a single-acting oscillating hydraulic pressure intensifier (SAOHPI), minibooster type, with low-pressure piston diameter of 16 mm, high-pressure piston diameter of 6.42 mm and the stroke of the assembly of the two pistons (with inertial mass) of 80 mm. The piston distribution valve (PCV) is simulated by the hydraulic component 3/2 proportional directional control valve. The intensifier also contains the two check valves, equivalent to CV1 and CV2 in Fig.1a). The deblockable check valve (POV in Fig.1a) is optional in the structure of a minibooster. For this reason and in order to simplify the simulation model, it was omitted;
- a single-acting hydraulic cylinder, represented by the hydraulic component single-acting hydraulic cylinder with spring return, stroke of 200 mm, inertial mass and ramp load.

To measure the parameters of interest of the system - hydraulic and mechanical - the simulation model also includes six transducers: three flow transducers and one for each of the following parameters: pressure, speed and force.



a)

Title	Value	Unit
type of fluid properties	**advanced**	
index of hydraulic fluid	0	
temperature	40	degC
name of fluid	**HEP46**	
General properties		
density	850	kg/m**3
bulk modulus	17000	bar
slope of bulk modulus [bar] in function of pressure [bar] (in percentage)	0	null
absolute viscosity	51	cP
Aeration		
absolute viscosity of air/gas	0.02	cP
saturation pressure (for dissolved air/gas)	1000	bar
air/gas content	0.1	%
polytropic index for air/gas/vapor content	1.4	null
Cavitation		
(advanced user) high saturated vapor pressure	-0.5	bar
(advanced user) low saturated vapor pressure	-0.6	bar
(advanced user) absolute viscosity of vapor	0.02	cP
(advanced user) effective molecular mass of vapor	200	null
(advanced user) air/gas density at atmospheric pressure 0 degC	1.2	kg/m**3

b)

Fig. 2. Numerical simulation model, developed in Simcenter Amesim, for a low-pressure pumping unit equipped with SAOHPI: a) simulation model; b) fluid properties

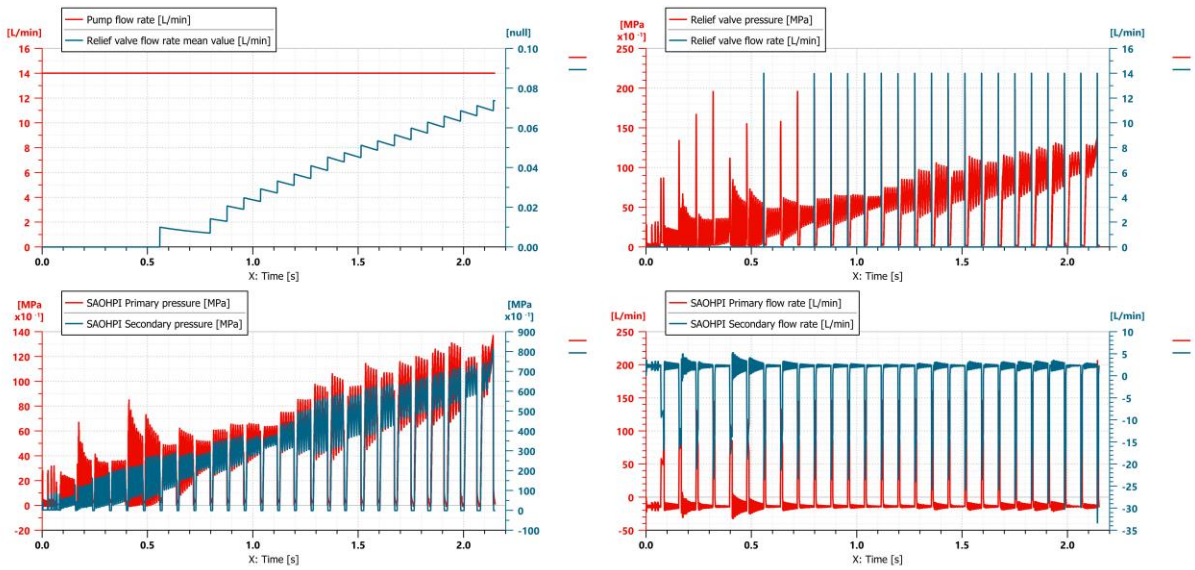


Fig. 3. Comparative time variation of: pump flow rate and valve flow rate (top left); pressure rates in the primary side and secondary side of the SAOHPI (bottom left); valve inlet pressure and valve flow (top right); flow rates in the primary side and secondary side of the SAOHPI (bottom right)

Following the simulations performed on the model in Fig. 2, equivalent to the simplified structure and operating principle of a minibooster, we obtained the dynamic characteristics represented in Fig. 3-6, namely:

In Fig. 3, comparisons between time evolutions of the following groups of hydraulic parameters: pump flow rate (top left, in red) and average flow rate through the pressure control valve (top left, in blue); pressure in the primary side of the SAOHPI (bottom left, in red) and pressure in the secondary side of the SAOHPI (bottom left, in blue); pressure at the inlet of the pressure valve (top right, in red) and the flow rate through it (top right, in blue); flow rate in the primary side of the SAOHPI (bottom right, in red) and flow rate in the secondary side of the SAOHPI (bottom right, in blue).

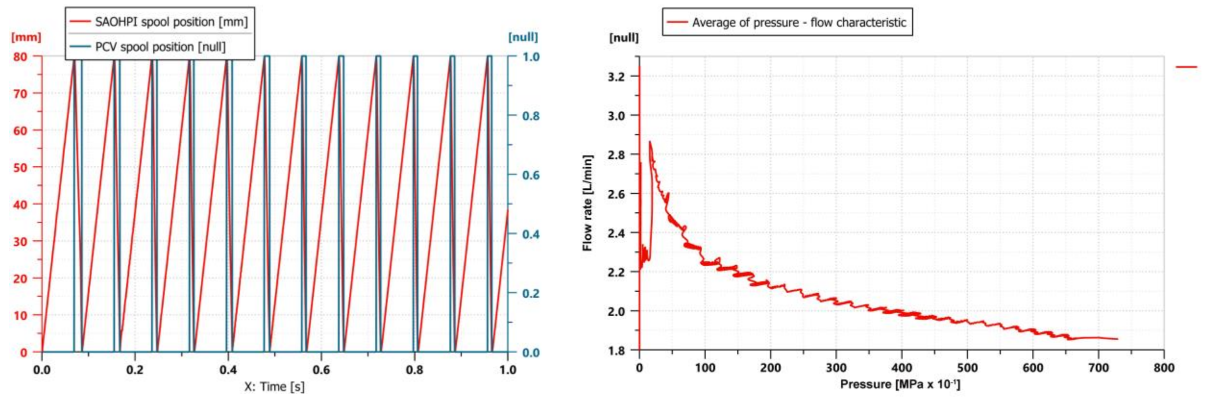


Fig. 4. Time variation of position of the pistons of the SAOHPI and the piston of the PCV (left); flow rate variation as a function of pressure in the secondary side of the SAOHPI

In Fig. 4: comparison between time evolutions of displacement of the SAOHPI pistons (left, in red) and displacement of the distribution valve PCV piston (left, in blue); variation of flow rate in the secondary side of the SAOHPI, depending on the pressure din in the secondary side of the SAOHPI (right, in red; the shape is similar to the flow / pressure characteristic in Fig. 1.b and the pressure / flow characteristic presented by miniBOOSTER Hydraulics A/S in [12]).

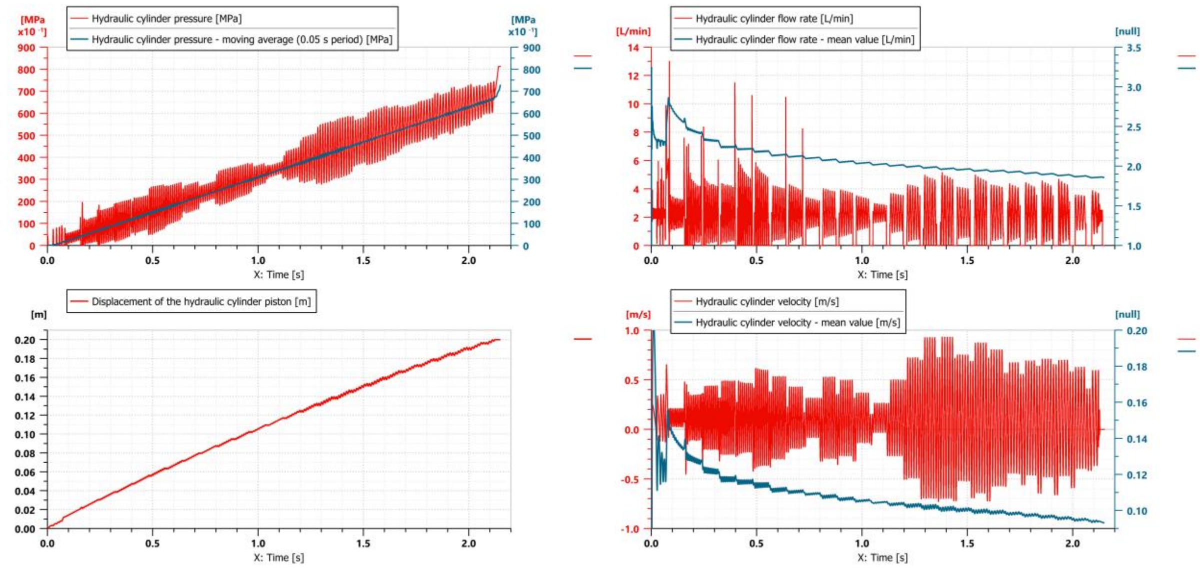


Fig. 5. Time variation of: oscillating and average pressure in the cylinder chamber (top left); cylinder displacement (bottom left); oscillating and average flow in the cylinder chamber (top right); oscillating and average cylinder speed (bottom right)

In Fig. 5: oscillating pressure variation (top left, in red) and average pressure variation (top left, in blue) in the cylinder chamber, at ramp load increase; time variation of the displacement of the hydraulic cylinder (bottom left, in red); oscillating flow rate variation (top right, in red) and average flow rate variation (top right, in blue) in the cylinder chamber, at ramp load increase; oscillating speed variation (bottom right, in red) and average speed variation (bottom right, in blue) of the cylinder piston, at ramp load increase.

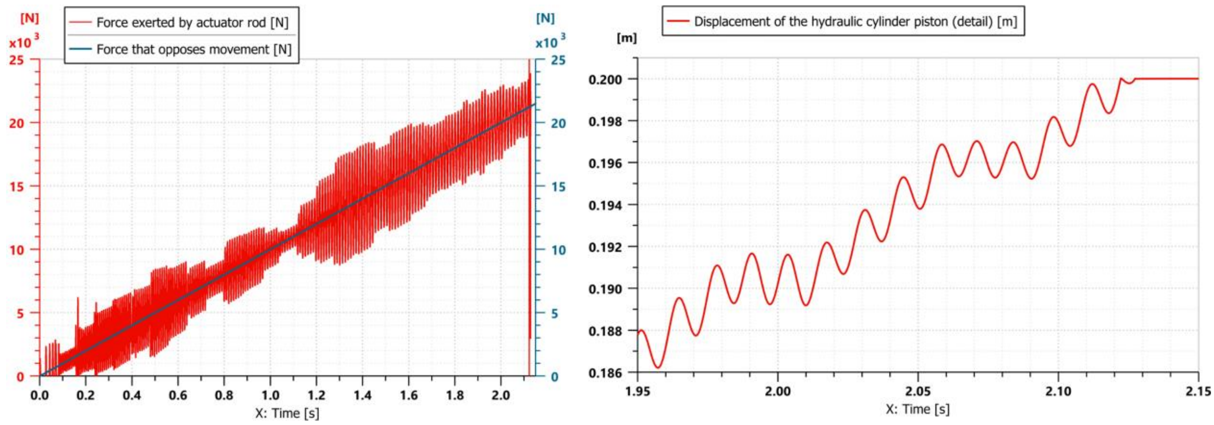


Fig. 6. Time variation of: cylinder force and load (left); oscillating displacement of the cylinder piston (right)

In Fig. 6: cylinder force variation (left, in red) and ramp load variation (left, in blue); detail of oscillating displacement of the hydraulic cylinder piston (right, in red).

After developing the test stand and conducting experimental tests, the numerical simulation model will be validated [15, 16, 17, 18].

4. Selecting a minibooster for a low-pressure pumping unit LPPU

For a 14 l/min and 20 MPa pumping unit, a minibooster from the HC7 group, code HC7-5.0-B-12, is identified; its functional diagram is shown in Fig. 7, and the main technical characteristics - in Table 1. The functional characteristics of the pump unit and the HC7 booster are similar to those in the numerical simulation model (Fig. 2) and functional diagram of the experimental stand (Fig. 8).

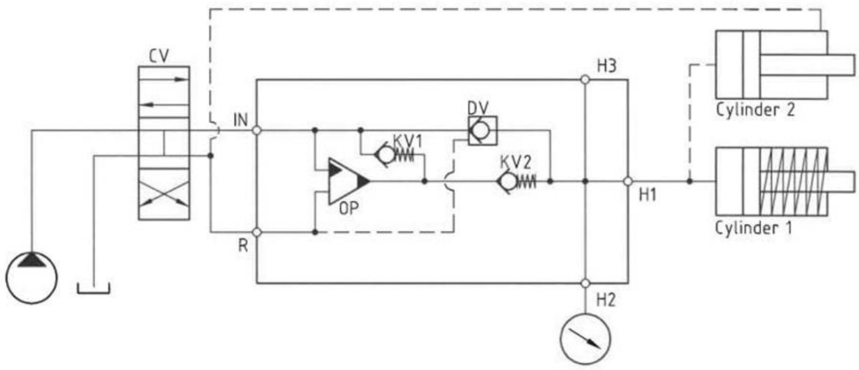


Fig. 7. Functional diagram of a pumping unit equipped with a HC7 series minibooster [19]

Table 1. Technical characteristics of the minibooster code HC7-5.0-B-12 [9]

Intensification factor i	Max. intensified outlet flow l/min	Max. inlet flow l/min	Connection types		
			IN / R	H1	H2
5.0	1.6	14.0	1/4" BSP	M22x1.5	9/16 -18 UNF

5. The stand for conducting experimental tests on an LPPU

On the stand with the functional diagram shown in Fig. 8 one can experimentally test pumping units and hydraulic cylinders grouped in two variants, namely:

a) low-pressure pumping units equipped with one HC7 series minibooster and hydraulic cylinders, single- or double-acting, with load on the advance stroke, at the end of the stroke or on the entire stroke;

b) low-pressure pumping units equipped with two HC7 series miniboosters and hydraulic cylinders, single- or double-acting, with load on the advance stroke and the retreat stroke, at the end of the stroke or on the entire stroke.

5.1. Functional hydraulic diagram of the stand for conducting experimental tests on an LPPU

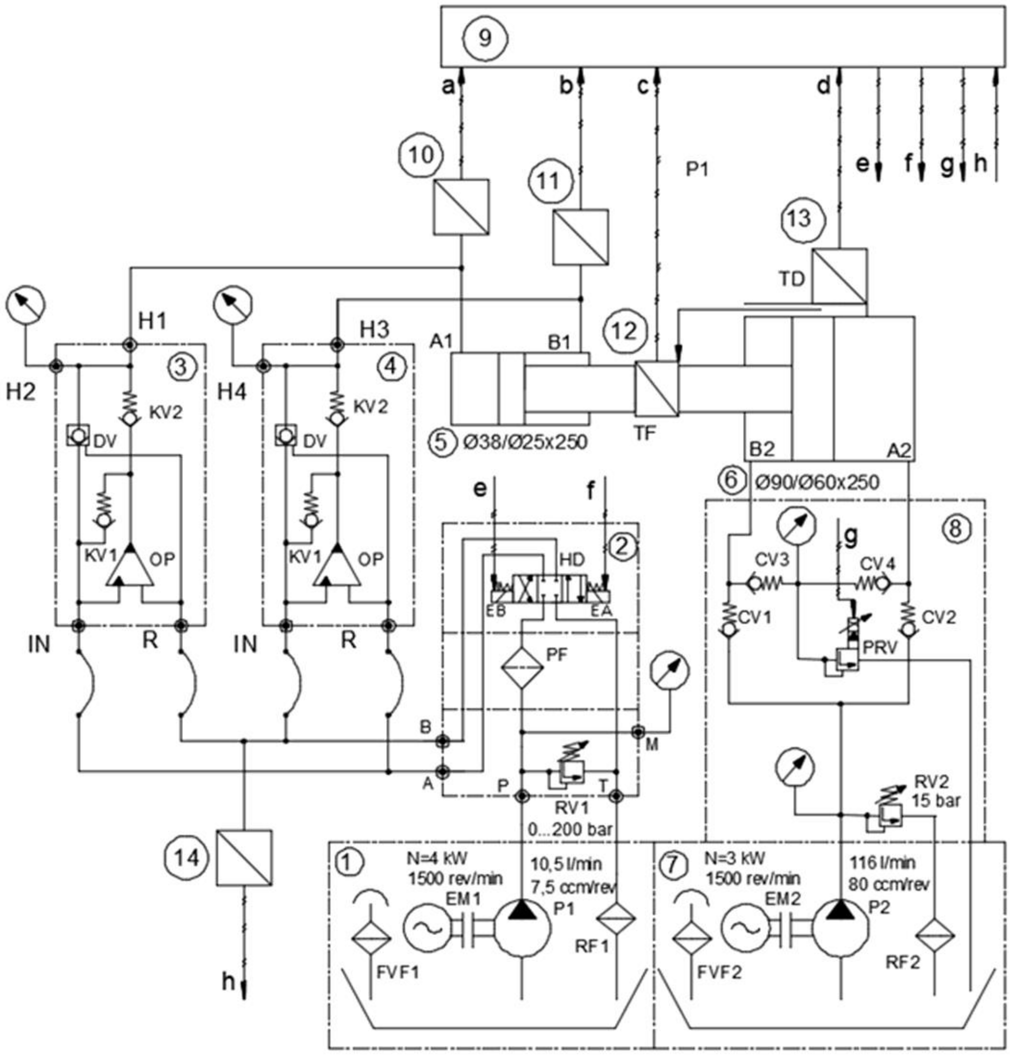


Fig. 8. Functional diagram of the stand for experimental tests on an LPPU

The stand in Fig. 8 includes nine main modules and five transducers, namely:

1- low-pressure pumping unit, which tests and supplies the test cylinder, provided with: oil tank, FVF1- filling and ventilating filter, EM- 4 kW and 1500 rev / min electric motor, P1- 7.5 ccm / rev positive displacement pump, RF1- return filter;

2- hydraulic block with four devices: RV1- 0 ... 200 bar pressure-control valve, PF- pressure filter, DH- 4/3 electrically operated hydraulic directional control valve, M- 300 bar manometer. It has an inlet port P and four outlet ports M, A, B, T;

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3, 4- HC7 series miniboosters, with four low-pressure ports (IN-inlet, R-return) and four high-pressure ports (H1, H3- for the cylinder being tested; H2, H4- for the 2000 bar manometers);
5- hydraulic test cylinder, with ports A1 / B1 and sizes Ø38 / Ø25 x 250 mm;
6- load simulation hydraulic cylinder, with ports A2 / B2 and sizes Ø90 / Ø60 x 250 mm;
7- low-pressure pumping unit, for filling the load simulation cylinder, equipped with: oil tank, FVF2- filling and ventilating filter, EM2- 3 kW and 1500 rev / min electric motor, P2- 80 ccm / rev positive displacement pump, RF2- return filter;
8- hydraulic block with six devices: RV2- 15 bar pressure valve, PRV- proportional pressure valve, CV1...CV4- check valves, M- 25 bar manometer. It has an inlet port (from P2) and four outlet ports (two to the tank and two to the cylinder 6);
9- PLC for data acquisition (from five transducers) and command signals (to the electromagnets EA, EB and the proportional pressure valve electromagnet);
10...14- transducers for: pressure (10,11), force (12), stroke (13), flow rate (14). H3-plug; B1(5)-to B(2); the rest, according to Fig. 8.

5.2. Description of the operating procedure used for the stand on which experimental tests are conducted on an LPPU

Depending on the equipment experimentally tested on the stand, grouped in the mentioned variants a) or b), the nine modules and five transducers will be coupled according to Table 2.

Table 2. Variants for coupling the stand modules

Variant no.	Cylinder 5 load simulation variants	Connections between stand components	Boosters coupled to the stand
a)	On the advance stroke and the retreat stroke	according to Fig. 8.	3 and 4
b)	On the advance stroke	H3- a plug is mounted; B1(5)- connected to B(2); the rest, according to Fig. 8	3

5.2.1. Operating procedure used for the stand; Table 2, variant a)

Step 1: Start the pump P2, with the valve PRV set to 20 MPa and the valve RV2 open, to fill the load cylinder 6 chambers. Then set the opening pressure of the valve RV2 to 15 bar.

Step 2: Start the pump P1, with the valve RV1 open and the hydraulic directional control valve HD not operating. After that, to move the cylinders to the right an electric control signal shall be sent to the electromagnet EA of the hydraulic directional control valve HD.

Step 3: Set the valve RV1 to 200 bar, then adjust the valve PRV, in the decreasing direction of the opening pressure, until the two cylinders start to move to the right.

The pump P1 supplies the port A1 of the cylinder 5 along the circuit: tank- P(block 2)- A(block 2)-IN(booster 3)-H1(booster 3)- A1. The port B1 is connected to the tank along the circuit: B1-H3(booster 4)- DV(booster 4)- IN(booster 4)- B(block 2)- T(block 2)-RF1- tank.

The pump P2 supplies the port B2 of the cylinder 6 along the circuit: tank- check valve CV1-B2. The port A2 is connected to the tank along the circuit: A2- check valve CV4- valve PRV- tank.

Step 4: Acquire the parameters measured by the transducers 10...14;

Step 5: Repeat steps 3 and 4 for other set values of the valve RV1 opening pressure (e.g. 150 bar, 100 bar, 50 bar);

Step 6: To move the cylinders to the left an electric control signal shall be sent to the electromagnet EB of the hydraulic directional control valve HD;

Step 7: Repeat steps 3, 4, 5 from moving to the right.

The pump P1 supplies the port B1 of the cylinder 5 along the circuit: tank- P(block 2)- B(block 2)-B1. The port A1 is connected to the tank along the circuit: A1- A(block 2)- T(block 2)-RF1- tank.

The pump P2 supplies the port A2 of the cylinder 6 along the circuit: tank- check valve CV2-A2. The port B2 is connected to the tank along the circuit: B2- check valve CV3- valve PRV- tank.

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5.2.2. Operating procedure used for the stand; Table 2, variant b)

To move the cylinders to the right, one shall follow **steps 1 ... 6**, identical to those of variant a).

The pump P1 supplies the port A1 of the cylinder 5 along the circuit: tank- P(block 2)- A(block 2)- IN(booster 3)-H1(booster 3)- A1. The port B1 is connected to the tank along the circuit: B1- B(block 2)- T(block 2)-RF1- tank.

The pump P2 supplies the port B2 of the cylinder 6 along the circuit: tank- check valve CV1-B2. The port A2 is connected to the tank along the circuit: A2- check valve CV4- valve PRV- tank. Steps 4,5,6 are identical to those of variant a).

Step 7: Moving of cylinders to the left is performed with no load, so with the valve PRV set to the minimum opening pressure and the electromagnet EB of the hydraulic directional control valve HD being sent an electric signal. Acquisition of the parameters measured by the transducers is no longer required.

The pump P1 supplies the port B1 of the cylinder 5 along the circuit: tank- P(block 2)- B(block 2)- IN(booster 4)-H3(booster 4)- B1. The port A1 is connected to the tank along the circuit: A1- H1(booster 3)- DV(booster 3)- IN(booster 3)- A(block 2)- T(block 2)-RF1- tank.

The pump P2 supplies the port A2 of the cylinder 6 along the circuit: tank- check valve CV2-A2. The port B2 is connected to the tank along the circuit: B2- check valve CV3- valve PRV (fully open)- tank.

6. Summary

The research aims to identify the amplitude and frequency of pulses of minibooster type oscillating pressure intensifiers, in order to integrate them on low-pressure pumping units, to supply small-sized hydraulic cylinders, able to move large loads with relatively constant travel speed over the entire stroke.

The working methods applied make use of: technical data presented in the catalogues of the minibooster manufacturer; numerical simulation and experimental identification to determine the amplitude and frequency of the pulses.

This paper presents the first part of the research, which includes: a preliminary model of numerical simulation of the dynamic operation of a minibooster; an experimental test stand for a low-pressure pumping unit, equipped with two miniboosters, able to determine the amplitude / frequency of booster pulses, and also their impact on the displacement of a hydraulic cylinder with load on the entire stroke.

The research will continue with the development of the stand, performance of experimental tests and completion of the numerical simulation model.

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References

[1] Yongchao X., Jinyan S.: The Design of a comparative amplifier for deep sea. Advances in Engineering Research 2018 (8th International Conference on Manufacturing Science and Engineering (ICMSE 2018)), vol. 164, pp. 493-496, ISBN: 978-1-5108-6418-4.

[2] Wang F., Gu L., Chen Y.: A hydraulic pressure-boost system based on high-speed On–Off valves. IEEE/ASME Trans. Mechatronics 2013, vol. 18, no. 2, pp. 733-743, DOI: 10.1109/TMECH.2011.2182654

[3] Zwier M. P., vanGerner H. J., Wits W. W.: Modelling and experimental investigation of a thermally driven self-oscillating pump. Applied Thermal Engineering 2017, vol. 126, pp. 1126-1133, DOI: 10.1016/j.applthermaleng.2017.02.063

[4] Khandekar S., Dollinger N., Groll M.: Understanding operational regimes of closed loop pulsating heat pipes: an experimental study. Applied Thermal Engineering 2003, vol. 23, no. 6, pp. 707-719, DOI: 10.1016/S1359-4311(02)00237-5

[5] Dobson R.T.: An open oscillatory heat pipe water pump. Applied Thermal Engineering 2005, vol. 25, no. 4, pp. 603-621, DOI: 10.1016/j.applthermaleng.2004.07.005

[6] Dobson R.T.: Theoretical and experimental modelling of an open oscillatory heat pipe including gravity. International Journal of Thermal Sciences 2004, vol. 43, no. 2, pp. 113-119, DOI: 10.1016/j.ijthermalsci.2003.05.003

[7] Yang F., Tadano K., Li G., Kagawa T.: Analysis of the Energy Efficiency of a Pneumatic Booster Regulator with Energy Recovery. Applied Sciences 2017, vol. 7, no. 8, paper ID 816, DOI:10.3390/app7080816

[8] Nazarov F., Rakova E., Weber J., Vardini A. R.: A Novel Approach for Pneumatic Pressure Booster. In: Proceedings of 11th International Fluid Power Conference 11. IFK, vol. 3, pp. 222-235, DOI: 10.18154/RWTH-2018-224786

[9] Sorokodum E.: Vortex-oscillating pump for pumping oil sludge. http://www.vortexosc.com/images/pdf/PumpOilSludgeEng.pdf [accessed: 16.10.2020].

[10] Levinsen A.: Scanwill fliud power—Unique hydraulic pressure intensifier solutions. http://www.luvra-hydraulik.de/fileadmin/web_data/downloads/Luvra-Hydraulik-Scanwill-0915.pdf [accessed: 16.10.2020].

[11] Gannon M.: How can hydraulic pressure intensifiers improve your system design? https://www.fluidpowerworld.com/can-hydraulic-pressure-intensifiers-improve-system-design/ [accessed: 12.10.2020].

[12] https://www.scanwill.com/files/documents/Scanwill-productsheet-en.pdf [accessed: 08.10.2020].

[13] Espersen C.: Pressure Boosters in Hydraulic Systems – A Solution Which Is Often Overlooked.

https://www.minibooster.de/fileadmin/user_upload/press_kit/english/minibooster_english.pdf [accessed: 12.10.2020].

[14] Pioneer Machine Tools, Inc.: The increase pressure actuation system of hydraulic boosters HC series. http://www.pmt-pioneer.com/en/product-detail5.html [accessed: 09.10.2020].

[15] Zardin B., Cillo G., Zavadinka P., Hanusovsky J., Borghi M.: Design and modelling of a cartridge pressure amplifier. In: Proceedings of the ASME/JSME/KSME Joint Fluids Engineering Conference 2019, vol. 1, article no. UNSP V001T01A043, DOI: 10.1115/AJKFluids2019-5474

[16] Bartnicki A., Klimek A.: The research of hydraulic pressure intensifier for use in electric drive system. IEEE Access 2019, vol. 7, pp. 20172-77, DOI 10.1109/ACCESS.2019.2897148

[17] Zardin B., Cillo G., Borghi M., Zavadinka P., Hanusovsky J.: Modelling and simulation of a cartridge pressure amplifier. In: Proceedings of the ASME-BATH Symposium on Fluid Power and Motion Control 2018, article no. V001T01A057

[18] Popescu T.-C., Chirita P.-Al., Popescu A. I.: Increasing energy efficiency and flow rate regularity in facilities, machinery and equipment provided with high operating pressure and low flow rate hydraulic systems. In: Proceedings of 18th International Multidisciplinary Scientific GeoConference SGEM 2018, vol. 18, pp. 401-408, DOI: 10.5593/sgem2018/4.1

[19] https://www.minibooster.com/hc7/ [accessed: 12.10.2020].

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Determination of rare earth elements in power plant wastes

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Keywords: rare earth elements (REE), power industry, power plant wastes, fly ashes, furnace slags

Słowa kluczowe: pierwiastki ziem rzadkich (REE), energetyka, odpady energetyczne, popioły lotne, żużle paleniskowe

Abstract:

The results of laboratory analyzes determining the share of rare earth elements (REE) in power plant wastes (fly ashes and furnace slag) are presented. The waste material was acquired from power plants located in the Upper Silesian Industrial District. Ashes and slags were analysed in the laboratory using the inductively coupled plasma mass spectrometry method (ICP-MS), aimed at determining the quantitative share of REE in power plant wastes. The results of measurement of rare earth elements content in fly ashes and furnace slags were compared with the literature data, showing some discrepancies in the intensity of valuable elements. On the basis of laboratory analyzes, the economic justification for recovering the valuable elements from the selected material was formulated.

Streszczenie:

Artykuł zawiera wyniki analiz laboratoryjnych, określających udział pierwiastków ziem rzadkich (REE) w odpadach energetycznych (popioły lotne i żużle paleniskowe). Materiał odpadowy pozyskany został z elektrowni znajdujących się na terenie Górnośląskiego Okręgu Przemysłowego. Analizy laboratoryjne popiołów oraz żużli przeprowadzono metodą spektrometrii mas z jonizacją w plazmie indukcyjnie sprzężonej (ICP-MS), mające na celu określenie ilościowego udziału REE w odpadach energetycznych. Wyniki pomiarów zawartości pierwiastków ziem rzadkich w popiołach lotnych i żużlach paleniskowych porównano z danymi literaturowymi, wykazując pewne rozbieżności w intensywności ich występowania. Na podstawie analiz laboratoryjnych sformułowano ekonomiczne uzasadnienie odzyskiwania cennych pierwiastków z wybranego materiału.

1. Introduction

Rare earth elements (REE), due to their high strategic importance in development of advanced technologies, have been classified by the European Union among the group of 20 critical mineral resources. It has been forecasted that the demand for rare earth elements will double by 2060, reporting systematic increases in the coming years [2]. In the countries of the European Community, the resources of fossil minerals containing valuable elements are gradually decreasing, therefore the institutions of the European Union launched numerous research projects to identify new prospective sources of rare earth elements and to develop innovative technologies for their recovery. Some actions are taken to maintain the continuity of raw material supplies, also through the recovery of a useful elements from waste [1].

The current projects on determination of rare earth elements content show the presence of these valuable elements in fly ashes and furnace slags. The content of REE in power plant combustion wastes exceeds the concentration of these elements in hard coal to be burned [2, 3].

Rare earth elements make a group of 17 elements which, due to their specific physicochemical properties, are used in state-of-the-art technologies. The term "rare earth elements" is imprecise because they are present in the earth's crust in a relatively large amount, but their concentration in the extracted ore is low, and therefore, their recovery often remains economically unjustified.

Examples of the economic application of each element are as follows [2, 4, 5, 6, 7, 8]:

- scandium (Sc) – aviation industry, aircraft construction and radiotherapy,
- lanthanum (La) – optical products, hybrid vehicles,
- yttrium (Y) – ceramics, metal alloys,
- cerium (Ce) –metallurgy, chine dye, analytical chemistry,
- praseodymium (Pr) – a dye for glass and stones,
- neodymium (Nd) – laser technology, magnetic materials,
- samarium (Sm) – cinematography, nuclear technology,
- europium (Eu) – nuclear engineering,
- gadolinium (Gd) – alloy additive, microwave technology,
- promethium (Pm) – Beta radiation source,
- terbium (Tb) – lasers, diodes,
- dysprosium (Dy) – petrochemical industry,
- holm (Ho) – nuclear technology, electronics,
- erbium (Er) – optical amplifiers,
- thulium (Tm) – magnetic materials,
- ytterbium (Yb) – microelectronics,
- lutetium (Lu) – ferrite production.

The largest deposits of rare earth elements showing their justified economic recovery are in China, USA, Russia, Australia and India. The global production of REE is at the level of 139 thousand Mg, and is dominated by China, which has 23% of the world's deposits. China also covers 93% of the global demand for these elements [2,9,10,11].

Poland does not have deposits of rare earth elements in its natural resources, therefore the following raw, secondary or waste materials may be the potential source of these elements in Poland [12]:

- fly ashes and furnace slags,
- hard coal,
- mine waste,
- sand and gravel deposits,
- waste electronic equipment.

Due to the expected presence of REE in power plant wastes and their economic importance, KOMAG Institute of Mining Technology launched an R&D program aimed at assessing the content of rare earth elements in fly ashes and furnace slag acquired from coal-fired power plants.

Currently, the Polish power industry is mainly based on hard coal and lignite - 58%. A systematic increase in electricity production is forecast in 2020-2040, reaching over 70,000 MW in 2040. The share of coal in the electric power generation in Poland will systematically decrease, while its share will still be significant, amounting to approximately 15,000 MW of electricity generated in 2040.

During the combustion of coal, large amounts of by-products are created, having a negative impact on the natural environment (emission of CO2, NOx, sulfur compounds and dust) when getting into the atmosphere. Fly ashes and furnace slags, which are the subject of the tests, are also by-products of the combustion process [13,14,15,16].

In 2019, the Polish power industry, by burning hard coal, generated about 20 million Mg of wastes, which was a mixture of fly ash and furnace slags [10,13,15].

Fly ashes are the fine particles obtained by electrostatic or mechanical precipitation from the off gases of a coal-fired furnace. According to the adopted classification, fly ashes are divided according to their chemical composition:

- silica-aluminum fly ashes with a predominance of SiO_2,
- silica-aluminum fly ashes with a predominance of Al_2O_3,
- sulphate-calcium fly ashes with a predominance of calcium compounds.

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However, this division does not take into account the specificity of Polish fly ashes, which have a variable chemical composition depending on the type of coal burned. In Poland, the following types of fly ash are distinguished on the basis of chemical composition:

- silica fly ashes (K) – from burning hard coal,
- silica-aluminum fly ashes (G) – from burning lignite (Turoszów Basin), where clay minerals are the main non-flammable components,
- silica-calcium fly ashes (W) - from burning lignite (Konin and Bełchatów Basin), with a significant share of calcium compounds [17].

In the publication [1], the results of fragmentary studies on the content of rare-earth elements in fly ashes from power plants located in the Upper Silesian Industrial Region are presented (Table 1).

Table 1. Content of rare-earth elements in fly ashes [1]

Material	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Sc	Y
	ppm															
GOP ashes	16-86	39-186	-	27-87	4-19	0.4-3.5	-	-	-	-	-	-	-	-	-	11-25.8
Łagisza Power Plant	39.3	79.6	9.3	35.8	7.43	1.74	6.64	0.98	5.54	1.06	2.85	0.36	2.18	0.31	15.6	26.5
Fly ashes	56.5	117.6	13.7	52.3	-	-	-	1.6	9.5	1.9	5.3	0.72	4.6	0.64	-	43.6

The data from Table 2 show that the concentration of REE in ashes vary in the range of 0.31 - 186.0 ppm. High content of cerium (39-186 ppm) and lanthanum (16-86 ppm), indicates their economic potential in fly ashes.

It should be noted, that there are inaccuracies in the results of the tests due to unknown place and date of sampling, the cognitive method determining the concentration of REE in the tested samples and the generalized name of "the GOP ashes" indicating that they may be mixtures of fly ashes from various power plants. Thus, the share of REE in the fly ashes for a given power plant of known characteristics of the furnace feed material is unknown.

Furnace slags, similarly to fly ashes, is a by-product formed after burning hard coal or lignite in the grate furnace of a power plant or a combined heat and power plant. The term raw furnace slag is defined as the residue after burning the coal on the grate, as well as on the furnace ash pan. Depending on the share of unburned coal, the following slags are distinguished:

- unburnt slag – dark gray, porous structure with pieces of unburned coal.
- burnt out slag – red, brick like colour, hard sinter and fine graining.

The furnace slags contain approx. 50% SiO_2 silica and has a significant share of Al_2O_3. Mineralogical composition showed the presence of mullite crystals, fused quartz, melilite, anorthite, burnt clay rock, magnetite and gypsum inclusions [13,16,18].

There were no extensive tests of furnace slags to determine the content of rare-earth elements in them (Table 2).

Table 2. Content of rare-earth elements in furnace slag [1]

Material	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Sc	Y
	ppm															
Furnace slag	55.1	112.2	13.2	50.3	-	-	-	1.5	9.0	1.7	5.1	0.72	4.6	0.64	-	43.6

The share of REE in furnace slags is similar to that found in fly ashes, varied from 0.64 to 112.2 ppm (cerium content). The content of lanthanum, cerium, neodymium and yttrium is high, what means their economic potential.

Unfortunately, the results for furnace slags are not quite reliable due to the lack of complete data. The places and dates of sampling and the cognitive method determining the concentration of REE are

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not known, similarly to fly ashes. The results represent a group of furnace slags with unknown chemical composition and origin.

2. Methodology and the testing material

The power plants, the waste material of which (fly ash and energy slag) was not previously tested were selected for analyses, thus extending the knowledge on the share of REE in this type of industrial waste.

Acquisition of the material samples was preceded by a formal letter requesting the delivery of samples, which was approved by three power plants. Due to the confidentiality agreement between KOMAG and power plants supplying power plant waste, each power plant has got individual mark to unable identification of the plant.

Three power plants using different feed, a mixture of certain types of coal, differing in type and origin, were selected. Characteristics of the feed material is as follows:

- Power Plant "A" – the power boiler feed consisted of hard coal from three mining plants. The power plant does not co-incinerate biomass with hard coal. The power plant waste material was delivered on March 22, 2019.
- Power Plant "B" – the power boiler feed consisted of hard coal from one mining plant. The power plant does not co-incinerate biomass with hard coal. The power plant waste material was delivered on March 22, 2019.
- Power Plant "C" - the composition of the power boiler feed was differentiated and consisted of hard coal from various mining plants. The power plant does not co-incinerate biomass with hard coal. The power plant waste material was delivered on June 05, 2019.

The composition and characteristics of fly ashes and bottom slags, due to the different type of coal burned in power plants, may change depending on the share of each feed product.

10 kg of fly ashes and bottom slags were collected from each plant. The ashes were collected from the storage silos at the truck ash loading stations. And the slags were collected from the loading stations, after being cooled in slag settlers.

The preparation of fly ash and bottom slags consisted in taking 0.5 kg of a representative sample of the material from a 10 kg sample using the Jones divider (Fig. 1, 2).

Fig. 1. Averaging the furnace slags by the sample divider

Fig. 2. Averaging the fly ash by the sample divider

Prepared samples containing fly ashes and bottom slags were determined regarding the dry matter content, and then they were mineralised in the Material Engineering and Environment Laboratory with the use of microwave mineralizers. The obtained solution, as the test material, was then analyzed by

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means of mass spectrometry with inductively coupled plasma (ICP-MS). The content of each rare-earth element exceeding 5 ppm are presented in (Table 4) [17].

3. Test results and discussion

Industrial heaps, as landfills for waste rock accompanying the mined minerals or as wastes generated during industrial transformation, still contain valuable minerals. In 2019, KOMAG commenced research and development project for estimating the possibility of recovering the rare-earth elements from power plant wastes, after previous grain size analyzes to determine the content of valuable elements. The results of laboratory analyzes are presented in Table 3.

Table 3. Content of rare-earth elements in the tested power plant wastes [19]

Material	Place of obtaining the material	Content of REE [ppm]					
		Scandium (Sc)	Yttrium (Y)	Lanthanum (La)	Cerium (Ce)	Neodymium (Nd)	Europium (Eu)
Fly ashes	Power Plant „A”	**8.8**	**17.3**	**12.0**	<5	<5	**5.1**
Fly ashes	Power Plant „B”	**9.4**	**18.7**	**15.2**	**34.0**	<5	<5
Fly ashes	Power Plant „C”	**9.0**	**17.9**	**12.5**	<5	<5	<5
Furnace slags	Power Plant „A”	<5	**16.2**	<5	**1.9**	<5	**6.7**
Furnace slags	Power Plant „B”	<5	**17.5**	<5	**1.8**	<5	**7.3**
Furnace slags	Power Plant „C”	**8.7**	**29.6**	<5	**26.5**	**7.8**	**9.6**

The following six rare-earth elements were found, with some degree of content variation:

- scandium (Sc) – from 8.7 to 9.4 ppm (the highest concentration – fly ash from the "B" Power Plant),
- yttrium (Y) – from 16.2 to 29.6 ppm (the highest concentration – furnace slags from the "C" Power Plant),
- lanthanum (La) – from 12 to 15.2 ppm (the highest concentration – fly ash from the "B" Power Plant),
- cerium (Ce) – from 13.9 to 34.0 ppm (the highest concentration – fly ash from the "B" Power Plant),
- neodymium – 7.8 ppm (furnace slags from the "C" Power Plant),
- europium – from 5.1 to 9.6 ppm (the highest concentration – furnace slags from the "C" Power Plant).

Content of valuable elements in fly ashes and bottom slags is at a similar level (fly ash – from 5.1 to 34.0 ppm, bottom slag – from 6.7 to 29.6 ppm). Total content of REE in fly ashes is 159.9 ppm, while in bottom slags it is – 160.6 ppm. Considering the level of accumulation of valuable elements due to their origin, their highest share was determined for power plant waste from the "C" Power Plant – 121.6 ppm, slightly lower for the "B" Power Plant – 118.9 ppm and for the "C" Power Plant – 80.0 ppm.

The remaining rare-earth elements (praseodymium, samarium, gadolinium, promethium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium) were not found, their content was <5 ppm.

Comparing the test results with the literature data (Table 1, 2) some disproportions are noticeable, therefore only the elements determined in tests conducted so far were compared in Table 4, 5.

Table 4. Comparison of literature data of REE content in the in power plant ashes with the obtained results

Rare-earth element [ppm]	**REE content in ashes based on the literature data [ppm] [1]**	**REE content in fly ashes based on own tests [ppm]**
Scandium (Sc)	15.6	8.8 – 9.4
Yttrium (Y)	11 – 26.5 (43.8*)	17.3 – 18.7
Lanthanum (La)	16.0 – 86 (56.5*)	12.0 – 15.2
Cerium (Ce)	39.0 – 186.0 (117.6*)	34.0
Neodymium (Nd)	27.0 – 87.0	<5
Europium (Eu)	0.4 – 3.5 (1.74*)	5.1

* fly ashes

Literature data for lanthanum, cerium and neodymium significantly exceed the values given in the presented tests. The scandium concentration is similar to that measured in previous tests, while the content of yttrium is within the given range. The europium content is an exception, as its content exceeds the amount determined so far.

Table 5. Comparison of REE concentration in furnace slags with the obtained results

Rare-earth element [ppm]	REE content in furnace slags based on literature data [ppm] [1]	REE content in furnace slags based on own tests [ppm]
Scandium (Sc)	not determined	8.7
Yttrium (Y)	43.6	16.2 – 29.6
Lanthanum (La)	55.1	<5
Cerium (Ce)	112.2	13.9 – 26.5
Neodymium (Nd)	50.3	7.8
Europium (Eu)	not determined	6.7 – 9.6

In the case of furnace slags, a significant disproportion in the content of rare-earth elements is noticeable. In the analyzes conducted so far, the concentration of yttrium, lanthanum and neodymium was several times higher. In the current analyzes, scandium and europium content was determined, although the elements was not previously found.

It should be emphasized that due to the lack of a full knowledge in the literature regarding the characteristics of the material, the results are only distinctive. Due to some ambiguities in the literature tests, the comparison with own tests is indicative.

4. Conclusions

Based on a literature review, the article shows the economic importance of rare-earth elements. The power plant wastes from three power plants, consisting of fly ashes and bottom slags, after selecting a representative sample, was analyzed using the inductively coupled plasma mass spectrometry method (ICP-MS).

The results were confronted with the results of analyzes carried out so far, but the cognitive method and specificity of the material are not fully known.

The R&D project realized in this area by KOMAG Institute of Mining Technology cover the full spectrum of knowledge regarding the parameters of analyzed material and the cognitive method of analysing the given group of elements.

The highest measured concentration of rare-earth elements in fly ashes and furnace slags oscillate around 30 ppm. Due to low content of REE and lack of possibility of industrial use of power plant wastes (in transport, mining), their economic recovery on an industrial scale is not justified. It has been estimated that the economically justified level of the REE content in power plant wastes is above 1000 ppm [20]. Economic justification depends on energy consumption in extraction/recovery and coal processing.

References

[1] Całus-Moszko J., Białecka B.: Analiza możliwości pozyskania pierwiastków ziem rzadkich z węgla kamiennego i popiołów lotnych z elektrowni. Gospodarka Surowcami Mineralnymi – Tom 29, z.1. Instytut Gospodarki Surowcami Mineralnymi i Energią PAN, Kraków, 2013.

[2] Całus-Moszko J., Białecka B.: Potencjał i zasoby metali ziem rzadkich w świecie oraz w Polsce. Prace Naukowe GIG. Górnictwo i Środowisko – Kwartalnik, Tom 4, s. 61-72. Główny Instytut Górnictwa, Katowice, 2012.

[3] Jaireth, S., Hoatson, D. M., & Miezitis, Y.: Geological setting and resources of the major rare-earth-element deposits in Australia. Ore Geology Reviews, 2014. No 62, 72–128.

[4] Balaram V.: Rare earth elements: A review of applications, occurrence, exploration, analysis, recycling, and environmental impact, Geoscience Frontiers, Volume 10, Issue 4, pp. 1285-1303, 2019.

[5] Case M., Fox R., Baek D.,Chien W.: Extraction of Rare Earth Elements from Chloride Media with Tetrabutyl Diglycolamide in 1-Octanol Modified Carbon Dioxide, Metals 2019 No 9 (4), 429.

[6] Charalampides G., Vatalis K. I., Apostoplos B., Ploutarch-Nikolas B.: Rare Earth Elements: Industrial Applications and Economic Dependency of Europe. Procedia Economics and Finance. 2015 No 24, pp. 126 – 135.

[7] Kathryn M. Goodenough K. M.,Wall F., Merriman D.: The Rare Earth Elements: Demand, Global Resources,and Challenges for Resourcing Future Generations, Natural Resources Research. 2018. volume 27, pp. 201–216,

[8] Mariano, A. N., & Mariano, A.:Rare earth mining and exploration in North America, Elements, 2012. No 8(5), 369–376.

[9] Jarosiński A.: Możliwości pozyskania metali ziem rzadkich w Polsce, Zeszyty Naukowe – Tom 92, s. 75-88. Instytut Gospodarki Surowcami Mineralnymi i Energią PAN, Kraków, 2016.

[10] Klich M., Kozłowski J.: Odnawialne źródła energii i gospodarka odpadami oraz ochrona i gospodarowanie zasobami przyrody – wybrane problemy w Polsce s. 23-31, Wydawnictwo Państwowej Wyższej Szkoły Zawodowej w Tarnowie, Tarnów, 2016.

[11] Lai Q. T., Thriveni T., Chilakala R., Hong Ha Thi Vu, Ji W. A., Jeongyun, Leaching K: Characteristics of Low Concentration Rare Earth Elements in Korean (Samcheok) CFBC Bottom Ash Samples, Sustainability 2019. No 11(9).

[12] Kanazawa Y., Kamitani M.: Rare Earth Minerals and Resources in the World. Journal of Alloys and Compounds. 2006. 408-412(19), pp. 1339-1343.

[13] Hordyńska M.: Popioły elektrowniane w procesach stabilizacji odpadów niebezpiecznych. Praca doktorska. Wydz. Inżynieria Materiałowa i Metalurgii, Politechnika Śląska, Katowice, 2003.

[14] Paulo A.: Pierwiastki ziem rzadkich pod koniec XX wieku, Przegląd Geologiczny Tom 47, s. 34-41. Państwowy Instytut Geologiczny, Warszawa, 1999.

[15] Ministerstwo Energii: „Polityka Energetyczna Polski do 2040 r", Warszawa, 2019.

[16] Smarzewski P., Barnat-Hunek D.: Mechaniczne i mikrostrukturalne właściwości betonu wysokowartościowego z dodatkiem żużla paleniskowego, Izolacje 2015 nr. 10.

[17] https://elopole.pgegiek.pl/Technika-i-technologia/Zasada-dzialania-elektrowni [accessed: 30.10.2020]

[18] Zapotoczna-Sytek G., Łaskawiec K. i inni.: Popioły nowej generacji do produkcji autoklawizowanego betonu komórkowego", Monografia, Instytut Ceramiki i Materiałów Budowlanych, Warszawa, 2013.

[19] Baron R.: Określenie zasobności oraz analiza możliwość odzysku pierwiastków ziem rzadkich z popiołów węgla kamiennego oraz odpadów elektrownianych, ITG KOMAG, Gliwice, 2019. (unpublished).

[20] Żukowski W.: Recenzja rozprawy doktorskiej pt. „Ocena możliwości otrzymywania koncentratów metali ziem rzadkich z odpadów energetycznych", Kraków, 2018.

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Development origin of hoisting equipment for a transportation of personnel and tourists in selected shafts of Wieliczka Salt Mine

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Słowa kluczowe: wyciąg, dźwig, turystyka, historyczna kopalnia soli

Abstract:

The article presents interesting examples of technical activities realized in the past years, having a significant impact on a development of hoisting systems in mines. An increasing number of visitors to the underground workings of the Wieliczka Salt Mine, including foreign tourists, caused a technical development of the vertical transport devices mainly used by visitors. It should be mentioned that an exploitation of underground seams is not conducted any more, but simultaneously a continuous increase of monumental underground objects availability occurs. There is no doubt about the fact that at the turn of the XX and XXI centuries a number of visitors, including foreign guests increased significantly and at present is reaches about 10 000 visitors per day (till March 2020). Such a situation caused a need of modernizing the transportation system and making considerable investments, ensuring a realization of vertical transport tasks, enabling a presentation of continuously developed and modernized exhibits of the underground mining exposition. However, these changes were mainly oriented onto a modernization of the vertical transport means for visitors. This requirement was met due to a development of cage winders in selected shafts, adapted for these purposes, mainly in the result of technical changes in the existing Daniłowicz Shaft and in the result of implementing an innovative solution in the completely rebuilt Regis Shaft. As regards the last one, in the place of the former winder with a winding machine, installed on the pit-bank, an innovative solution for the underground mining transport was used. It has been in operation since 2012. It is a passengers-goods hoisting device used so far only in high buildings on the ground and in technical - view towers. The article contains a compact description, giving an image of a certain technical development origin of cage winders - from horse gears to cabin passengers-goods devices.

Streszczenie:

Wzrastająca liczba zwiedzających podziemia Kopalni Soli w Wieliczce, w tym turystów zagranicznych spowodowała przy zaniku eksploatacji złóż podziemnych, a równocześnie ciągłym rozwojem udostępniania turystom zabytkowych podziemnych obiektów – były powodem istotnego rozwoju technicznego urządzeń transportu pionowego przeznaczonego głównie dla zwiedzających. Niewątpliwie na przełomie XX i XXI wieku liczba ta, w tym także gości zagranicznych znacznie wzrosła, obecnie dochodzi do około 10000 na dobę (do marca 2020 r.). Spowodowało to konieczność modernizacji i znacznych inwestycji zapewniających spełnienie zadań, także w transporcie pionowym, stale rozwijanych i unowocześnianych zasobów podziemnej ekspozycji górniczej. Podstawowym jednak celem tych zmian było unowocześnienie transportu pionowego dla zwiedzających. Spełniono to poprzez rozwój wyciągów klatkowych w wybranych i dostosowanych dla tych celów szybach górniczych, głównie poprzez zmiany techniczne w istniejącym szybie Daniłowicz oraz zastosowanie innowacyjnego rozwiązania w całkowicie przebudowanym szybie Regis. W tym ostatnim w miejsce dawnego wyciągu z maszyną wyciągową zabudowaną na zrębie szybu, zastosowano funkcjonujące od 2012 roku innowacyjne rozwiązanie w transporcie górnictwa podziemnego, to jest urządzenie zjazdowe osobowo-towarowe stosowane dotychczas jedynie w wysokościowych budynkach naziemnych oraz wieżach techniczno – widokowych. Bardzo zwięzły opis stanowiący obraz pewnej genezy technicznego rozwoju wyciągów klatkowych – od wyciągów kieratowych do urządzeń kabinowych osobowo-towarowych stanowi przedmiot niniejszego opracowania.

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1. Introduction

The main problem in underground mines technology is a technical development of vertical transport devices used not only for hoisting minerals, but also personnel, materials, machines, equipment and in some cases a big number of tourists.

It concerns, among others, the Wieliczka Salt Mine, having a multi-century tradition, known all over the world, where the daily number of visitors reaches 10 000 people.

Aiming at presentation of problems, experienced within recent years as regards a development of cage winders, the Authors concentrated mainly on the technical development during the period of nearly 70 years, realized together with the employees of AGH – University of Science and Technology in Cracow, in collaboration with selected employees of the Mine. Several times they presented and published their papers in conference proceedings [1, 2, 4].

2. Vertical transport of Wieliczka Mine visitors

In the end of the XVIII century Wieliczka, and mainly the Salt Mine became a very popular tourist attraction in the world scale due to a multi-year tradition of mining salt. According to the first visitors` books from 1774 the number of visitors reached a hundred people per week.

Until the XVIII century descending into mine took place in the Seraf Shaft which does not exist anymore.

It was sank to Level I (-64 m) in 1442 and was equipped with a stairs compartment and a winder, consisting of a horse gear and a shaft with a brake disk, on which a rope was wound.

The horse gear was moved by four pairs of horses. The vertical wheel drove the shaft on which the rope was wound. The shaft was equipped with one caliper brake started manually by the brake operator. A descent of miners and tourists was carried out in saddles made of lime phloem or hemp cord, fixed to the rope with belts.

Usually, 5 or 6 pairs of people were hung on the rope end. Such a trip was very dangerous as quite often attachments of saddles to the rope came off, which made the people fall down the shaft. In 1661 a new shaft, called Leszno, also not existing at present was sank to the Level I. It was equipped with sinuous stairs to be used by visitors.

Since the XVIII century tourists have been able to descent to the Level III using the Daniłowicz Shaft, sank in 1635, using saddles hung on the rope or stairs in the Leszno Shaft or Paderewski Shaft, using stairs to the Level I. The monumental underground part of the Wieliczka Mine served for tourist purposes.

Some parts near the shaft were separated, initially on the Level I and since the middle of the XIX century also on the Levels II and III. In the end of the XIX century a double cage winder in the Daniłowicz Shaft was used for visitors` descending and ascending, but till 1939 they descended only to the Level I and after having visited this part, they walked along galleries and chambers to the Level III, from which they were transported to the surface.

At present visitors, in general, walk down the stairs in the Daniłowicz Shaft to the Level I at the depth of 64 m and after having visited the monumental part (workings, chambers, chapels, lakes etc.) they continue walking until they reach the Level III (at the depth of 135 m). Then they take the cage winder to the surface. A small double cage winder, driven by a double drum winding machine with a steam engine, used to be operated in the Daniłowicz Shaft.

In the end of the fifties a development of tourism in the Wieliczka Mine was limited by a possibility of ascending visitors from the Level III, using the Daniłowicz Shaft. The winder, operated there, was considered to be out-of-date. Its transport capacity using two-floor cages moving at a small speed of 2 m/s and carrying a small number of people in the cage (10 persons), was limited due to the fact that the winder was small.

There were also other disadvantages of the equipment design, among others of the head-frame, so the Mine management decided to modernize the winder and to up-date and partly rebuild elements of the Daniłowicz Shaft, which enabled a significant increase of the winder capacity to even 4000 persons per day at a simultaneous exchange of the winging machine drive, replacing the steam engine by an electric motor. This change was introduced in the sixties of the XX century.

3. Planed reconstruction of the winder in the Daniłowicz Shaft

In 1958 a modernization and improvement of the vertical transport means for tourists, visiting the Wieliczka Salt Mine, were conducted under the supervision of Prof. Zygmunt Kawecki from the Department of Shaft Equipment at the Division of Mining Machines and Equipment at the AGH University of Science and Technology in Cracow [1].

The project embraced a series of alternative solutions, but in all of them a change, among others, of the shaft cross-section together with a significant increase of the winder traffic capacity, due to an application of advanced solutions of the shaft equipment, was planned.

As a transport of people in the Daniłowicz Shaft is of a specific character, a solution to the problems could not be in a stereotyped fashion similarly to the case of the workers` everyday descend (as well as in the case of additional materials and also the run-of-mine ascend) in underground mines. Tourist descending or ascending this Mine, usually use such means of transport for the first time in their lives and that is why they must be instructed at their each step, how they should behave and the winder should be constructed in such a way that visitors feel safe.

In the Daniłowicz Shaft it is characteristic that the majority of tourists walk down the stairs to the Level I and all of them ascend from the Level III, taking the shaft winder. As far as technical and economical conditions were concerned it was right to install a cage winder with a counterweight. A single cage system also simplified the shaft signaling system considerably. It should be mentioned that in the case of the Daniłowicz Shaft there is a big irregularity of the winder operations in the case of sight-seeing tours.

Suggested design solutions

In the framework of the AGH project, mentioned above, two different solutions were suggested [3]:
Solution I consisting in taking advantage of the Daniłowicz Shaft reconstruction which was indispensable all the same and an installation of a single cage winder with a counterweight reaching the Level IV, driven by different winding machines. It was decided to present the following alternative solutions:

- **Alternative I** – double drum winding machine with drums of 3 m. dia., driven by a DC motor of 62 kW power at the speed of 4 m/s. The motor operated in the former Okrzeja (Regis) Shaft before, also in the Wieliczka Salt Mine. A two-floor cage was suggested as a conveyance, assuming that a traffic capacity of this type device will be about 3500 persons within 10 hours.
- **Alternative II –** with the winding machine as in Alternative I, but with a new asynchronous motor of the power about 110 kW, typical for this winding machine. Four –floor cage with a counterweight - a traffic capacity of about 4300 persons within 10 hours.
- **Alternative III –** with a four-rope winding machine with a friction pulley of 2 m. dia. Installed in the head-frame, driven by an asynchronous motor of the power about 100 kW at the travel speed of 4 m/s. Single cage winder as in Alternative II.

Solution II - an application of two identical hoisting devices with two-floor cages with a counterweight, one servicing the Levels I and III; the other one – the Level III, assuming that the first one would reach the Level IV, whereas the other one – the Level VI.

These systems were to be driven by two identical four-rope winding-machines with pulleys of 1.25 m. dia. installed in the head-frame, with driving motors of the power about 50 kW. The traffic capacity at the steady-state speed of 4 m/s was 4000 persons /10 hours. It was recommended to implement an automatic control of these machines, eliminating a winding- machine operator. The drive start-up could be realized by a shaft banksman.

4. Present condition of hoisting equipment in the Shafts: Daniłowicz and Regis at the Wieliczka Salt Mine

Basing on multi-alternative solutions of design changes in selected shafts of the Wieliczka Salt Mine in the case of continually increasing number of visitors, also caused by a development and availability of new underground resources of monumental workings and exhibits, it was decided to undertake a multi-year modernization and development of the winder in the Daniłowicz Shaft in the sixties of the XX century.

Besides, due to increasing interest in the Wieliczka Mine in the world scale, at the turn of the XX and XXI centuries, a totally innovative reconstruction of the Regis Shaft was realized.

Significant changes in the Daniłowicz Shaft were undertaken in 1959. They improved sight-seeing conditions underground. These changes concerned not only the shaft itself, but also an exchange of the winder, i.e. an installation of a single cage winder with a counterweight (four-floor cage), a replacement of a steam engine by an electric drive and an overhaul of the existing landing together with a construction of a new engine room and an exchange of a pine wood shaft lining for an oak one down to the Level II.

After the overhaul the visitors` means of transport consisted of walking down the stairs compartment to the Level I as ascending from the Level III by a cage winder (Fig.1).

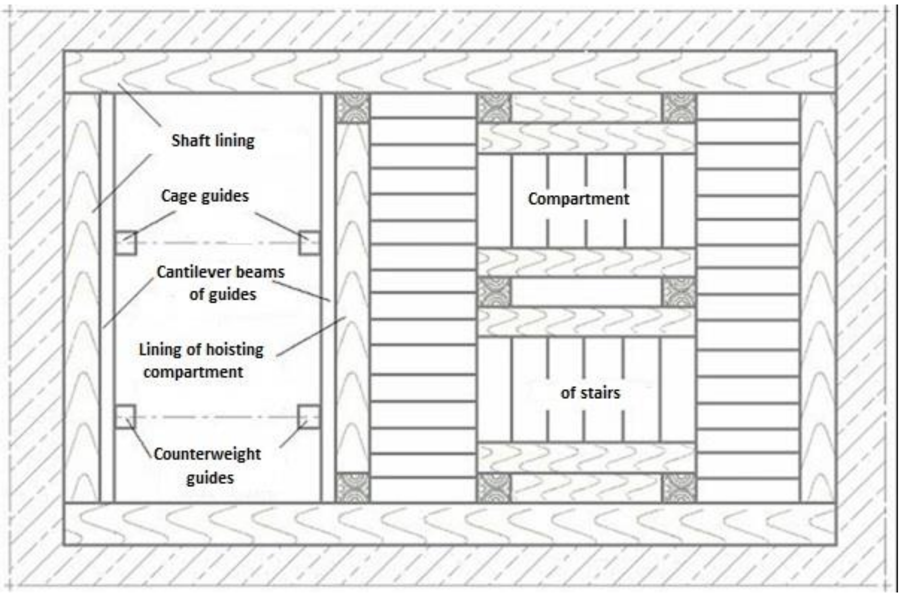

Fig. 1. Present cross – section of the Daniłowicz Shaft [4]

The following overhaul of the Daniłowicz Shaft was conducted in the years 1987-1989. Its scope included a control of geological hazards and a possibility of two-level getting on and off the cage on the Levels: I and II. The repair and investment work, together with a modernization of landing and an installation of air – conditioning aggregates drying the air directed to the tourist route, was realized in the end of nineties. Then another change was introduced, the BB-3000 machine was replaced by the BB-2500 machine with supply and control systems.

In the end of the XX century an exploitation of salt in the Wieliczka Mine was stopped completely. A chance for a development of the Mine and of the town consisted in a development of tourism, so the enterprise management of that time took a decision about a reconstruction and modernization of the Regis Shaft. An increasing number of visitors in the second half of the XX century from 3500 to about 5000 guests, whereas at present it reaches 10 000 tourists per day, confirmed the rightness of earlier decisions concerning a broad development of the vertical transport system in the Regis Shaft.

A detailed description of the shaft modernization as well as of the investments made in the shaft surroundings, similarly to the Daniłowicz Shaft, is presented in monographs elaborated by the employees of the Wieliczka Salt Mine and the AGH University of Science and Technology in Cracow [1, 6].

Looking for safe and economically feasible as well innovative solutions of vertical transport, the Wieliczka Salt Mine management decided to implement passengers-goods elevators, commonly used in transport systems, mainly in high buildings, observation and view towers. To a certain extent this solution is similar to the Solution II, which has already been mentioned, suggested for the Daniłowicz

Shaft and for multi-rope winders installed in the head frame. However, such solutions are not commonly used in underground mines. A difference consists in a replacement of typical multi-rope winding machines, installed in the head-frame, by elevators. After having conducted technical analyses it was possible to select a solution which guarantees a high level of safety. It was decided to choose an elevator for a transport od 20-person groups of visitors interested in visiting a newly available area of the Mine through the Regis Shaft. An assembly of two passengers-goods elevators was conducted by the Kone Company from Warsaw.

In the Regis Shaft each elevator has the hoisting capacity of 1600 kg (21 persons) - Fig 2. In July 2012 the device was commissioned and obtained a permit for operation in an underground mine, i.e. the Wieliczka Salt Mine [5].

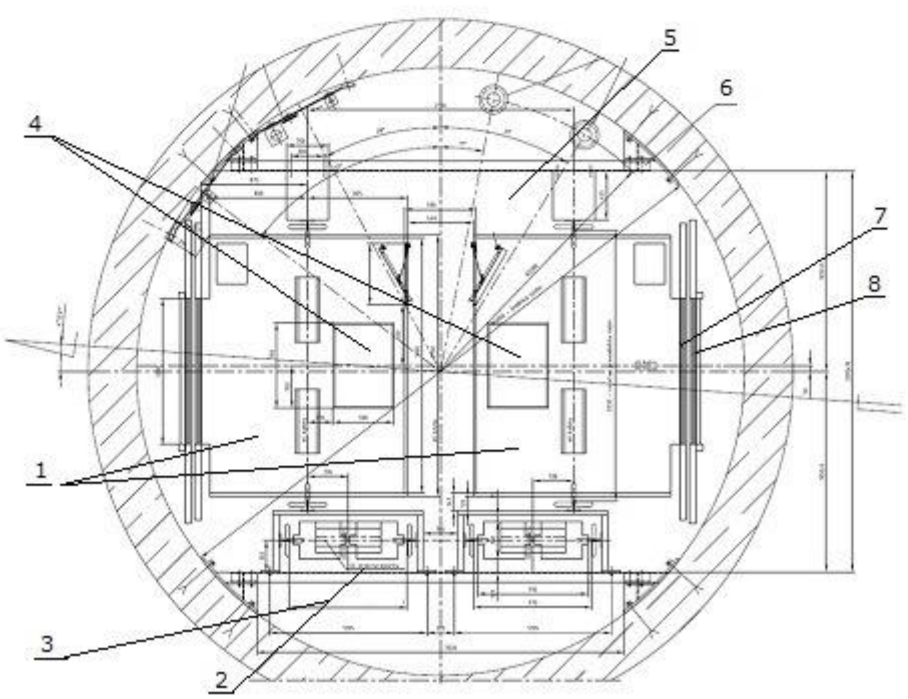

Fig. 2. The Regis Shaft cross-section [1]

<u>Explanations to Fig.2:</u>

1- Cabin
2- Axis of counterweight
3- Spacing of counterweight guides
4- Roof manhole
5- Door for passage from cage to cage in case of failure of one of the compartments
6- Reinforcement of Regis Shaft
7- Cabin door
8- Arrest door

To compare the implemented solution in the Regis Shaft with the suggested Solution II, according to the concept for the Daniłowicz Shaft, from 1858, schematic diagrams of the shaft equipment are presented additionally in Fig. 3 and Fig. 4.

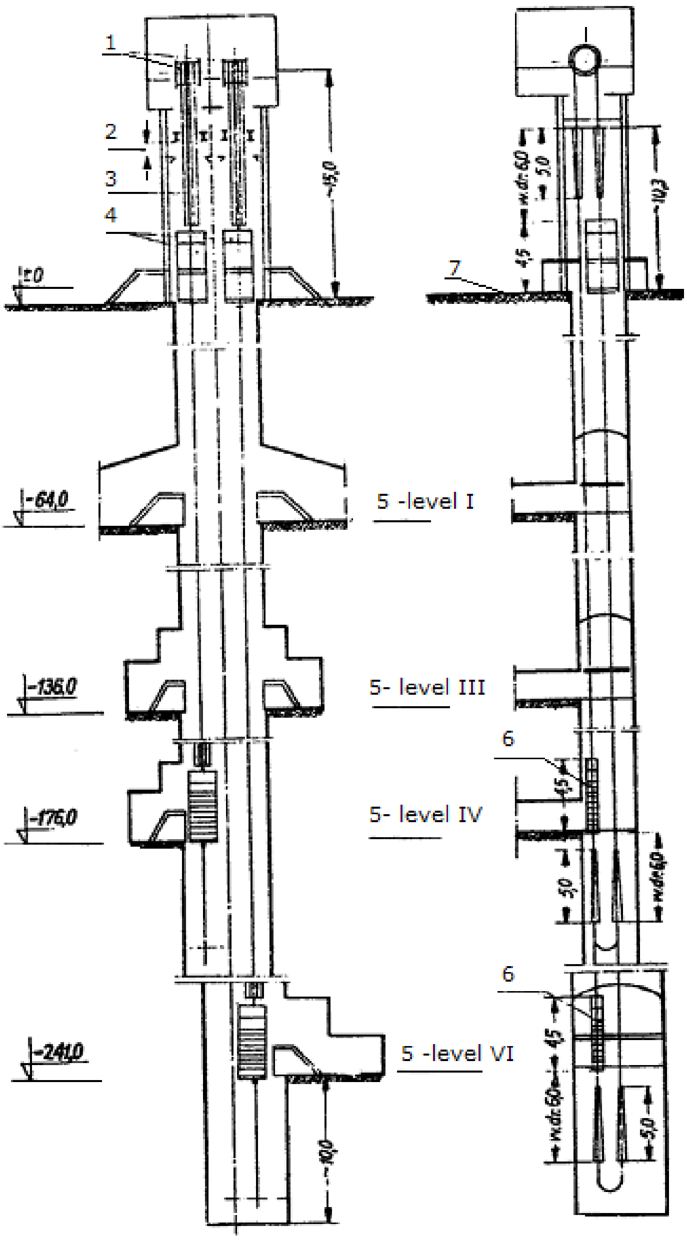

Fig. 3. Cross-section of the Daniłowicz Shaft according to the Solution II [3]

Explanations to Fig. 3:

1- Two four-rope winding machines Φ 1.25m
2- Bumping beams. Cage keep
3- Four load-carrying ropes
4- Two two-level cages
5- Levels: I, III, IV, VI
6- Counterweight
7- Pit bank

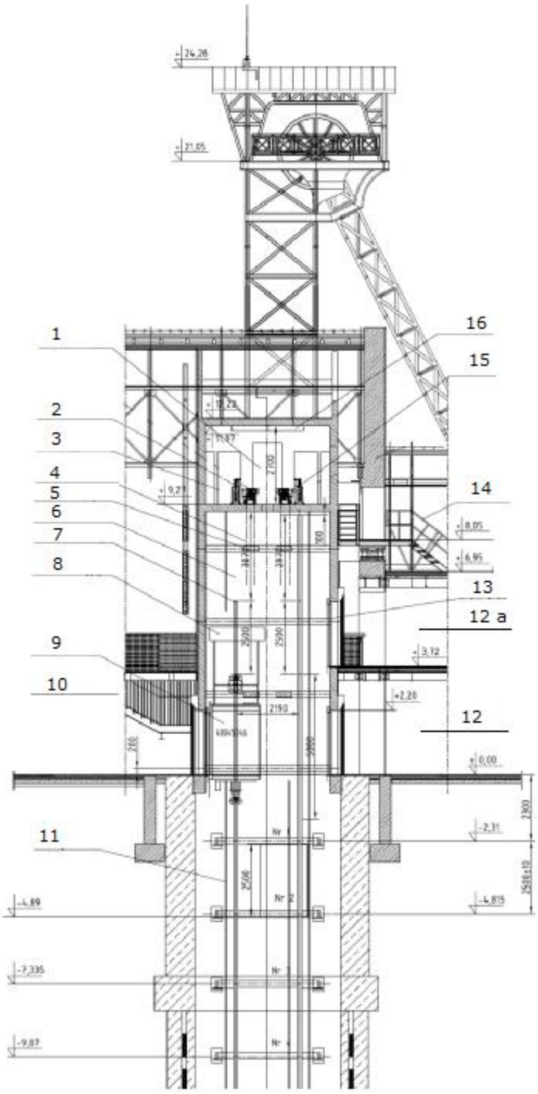

Fig. 4. Cross-section of the pit bank and of the engine room at the Regis Shaft [1]

<u>Explanations to Fig. 4:</u>

1- Assembly arch
2- Rope suspension gear
3- Engine room of elevators
4- Rope of limiter
5- Shaft lighting
6- Hoisting ropes
7- Elevator guides acc. to KONE design
8- Inspection roof acc. to KONE design
9- Elevator cabin acc. to KONE design
10- Reinforcement of the shaft surface part acc. to EKSPO design
11- Shaft guide beam acc. to KONE design
12- Level 0
12a- Level 1
13- Arrest door acc. to KONE design
14- Technical entrance to engine room
15- Speed limiter
16- Assembly beam – hoisting capacity 20 kN.

The passengers-goods elevators, which started their operation in 2012, are characterized by the following technical parameters:

- calculated traffic capacity of passengers from the Level III (-127,7 m), assuming a 10-hour operation, to the surface is 1134 persons/hour, and in the case of 10-hour operation-11340 visitors. The elevators move at the speed of 4 m/s,
- power of 8-rope elevators is 28.5 kW each.

It should be highlighted that both cage winders are characterized by very good technical and economical parameters, they do not require separate, traditional winding machines, special rooms and they can be controlled directly from the conveyance, i.e. from the elevator cabin.

5. Conclusions

The history of the Daniłowicz Shaft as well as of the Regis Shaft at the Wieliczka Salt Mine indicates that engineering of mine shafts, but in particular mechanical engineering, which is its integral part, require interdisciplinary technical knowledge and abilities including an out-of-the-box thinking and approach.

An increasing number of visitors to the underground workings of the Wieliczka Salt Mine caused an urgent necessity of improving the hoisting system capacity. At present, after several years of using elevators in the Regis Shaft, it can be clearly seen that the decision about a complete modernization of the hoisting installation was right. At present visitors` transport capacity exceeds 10 000 persons per day. It should be highlighted that the modernized hoisting systems are characterized by a high reliability and very good operational as well as economical parameters.

All the modernization stages of hoisting systems at the Daniłowicz and Regis Shafts contributed to a safety improvement, meeting the requirements not only of regulations but also of thousands of visitors.

References

[1] Czyżowski J., Zuski Z.: Transport pionowy dźwigami osobowo-towarowymi w kopalni soli Wieliczka – Zabudowa i uruchomienie dźwigów osobowo-towarowych w górniczym szybie Regis – Monografia CBiDGP – Lędziny 2013.

[2] Czyżowski J., Zuski Z.: Modernizacja górniczych wyciągów szybowych Kopalni Soli Wieliczka S.A. In: Transport szybowy, Monografia ITG KOMAG 2013. ISBN 978-83-60708-73-6.

[3] Klich A.: Analiza transportu turystów na kopalni Wieliczka. Wiadomości Górnicze 1959 nr 12.

[4] Klich A., Czyżowski J., Zuski Z., Płachno M.: Szyb Daniłowicz Kopalni Soli Wieliczka – historyczne dziedzictwo i nowoczesność. Monografia CBiDGP Lędziny 2018.

[5] Wojciechowski D., Zuski Z.: Transport pionowy dźwigiem osobowo towarowym w górniczym szybie Regis Kopalni Soli Wieliczka doświadczenia eksploatacyjne.

[6] Zuski Z., Czyżowski J., Wójcik M.: Transport pionowy przy pomocy dźwigów towarowo osobowych w Kopalni Soli Wieliczka. Możliwości realizacji transportu pionowego w górniczym szybie Regis, Cz. 1 Monografia CBiDGP – Lędziny 2019.

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Contributions to the modernization of fluid power field by integration of intelligent equipment

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Keywords: digitization, digitalization, hub, intelligent hydraulics, intelligent hydraulic stands, Industry 4.0

Słowa kluczowe: cyfryzacja, digitalizacja, hub, inteligentna hydraulika, inteligentne stojaki hydrauliczne, Przemysł 4.0

Abstract:

The article refers to some directions of modernization in the field of hydraulics focusing on digitalization and the transition to intelligent hydraulic equipment and systems. Before exposing the achievements, the authors try to remove some confusion related to digitization and digitalization. The article presents two intelligent equipment designed by IHP, a proportional directional valve and a digital actuator and two intelligent stands, one of servo-valves and one of digital hydraulic cylinders, existing in operation in laboratory and which by the endowment and working procedures represent solutions in the field of intelligent hydraulics.

Streszczenie:

W artykule odniesiono się do wybranych kierunków modernizacji hydrauliki, koncentrując się na cyfryzacji i przejściu na inteligentne urządzenia oraz systemy hydrauliczne. Przed przedstawieniem osiągnięć autorzy artykułu starają się usunąć zamieszanie związane z pojęciami cyfryzacji i digitalizacji. W artykule przedstawiono dwa inteligentne urządzenia zaprojektowane przez IHP, rozdzielacz proporcjonalny i siłownik cyfrowy oraz dwa inteligentne stanowiska, jeden z serwozaworów oraz jeden z cyfrowych siłowników hydraulicznych, stosowane w laboratorium, które ze względu na wyposażenie i procedury robocze są rozwiązaniami inteligentnej hydrauliki.

1. Introduction

Hydraulic drive has become extremely useful and is used very intensively due to the fact that in addition to the power transmission load, it also lubricates the system and dissipates generated heat.

In recent years there has been a technological development that, within Industry 4.0, leads to a radical change in industrial production, with the main support of digitalization and smart equipment.

Intelligent hydraulic equipment and systems are a combination of hydraulics, which brings traditional power, with the intelligence of electronics, to which sensors and informatics are added [1, 2, 3, 4]. This combination serves both the process of monitoring the parameters and the predictive maintenance activity, or modernized variants of it. It is also important that all the information retrieved is processed, transferred, used to establish commands, permanently using Internet technology (Ethernet).

2. Digitalization of hydraulics

In recent years, technique and technology have undergone essential changes [5, 6], and all this falls into several priority directions, such as: Industry 4.0, digitalization, renewable energy resources or the circular economy [7, 8]. With the development of a powerful Internet infrastructure, things in the technological fields have become a field of progress, difficult to anticipate 50 years ago. The problem is that there has also been a confusion of terms, due to the superficiality of some, who without understanding the correct meaning of these novelties, permanently misuse the term with purpose, but especially without purpose.

One of the big confusions is the incorrect use of the terms digitization and digitalization.

Digitization, as a general idea, is the process of switching from analog data, or collecting all available and accessible information, in digital formats. Digitization takes place in two stages: discretization and quantization. The discretization realizes the division in time (frequency) of the signal, and the quantization represents the phase of discretization in amplitude of the signals, which in practice is usually realized simultaneously [9]. Objects, images, sounds, texts and other forms of information are finally converted from analog signal to binary signal.

Digitalization is a process making intense use of digital technologies to generate, process and exchange information, or according to some specialists is the use of technologies supported by the Internet in actions of storage, processing, search and use of information. A rather dangerous idea is that digitization is easily solved by acquiring computer technology. Digitalization is a later phase of digitization, through which binary information is used in centralization, automatization and command, but this requires the industry software, which will develop continuously in the coming years. Along with the Internet, the role of tablets and phones will increase, which will increase their importance in taking over the processing and storing data, reducing from the basic function of the phone to ensure only phone calls. One of the interesting consequences, pronounced during this period, is the development of the working from home variant, or how a lot of people express outsourcing to their own home. In the field of hydraulics there have been digital activities for a long time, such as those in transferring data from one company to another, in the field of testing, when data are taken from sensors, stored, processed and prepare the system for new orders, or in the field of maintenance. The institute investigates new applications that take digitized data and use digitalization methods to modernize the field. Unfortunately, hydraulics is only at the beginning of digitization, digitalization and digital transformation, the essential element being in our opinion the precariousness of specific knowledge of design and manufacturing workers.

Without a management with digital experience, without understanding that production also includes design, sales, communication and maintenance, it is almost impossible to make the domain progress. A first major action at European level is the emergence of digital innovation centers that represent groups of companies, including research, whose main role is to provide expertise and digital transformation services, as well as services related to artificial intelligence, high performance computing and cyber security. Among other activities, these centers provide the group with training courses in the issues of hydraulic domain digitalization and in many situations the testing facilities. It is important that the field of expertise of the hubs differs. These hubs are specialized in these fields, but at national or even European level that implies a complementarity of their activity, which would allow them to expand the area of expertise on the essential issues of economic and industrial development. In the field of hydraulics, IHP has started taking steps for the development of a digital innovation center that, starting from the principles of Industry 4.0 and circular production methods, will be able to help productive enterprises solve some problems of digitalization and use of artificial intelligence.

3. Equipment and intelligent hydraulic systems

The specialists of Frost & Sullivan show in the material: Smart Hydraulics: Giving the Hydraulics Industry of Second Wind [10], their opinion on the comparison between technical-economic characteristics of electrical systems and hydraulic and intelligent hydraulic ones.

From Fig. 1 they conclude that intelligent hydraulics, although more expensive than ordinary hydraulics, are cheaper than electric drive and even if it is slightly below its efficiency, the differences are insignificant in most specific applications of hydraulics. It is also found that hydraulics, even in its intelligent form, is still in terms of power density above the level of electric drive, and slightly lower controllability is more theoretical, as in practice things are refined by the fact that they also use electronics and computing used by all systems.

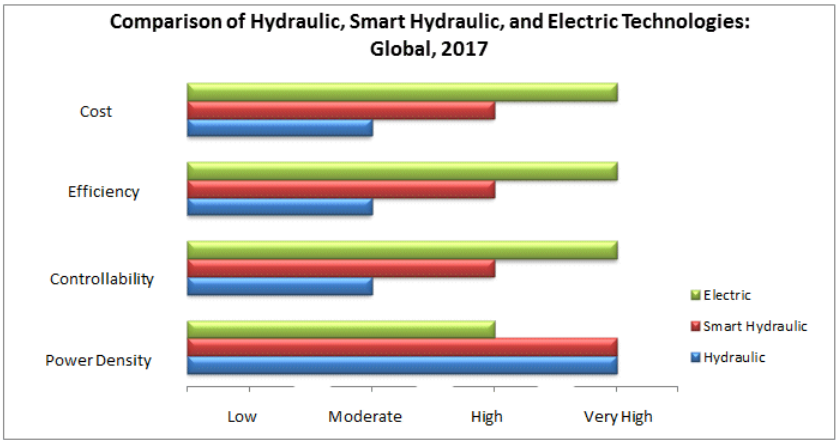


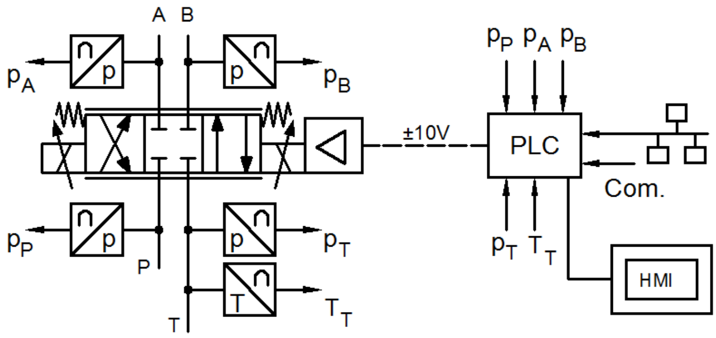
Fig. 1. Comparison of Electric, Smart hydraulic and Hydraulic (Frost&Sullivan)

Within the institute there are activities for the development of intelligent hydraulic equipment, from which a directional valve and an actuator is presented below.

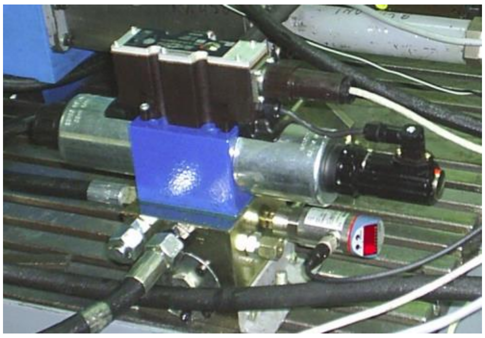
3.1. Smart proportional directional valve with pressure and temperature sensors

In our specialized laboratory a proportional hydraulic directional valve has been developed at a level that can be appreciated as intelligent (Fig. 2). In this sense, we attached to a proportional directional valve a plate (block) in which we integrated compact pressure sensors, and we control it with a PLC (Programable Logic Controller).

The integrated pressure sensors can be used to monitor the operating status of the appliance or to control the pressure [11, 12]. The control and monitoring of the operation of the smart hydraulic equipment is done through a PLC and a PC (personal computer) application [13, 14, 15]. The communication is made through the LAN. Via the PLC, the proportional directional valve can be controlled in three ways: via serial port, via analog signal 0… 10 V or via Ethernet LAN. Also, for local control, an HMI (Human Machine Interface) can be attached to the PLC.



a) Schematic

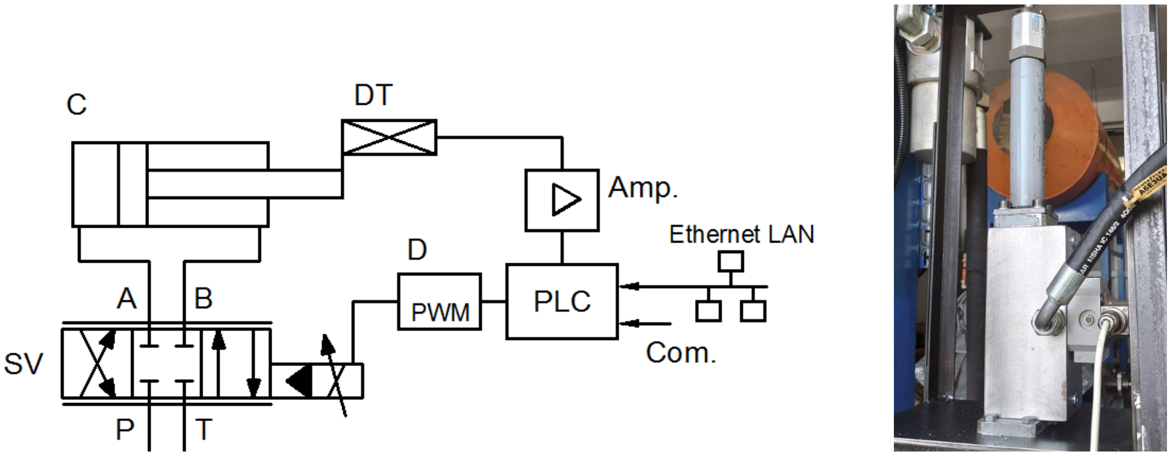


b) Directional prop. valve with sensors block

Fig. 2. Smart hydraulic proportional directional valve

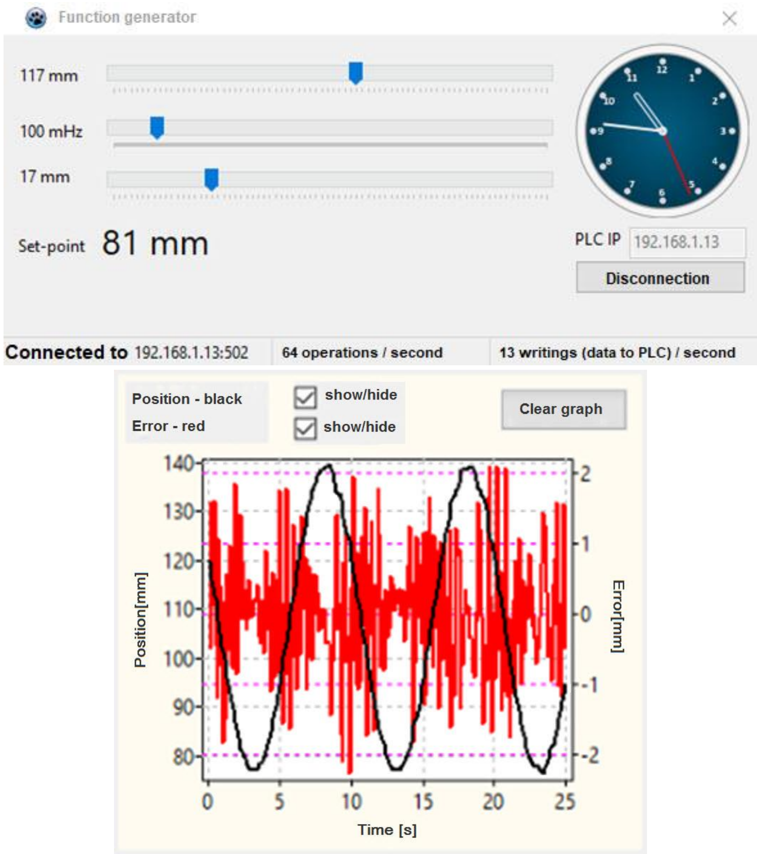
3.2 Smart hydraulic actuator

Another hydraulic equipment is the smart actuator which consists of a hydraulic cylinder (C), an servo-valve (SV), a displacement transducer (DT) with electronic amplifier included, a PWM driver (D) and a Programable logic controller (PLC). The actuator can be controlled via the serial interface, with an analog signal 0… 10 V or via a specific application via Ethernet LAN. Fig. 3 shows the diagram of a smart hydraulic actuator and a view of such an actuator provided with displacement transducer. To test the actuator, a function generator application is used (Fig. 4) obtaining the position response and the error.



a) Schematic b) Actuator view

Fig. 3. Smart hydraulic actuator



a) Function generator interface

b) Actuator response and positioning error

Fig. 4. Application for testing the smart actuator

4. Intelligent test stands

4.1 The international development of hydraulic testing equipment

In recent years, there have been quite a few stands that have included elements of intelligence in their structure, but an extremely interesting option will still be presented.

The stand proposed by NOVOTEST (Fig. 5) is equipped with a fairly simple interface programmed in Windows, in a simple solution, but functionally efficient.

Data retained:
- Analog data
- Digital data (SSI etc.)
- CAN data (with analog data synchronization)

Stored data:
- Data export as a text file (.csv), DIADEM file
- Database connection ODBC, MS Access, SQL Server

The stand allows creating and editing test programs.

Fig. 5. The intelligent stand proposed by the Novotest

4.2 Test stands made by authors at IHP Bucharest

4.2.1 Servo technique test stand

In the context of the large-scale digitalization of industrial processes, IHP researchers have started a computerization program of existing laboratories [16, 17]. Thus, the servo technique stand, having as main components two linear hydraulic axes, was equipped with a hardware/software automation system that allows the integration of the stand in the computer network of the institute, which can be accessed on any computer from the network and also through the Internet. Also, *the operating data collected* from the transducers on the stand or *command data* of the various execution components are managed by an existing MySQL database in the computer system of the institute.

The automation system of the stand is built around a general-purpose programmable controller *Modicon M221 Logic Controller from Scheneider Electric*, TM221CE16U (Fig. 6).

The programmable controller monitors the positions of the rods of the two hydraulic axes from the stand component through two analog/digital inputs and commands the electrohydraulic servo-valves, which consists the components of the linear hydraulic axes, with two digital PWM (Pulse Width Modulation) outputs.

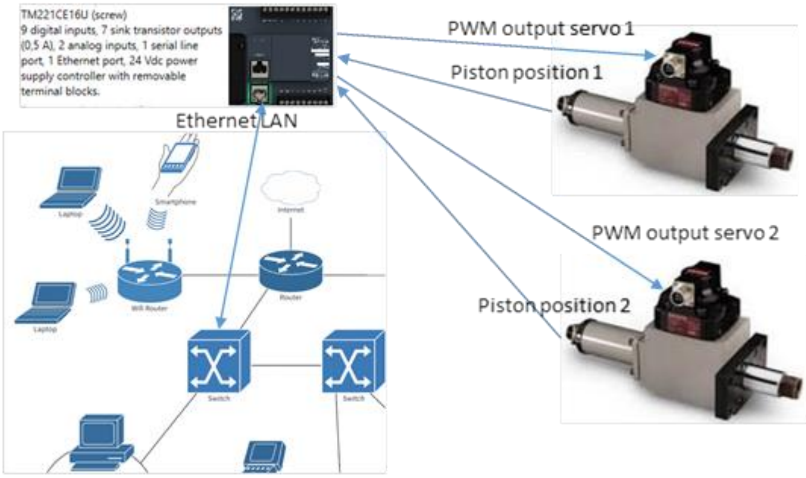
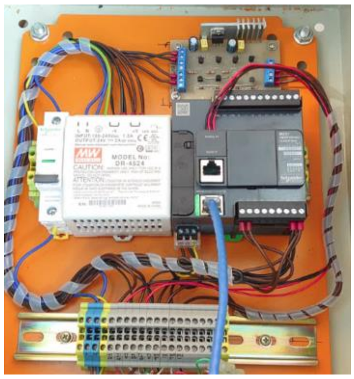


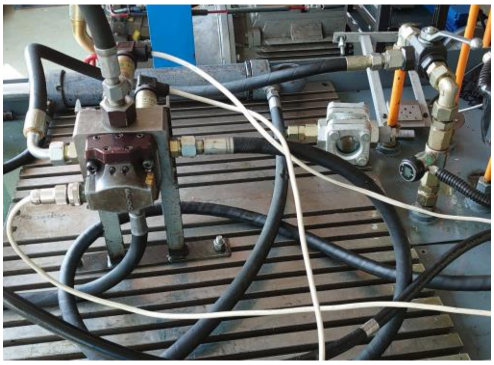
Fig. 6. Automation system of the Servo-technic test stand

It should be mentioned that a read out cycle, command calculation with PID controller and PWM output update, lasts 1ms; the desired values for the positions of the two linear axes are taken over by the PLC from a computer connected to the same Ethernet data network as this one.

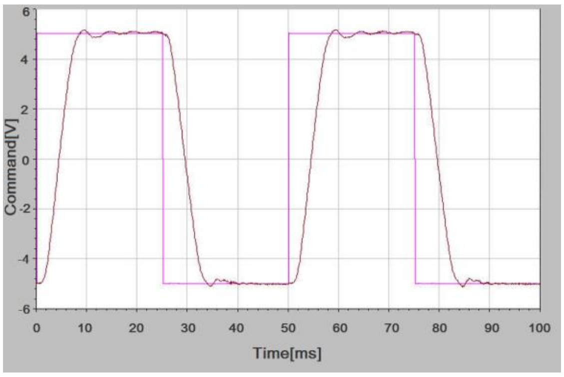
a) Command Panel and HMI



b) PLC and PWM driver



c) The servo-valve during testing



d) Dynamic response of the servo-valve tested

Fig. 7. Servo valve test stand

From the point of view of the software architecture, the client/server configuration was used; thus, the PLC is configured as a server using the *MODBUS TCP / IP* protocol [18]. The developed client applications; test signal generator, the parameterization and control application of the linear hydraulic axes and the monitoring and data management application, respectively are connected with the institute database. It should be noted that software applications are developed to work on Windows or Linux operating systems, one set for each operating system; the average communication speed with the programmable controller of the software applications is approximately *50 transactions per second* under the Windows operating system and *100 transactions per second* under the Linux operating system, given that all three applications (generator, servo-controller and parameter visualization) run on the same computer located in the same LAN network with the programmable controller of the servo technique stand.

In Fig. 7 one can see the panel of the servo-technique stand provided with control buttons and HMI interface. Fig. 7 also shows the electrical panel of the stand with PLC, PWM driver and power supply, as well as a step signal response diagram for a servo-valve.

4.2.2 Digital hydraulic cylinder test stand

For the testing of the digital hydraulic cylinders (Fig. 8) designed and manufactured in the institute, a test stand was made.

Digital hydraulic drive is a new approach to linear drive [19, 20]. The basic principle is the division of the active surface of the cylinder. By dividing the working area of a piston into binary multiplier ring areas, or according to other criteria, the selective pressurization of the ring chambers results in a cumulative output force that can be actively controlled in relation to the system requirements.

The stand (Fig. 9) contains a mounting device with hydraulic load cylinder, transducers, data acquisition system and a pumping unit.

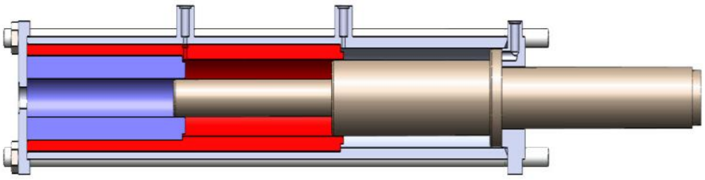
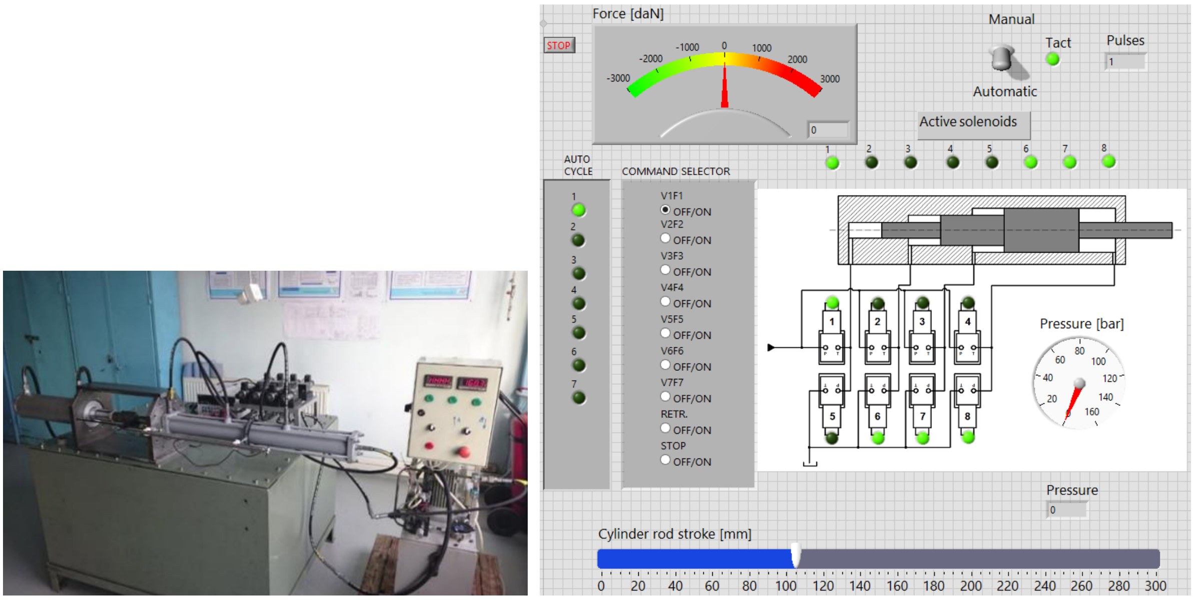


Fig. 8. The structure of a digital hydraulic cylinder

A Virtual Instrument made in the LabView environment software was used for testing, but for industrial or mobile operation it is very convenient to use a programmable logic controller (PLC), which controls the solenoids of the hydraulic directional valves according to a diagram of forces and speeds necessary in hydraulic actuation and allows Modbus TCP / IP communication.



a) View of digital hydraulic cylinder test stand b) Labview virtual instrument for test stand

Fig. 9. Digital hydraulic cylinder test stand and software application

In the Fig. 10 one can see the diagrams obtained with the LabView virtual instrument tool and the data acquisition system. The diagrams represent the evolution of the following parameters: rod displacement, rod speed, system pressure and pump flow.

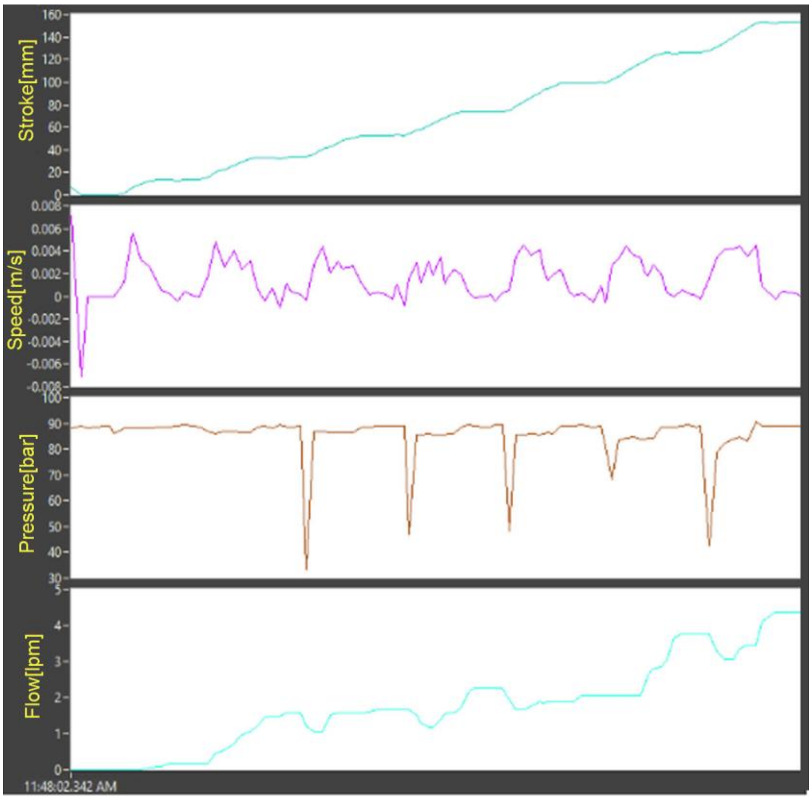


Fig. 10. Diagrams obtained during testing of the digital hydraulic cylinder

5. Summary

Hydraulics remains one of the basic drive systems and through the intelligent hydraulics variant it strengthens this role.

Testing is an important branch of intelligent hydraulics.

In order to modernize hydraulics to be included in Industry 4.0 it is necessary to understand exactly the new directions and their correct definitions.

As electronics will make hydraulic equipment smarter, hydraulic specialists will soon acquire many skills in electronics.

The 4th industrial revolution, Industry 4.0 will develop the manufacture of hydraulics, but will also use as a basic element the hydraulics in many revolutionary technologies.

Maintenance in hydraulics, in its modern forms, will become increasingly important in increasing the life of systems and their economic efficiency.

Acknowledgements

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References

[1] Marin V., Moscovici R., Teneslav D.: Sisteme hidraulice de actionare si reglare automata (Hydraulic drive and automatic adjustment systems), Technical Publishing House Bucharest, 1987.

[2] Comes M., Duțu I., Vasile Al.: Sistem mecatronic de pompare a fluidelor sterile (Sterile fluid mechatronic pumping system), Proceedings of HERVEX, 2007.

[3] Wang B., Ji H., Chang R.: Position Control with ADRC for a Hydrostatic Double-Cylinder Actuator, Actuators Journal, 2020.

[4] Linjama M., Vihtanen H.-P., Sipola A., Vilenius M.: Secondary controlled multi-chamber hydraulic cylinder In: Conference paper at the 11th Scandinavian International Conference on Fluid Power, Linköping, Sweden, 2009.

[5] Scheidl R., Linjama M., Schmidt S., Is the future of fluid power digital? Proceedings of the Institution of Mechanical Engineers. Part I, Journal of Systems and Control Engineering, 2012.

[6] Brandstetter R., Deubel T., Scheidl R., Winkler B.: Digital hydraulics and "Industrie 4.0", paper in Proceedings of the Institution of Mechanical Engineers. Part I Journal of Systems and Control Engineering, 2016.

[7] Theissen H.: Fluid Power For Sustainbility. In: Conference paper at International Conference of Hydraulics and Pneumatics-HERVEX, 7 - 9, Calimanesti-Caciulata, Romania, November 2012.

[8] Vukovic M., Murrenhoff H.: The next generation of fluid power systems. Procedia Engineering, No.106, 2015.

[9] Ivanovici M., Coliban R.: Cuantizarea semnalelor (Quantization of signals), Ch.8, Laboratory guide, Transilvania University of Brasov Publishing House, 2018.

[10] Frost & Sullivan: Smart Hydraulics: Giving the Hydraulics Industry a Second Wind, 2018.

[11] Ma Z., Wang S, Shi J., LI T., Wang X.: Fault diagnosis of an intelligent hydraulic pump based on a nonlinear unknown input observer. Chinese Journal of Aeronautics, 31(2), 2018.

[12] Athanasos P., Costopoulos T.: Condition monitoring techniques for industrial fluid power systems. In: Conference paper at 1st International Conference on Experiments / Process / System Modelling /Simulation / Optimization, Athens Greece, 2005.

[13] Duţu I., Dumitrescu C., Matache G.: Smart diagnosis of proportional electrohydraulic equipment using specific virtual instruments. Romanian Review Precision Mechanics, Optics and Mechatronics, No. 43, 2013.

[14] Munziger C., Weis M., Herder S.: Smart adaptronic hydrostatic guiding system for machine tool slides. In: Proceedings of SPIE - The International Society for Optical Engineering, The 16th International Symposium on: Smart Structures and Materials & Nondestructive Evaluation and Health Monitoring, 2009.

[15] Banyai D., Vaida L.: Electro-hydraulic control system for variable displacement machines. In: Conference paper at 12th International Conference „Automation in Production Planning and Manufacturing“, At: Zilina Slovacia, 2011.

[16] Duţu I., Matache G.: Computer assisted electro-hydraulic stand for testing servovalves, Hidraulica, No. 3 – 4, 2012.

[17] Weber J., Lohse H., Thermo-energetic Analysis of the Fluid System in Cutting Machine Tools, In: Confeence paper 10IFK in Dresden, 2016.

[18] https://en.wikipedia.org/wiki/Modbus [accessed on 1.10.2020].

[19] Costa G. K., Sepehri N.: A Critical Analysis of Flow-Compensated Hydrostatic Single Rod Actuators: Simulation Study, Actuators Journal, 2020.

[20] Costa G.K. Sepehri N.: A Critical Analysis of Valve-Compensated Hydrostatic Actuators: Qualitative Investigation, Actuators Journal, 2019.

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Estimation of strength properties of the UWZ-1 device for withdrawing the powered roof support

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Keywords: mining industry, liquidation of a longwall panel, powered roof support, withdrawal of the roof support, strength verification

Słowa kluczowe: górnictwo, likwidacja ściany wydobywczej, sekcja obudowy zmechanizowanej, wybudowa sekcji obudowy, weryfikacja wytrzymałościowa

Abstract:

The concept of a device for withdrawal of a powered roof support during the liquidation of a longwall panel is presented. This device is a part of the system developed by KOMAG for the withdrawal of a roof support from a row and its transportation in the liquidated longwall. The suggested solution significantly improves efficiency and safety of this process. The basic parameters of the device, a description of the design and principle of operation are presented. Strength properties of its basic components were estimated, taking into account the way the device operated during the withdrawal of the roof support. The paper describes the problems faced by engineers when designing the non-standard mining device, which is the UWZ-1 device. The advantages of the discussed device are also presented.

Streszczenie:

W publikacji przedstawiono koncepcję urządzenia do wybudowy sekcji obudowy zmechanizowanej w procesie likwidacji ściany wydobywczej. Urządzenie to jest elementem opracowanego w ITG KOMAG systemu do wybudowy sekcji z szeregu i jej transportu w likwidowanej ścianie. Zaproponowane rozwiązanie poprawia w zdecydowany sposób efektywność i bezpieczeństwo tego procesu. Przedstawiono podstawowe założenia urządzenia, opis konstrukcji oraz zasadę działania. Oszacowano właściwości wytrzymałościowe jego podstawowych elementów uwzględniając sposób pracy urządzenia w czasie wybudowy sekcji. W publikacji opisano problemy z jakimi spotykają się inżynierowie przy projektowaniu konstrukcji nietypowego urządzenia górniczego jakim jest urządzenie UWZ-1. Przedstawiono także zalety jakie posiada przedmiotowe urządzenie.

1. Introduction

The process of disassembling the technical equipment in the liquidated longwalls and its transportation to new workings is one of the most difficult processes with a significant accumulation of factors favoring the disturbance of this process [1]. Operations related to the withdrawal of the powered roof support from a row and its transportation to the main transport roadway are of particular importance due to the weight and number of transported components. Machines and devices used in Polish hard coal mines are presented in [2, 3, 4, 5].

Based on the experience gained during operating the equipment used for withdrawal [6, 7, 8], chain broaching machines [9] and mine operation [10, 11], KOMAG developed a concept of a new system for the withdrawal of a powered roof support from a row and its transportation in a liquidated longwall panel [12]. UWZ-1 device designed for withdrawal of a powered roof support from the row is the key component of this system. This device has to fulfill the following three basic tasks:

– support the roof in the transportation area of the cross-cut entry in the area of the roof support withdrawal,

– enable the roof support to be moved from the row and relocated to the transportation area of the cross-cut entry and loading it onto a transportation platform using the set of hydraulic cylinders and roof support advancing system,
– move along the cross-cut entry using its own advancing system,
– as well as to meet the requirements of regulations [13, 14, 15, 16, 17, 18].

The issues of estimating the strength properties of basic components of the UWZ-1 device at the concept stage are presented.

2. Description of the device's design and principle of operation

The UWZ-1 device with a transportation platform onto which the withdrawn roof support is pulled, is shown in Fig. 1.

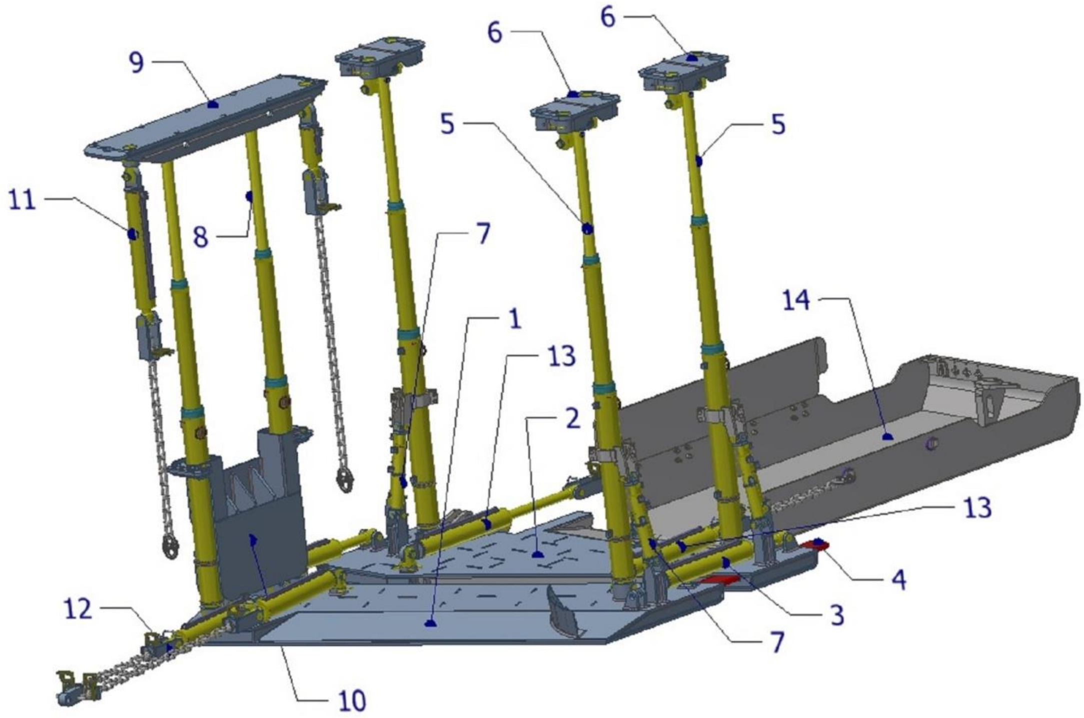

Fig. 1. Visualization of the device for withdrawal of the UWZ-1 roof support during liquidation of a mining longwall panel along with a transportation platform

The UWZ-1 device is made of two moving segments inrun (item 1) and descending (item 2) connected by an advancing system.

The advancing system consists of two hydraulic cylinders (item 3) and two guiding boards (item 4). The advancing cylinders are attached to the eyes of each advancing segment. The guiding boards are fixed in the inrun segment, while in the descending segment, the guiding tunnels are installed allowing the guiding boards to slide. The advancing cylinders have 800 mm range of movement. The inrun segment consists of a platform equipped with a descending wedge and a guiding buffer. The wedge and buffer are used to guide the withdrawn roof support into the device's transportation tunnel.

A single hydraulic leg (item 5) is installed on the side of the buffer and the wedge. A small bolting canopy (item 6) is installed on the hydraulic leg. The leg is stabilized with a stabilization unit (item 7) consisting of a pair of hydraulic cylinders and a stabilizing clamp. The stabilization unit stabilizes the leg vertically with possibility of its correction in two planes by ±10˚. On the other side of the inrun segment, there are two interlocked hydraulic legs (item 8).

A large bolting canopy (item 9) is installed on the legs. The legs are stabilized with a stabilization unit (item 10), consisting of a platform and a hydraulic cylinder. The stabilization unit stabilizes the leg vertically with possibility of its correction in one plane by ±10˚.

The large canopy is equipped with two auxiliary hydraulic cylinders (item 11), fixed with two pairs of hinged joints with mutually perpendicular axes of rotation. The cylinders are used as auxiliary components in the operation of pulling the withdrawn roof support into the transportation tunnel of the device and correcting its position in the tunnel. On the side of the interlocked hydraulic legs, there is a roof support withdrawing unit (item 12). It consists of a pair of hydraulic cylinders connected to the inrun segment platform using the same method of fixing as the item 11 cylinders.

On the side of a single hydraulic leg there is a hydraulic cylinder of the transportation platform (item 13), which also uses the same method of fixing as the item 11cylinders. It is used to pull and stabilize transportation platform in relation to the device for withdrawal of roof support. In addition to the guiding buffer, there are additional eyes for installation of the cylinder, and which can be used to correct position of the withdrawn roof support in the transportation tunnel. The descending segment consists of a platform (item 2) equipped with a descending wedge and a set of eyes for installation of the chain puller's return end. The descending wedge is used to facilitate moving the withdrawn roof support from the device's transportation tunnel onto the transportation platform (item 14). Double eyes and fastening pins are used to connect the roof support withdrawing device with the return end of the chain puller. Single hydraulic legs are installed on both ends of the segment (item 5).

Small bolting canopies (item 6) are installed on the hydraulic legs. The legs are stabilized with stabilization units (item 7) similarly to the stabilization of a single leg of the inrun segment. The hydraulic cylinder of the transportation platform (item 13) is located on the side of the chain puller's return end, connected to the descending segment platform by a set of two mutually perpendicular articulated pairs. It pulls and stabilizes the transportation platform in relation to the roof support withdrawing device.

A removable handle for mounting the chain is placed in the area of the descending wedge. The chain connects the handle with the beam of the sliding system of the withdrawn roof support moved into the device's transportation tunnel. The canopies of the moving segments form a transportation tunnel into which the withdrawn roof support is pulled.

Fig. 1 also shows a transportation platform onto which the withdrawn roof support is pulled.

<u>The principle of operation of the UWZ-1 device</u>

The UWZ-1 device is installed at the height of the powered roof support neighboring to the roof support to be withdrawn (Fig. 2). It is set to load using the canopies and hydraulic legs. The empty transportation platform is pulled to the unit and anchored with an additional individual hydraulic leg (not shown in figure).

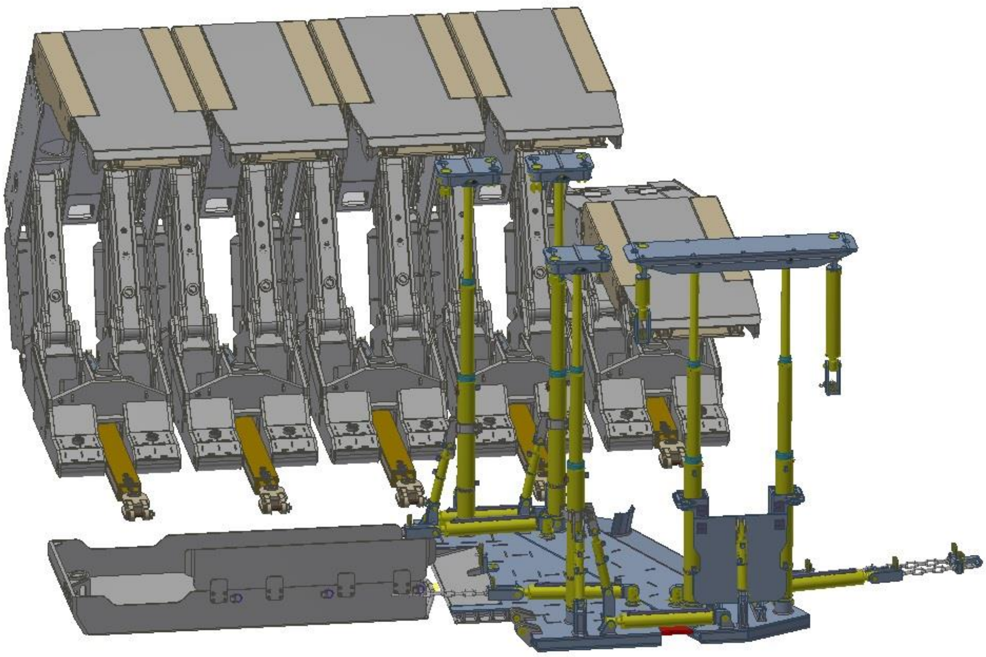

Fig. 2. Visualization of the UWZ-1 device prepared for withdrawal of the roof support from a row.

The roof support to be withdrawn from the row is pulled out using a set of pulling cylinders, correcting its position using the auxiliary cylinder installed on the large canopy of the device. The withdrawn roof support is pulled into the transportation tunnel of the securing support using the roof support's advancing system while auxiliary cylinders are correcting its position., The roof support withdrawn from the transportation tunnel is pulled onto the transportation platform using its advancing system.

3. Estimation of strength properties of UWZ-1 device

The description of the design and operating principle of the device for withdrawal of the roof support presented above shows that the device technical parameters and dimensions must be adapted to the local conditions in the longwall (roadway height, load-bearing capacity of the roof and floor) and the weight and dimensions of the roof support to be transported. In such a situation, designing a series of types of devices is not rational and therefore each withdrawing device should be designed for a specific application.

Therefore, at the current stage of development of the device, the strength calculations were limited to a preliminary determination of the stress of each component. For this purpose, the Finite Element Method module available in the Autodesk Inventor Professional 2019 engineering program was used. Due to the large number of assemblies included in the UWZ-1, the complex interactions of each of them and the limitations of Autodesk Inventor, it was decided to narrow the scope of the simulations to a few basic assemblies most exposed to loads resulting from cooperation with the surrounding components of the device working environment.

The simulation covered the inrun and descending segments cooperating with the floor, as well as small canopy and large canopy cooperating with the roof lining of the cross-cut entry.

The following assumptions were made for the simulation purposes:

- the device can be used for the withdrawal of a roof support of a pitch 1.5 m and a weight of ~23,000 kg,
- the height range of the device is 2400 ÷ 4400 m,
- the width of the transportation tunnel for the withdrawn roof support should be ~2400 mm,
- hydraulic legs will be two-telescopic with a diameters Ø160/Ø140/Ø100, operating at a working pressure of 34 MPa,
- the device will be self-advancing with 800 mm advance,
- when estimating the strength properties of the device, cylinders for withdrawing the roof supports were neglected due to insufficient force compared to the force of the hydraulic legs.

<u>Estimation of the strength properties of a small canopy</u>

The method of supporting the canopy, shown in Fig. 3, was adopted for the simulation. Two beams with a cross-section 100x100 mm, located at the ends of the canopy, were used to simulate the supporting method.

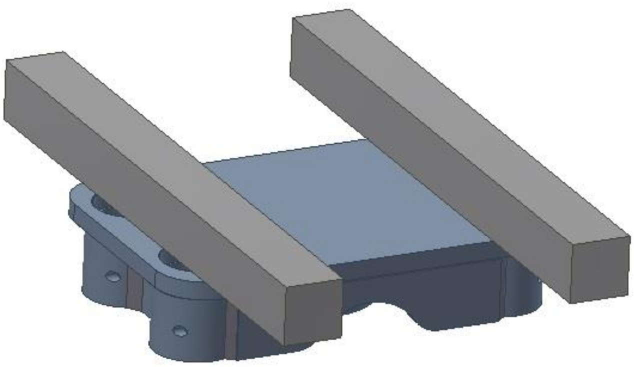

Fig. 3. The method of supporting a small canopy

The canopy was loaded with the force from the hydraulic leg applied at the leg fixation. The simulation results are shown in Fig. 4.

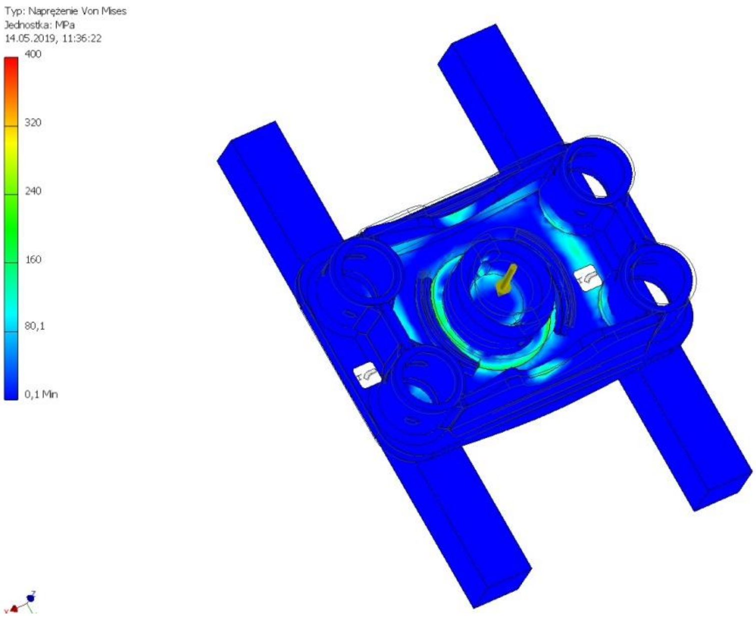

Fig. 4. Map of reduced stresses in a small canopy

The stress map in Fig. 4 shows that the local reduced stress is lower than 400 MPa. Therefore, the small canopy can be made of typical available construction materials (e.g. S460N steel).

<u>Estimation of strength properties of a large canopy</u>

Due to the possible different methods of cooperation of the large canopy with the roof lining of the cross-cut entry, it was decided to limit the computer simulation to the two most unfavorable and, at the same time, the most common methods of supporting the canopy.

I support method.

The cooperation of the canopy with the lagging is modelled by a 100x100 mm beam located in the middle of the canopy (Fig. 5).

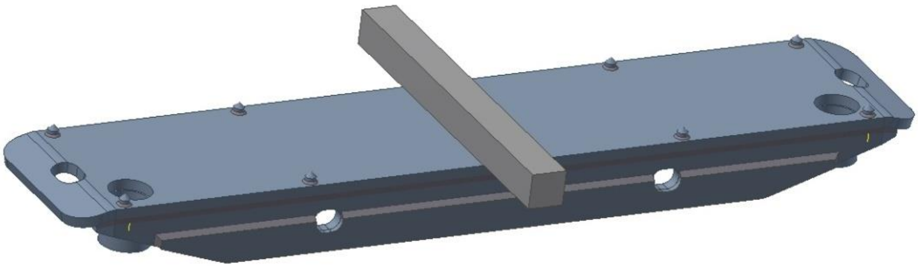

Fig. 5. First method of supporting a large canopy

The canopy was loaded with forces from two hydraulic legs applied at the legs fixation points. The results of the simulation in the form of a map of reduced stresses on the deformed model of the canopy are shown in Fig. 6.

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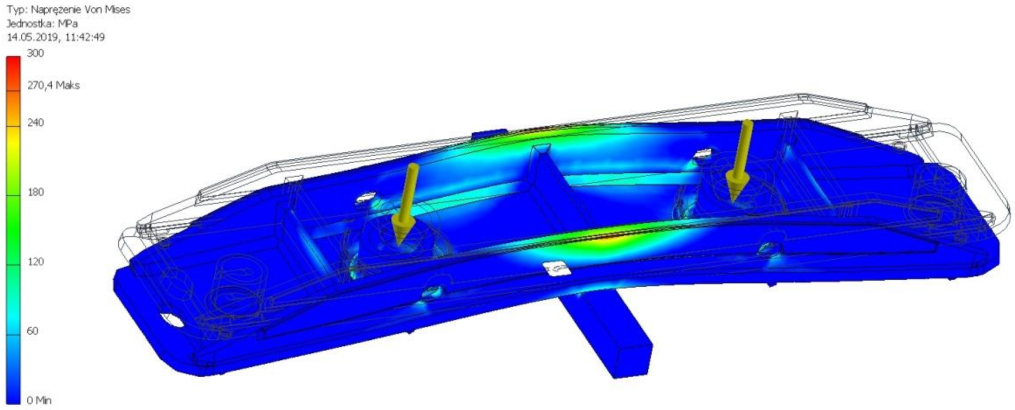

Fig. 6. Map of reduced stresses in a large canopy - I supporting method

With this method of loading, the reduced stress in the canopy is lower than 300 MPa.

II support method.

The impact of the roof lining on the canopy is modelled by two 100x100 mm beams, moved away by 100 mm from the canopy ends. The canopy was loaded with forces from two hydraulic legs applied at the legs fixation points. The results of the simulation are presented in Fig. 7.

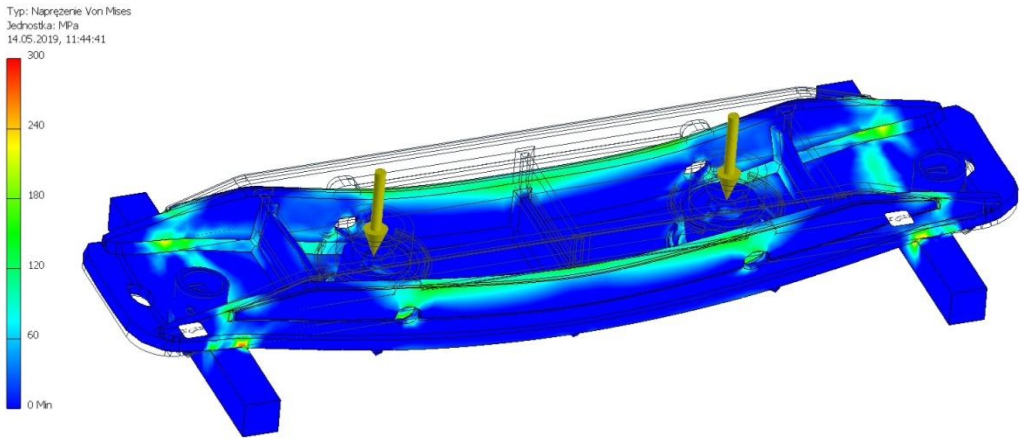

Fig. 7. Map of reduced stresses in a large canopy - II support method

Fig. 7 shows that the stresses in the canopy are lower than 300 MPa. The results of both simulations allow concluding that the typical available construction materials (e.g. steel S420N) can be used for its manufacturing.

Estimation of strength properties of the descending moving segment

The segment is supported by a beam located halfway between hydraulic legs. Such a supporting method results from the principle of kinematically variable system striving to take the balanced position. The adopted model of supporting the descending segment as a 100x100 mm beam is shown in Fig. 8.

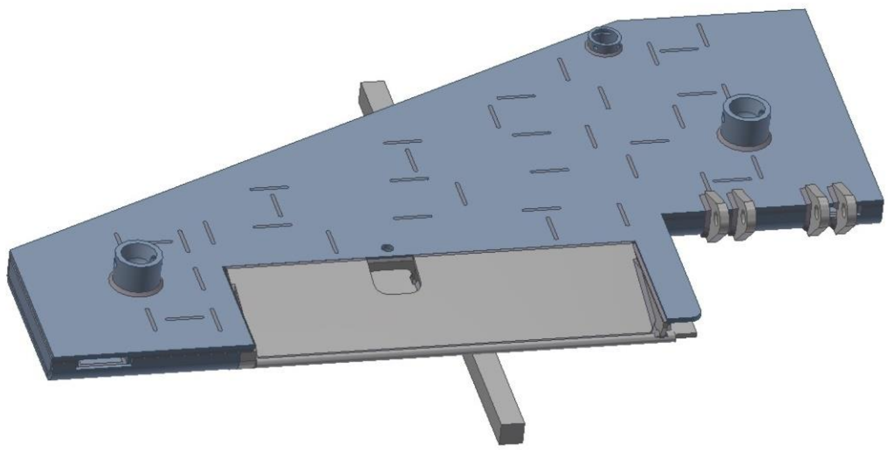

Fig. 8. The method of supporting the descending moving segment

The segment was loaded with forces from two hydraulic legs applied in the place of legs fixation. Results of the simulation are shown in Fig. 9.

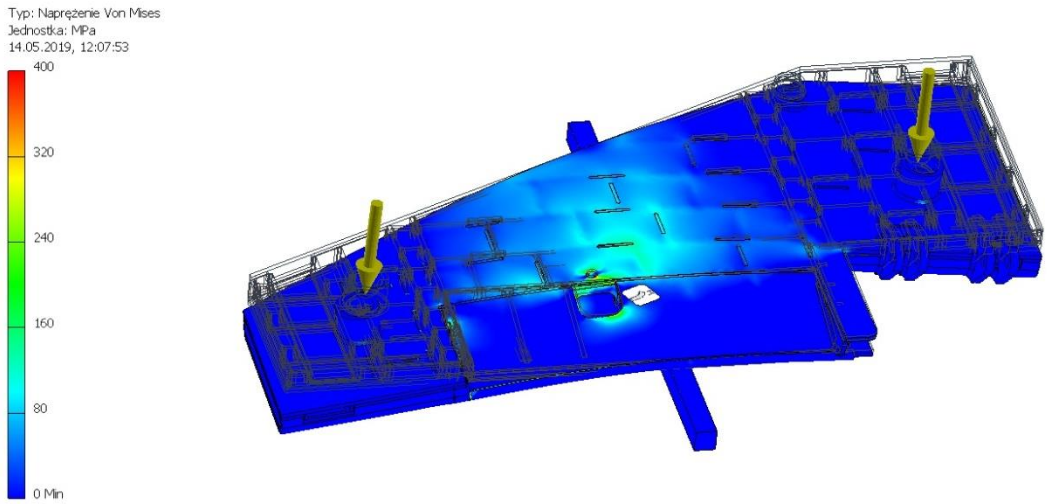

Fig. 9. Map of reduced stresses in the descending moving segment

The stress map shown in Fig. 9 shows that the local reduced stress is lower than 400 MPa. The descending moving segment can therefore be made of construction materials available on the market (e.g. S460N steel).

<u>Estimation of strength properties of the inrun moving segment</u>

The most unfavorable variant of loading the segment consists in supporting it with one beam. Its position on the surface of bottom plate of the segment was determined using the equilibrium state of the discussed system. Assuming such a supporting method also results from the principle of kinematically variable system striving to take the balanced position. The adopted model of supporting the inrun segment as a 100x100 mm beam is shown in Fig. 10.

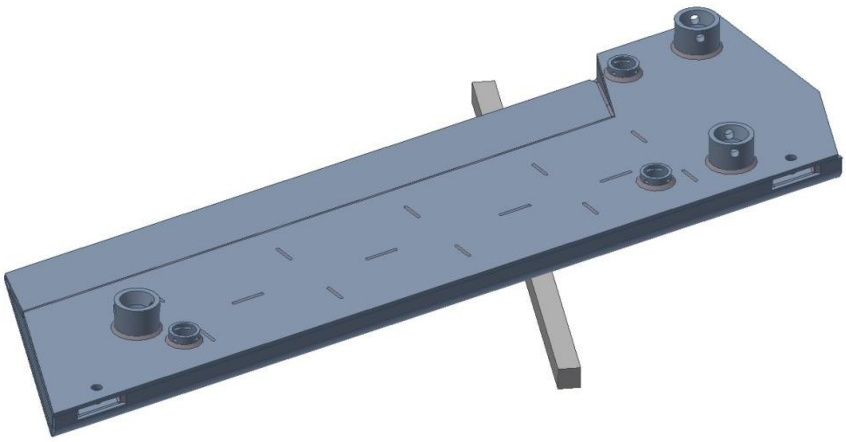

Fig. 10. The method of supporting the inrun moving segment

The segment was loaded with the forces coming from two hydraulic legs applied at the legs fixation point. Results of the simulation are shown in Fig. 11.

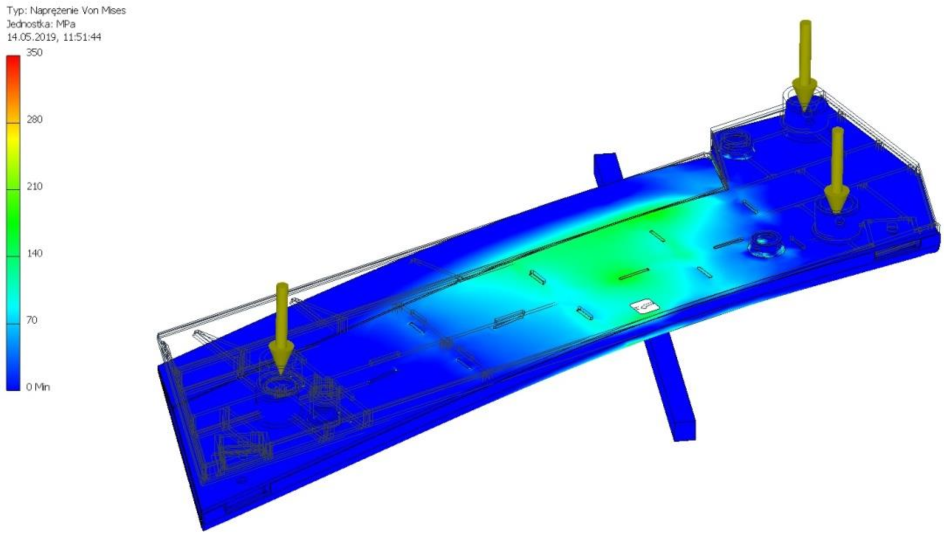

Fig. 11. Stress map of the inrun moving segment

The stress map shown in Fig. 11 shows that the local reduced stress is lower than 350 MPa. The inrun moving segment can therefore be made of construction materials available on the market (e.g. S420N steel).

4. Conclusions

The method of estimating strength properties of the presented UWZ-1 device for withdrawal of powered roof support, illustrates the complexity of problems faced by designers of such devices. It is not enough to create 3D models of the device components of such a device, but each phase of its operation, method of cooperation with the components of the cross-cut entry, the shape of the floor and the specificity of the withdrawn roof support design needs to be known. The knowledge of the problems allowed to adopt proper supporting methods allowing to estimate strength properties of the UWZ-1 device for withdrawal of roof support.

The basic advantages of UWZ-1 roof support are as follows:

- possibility of securing and supporting the roof of cross-cut entry in the area of the roof support withdrawal,
- mechanization of withdrawal process of the roof support starting from its removal from the row to the loading it onto the transportation platform, under the permanently protected roof,

– the device is self-advancing, what means that its mobility does not require any additional equipment for moving.

All these advantages significantly improve the efficiency of the entire process as well as the comfort and safety of the personnel during withdrawal of the powered roof support from the liquidated longwall panel.

References

[1] Tchórzewski S.: Ryzyko w realizacji procesu zbrojenia i likwidacji ściany – czynniki tworzące –analiza ilościowa, Zeszyty Naukowe Politechniki Śl., Seria. Organizacja i Zarządzanie, Z 89, s.465-478, Gliwice 2016.

[2] Mazurek K., Szyguła M., Turczyński K.: Development of technology for withdrawal of the powered roof support from a row and its relocation from the liquidated longwall system. In: IMTech 2019, Innovative Mining Technologies, Scientific and Technical Conference - part 2, Szczyrk, Poland, 14-16 October 2019 s. 11, (IOP Conference Series: Materials Science and Engineering 2019 vol. 679) ISSN 1757-899X.

[3] Kania J., Szweda S., Szyguła M.: Analiza procesu wybudowy sekcji obudowy zmechanizowanej z wyrobiska ścianowego w aspekcie bezpieczeństwa. Maszyny Górnicze 2018 nr 3, s. 24-34.

[4] Winkler T and Tokarczyk J 2010 Multi-Criteria Assessment of Virtual Prototypes of Mining Machines. In: Proceedings of the World Congress on Engineering and Computer Science 2010 vol II. WCECS 2010, October 20-22, 2010, San Francisco, USA. ISSN: 2078-0958 pp 1149-53.

[5] Nikitina A M, Rib S V, Borzykh D M, Dadynsky R A: Remounting of a mechanized complex using Petitto Mule equipment in the conditions of mines in the south of Kuzbass. In: IOP Conference Series: Earth and Environmental Science, Volume 206, International Scientific Conference "Knowledge-based technologies in development and utilization of mineral resources" 5–8 June 2018, Novokuznetsk, Russian Federation.

[6] Technical and operational documentation. Urządzenie UDW typu Ryś do wybudowywania sekcji obudowy zmechanizowanej. CMG KOMAG, Gliwice 2006. (unpublished materials).

[7] Technical manual of the device for rotating and pulling out the powered roof support from a technological line type UWS-PUMA dla KWK „Knurów-Szczygłowice". SIGMA S.A., Barak 6; 21-002 Jastków.

[8] www.sigmasa.pl [access 17 June 2020]

[9] www.kolk.de [access 10 April 2018]

[10] Nawrat S., Pytlik P.: Bezpieczna likwidacja ścian w kopalniach węgla w warunkach zagrożenia wybuchem metanu. Bezpieczeństwo Pracy i Ochrona Środowiska w Górnictwie 2013 nr 2, s. 3-12.

[11] Stefaniak R., Janik M., Kuska J.: Nowe rozwiązania organizacyjno-techniczne wprowadzone przy przezbrajaniu kompleksu ścianowego ze ściany 904 do ściany 905 i zmiany wprowadzone do maszyn i urządzeń wyżej wymienionego kompleksu. In: Innowacyjne, bezpieczne oraz efektywne techniki i technologie dla górnictwa Człowiek – Maszyna – Środowisko. KOMTECH 2009. Instytut Techniki Górniczej KOMAG, Gliwice 2009 s. 53-63; ISBN 978-83-60708-38-5.

[12] Gerlich J., Jenczmyk D., Mazurek K., Szyguła M., Stępor J., Turczyński K.: Rozwój innowacyjnych rozwiązań mechanizacyjnych dla ścianowych i chodnikowych systemów górnictwa surowców mineralnych. Opracowanie koncepcji technologii do wybudowania i transportu sekcji obudowy zmechanizowanej w procesie likwidacji ściany wydobywczej. ITG KOMAG , Gliwice 2019 (unpublished materials).

[13] Ustawa z dnia 9 czerwca 2011 r. - Prawo geologiczne i górnicze (Dz.U. 2011 nr 163 poz. 981, z późniejszymi zmianami) [Journal of Laws 2011, No. 163, item 981, with further amendments].

[14] Rozporządzenie Ministra Energii z dnia 23 listopada 2016 r. w sprawie szczegółowych wymagań dotyczących prowadzenia ruchu podziemnych zakładów górniczych (Dz. U. 2017, poz. 1118) [Journal of Laws 2017, item1118].

[15] Rozporządzenie Ministra Środowiska z dnia 29 stycznia 2013r. w sprawie zagrożeń naturalnych w zakładach górniczych (Dz.U. 2013 poz. 230, z późniejszymi zmianami) [Journal of Laws 2013, item 230, with further amendments].

[16] Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery.

[17] Ustawa z dnia 13 kwietnia 2016 r. o systemach oceny zgodności i nadzoru rynku (Dz. U. 2016 poz.542) [Journal of Laws 2016 item 542, with further amendments].

[18] Directive 2014/34/EU of the European Parliament and of the Council of 26 February 2014 on the harmonization of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres.

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25 years of accreditation of the Testing Laboratory at KOMAG Institute of Mining Technology

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Keywords: accreditation, standard, testing, test stand, powered roof support

Słowa kluczowe: akredytacja, norma, badania, stanowiska badawcze, obudowa zmechanizowana

Abstract:

The article presents the 25-year history of accreditation of the Testing Laboratory of the KOMAG Institute of Mining Technology in Gliwice. It describes the process of implementing and applying the management system in accordance with the standards being in force within the years 1995-2020. The article shows the process of changing the standards requirements for the accreditation for testing laboratories. The most important changes in the approach to laboratory activities, which are currently focused on activities that determine their quality, are highlighted. Minimization of documentation is the result of the change in approach to testing activities and competence of the personnel is of key importance. At the same time, the changing requirements for the testing process itself are presented on the example of testing the powered roof supports.
The article describes changes in the testing infrastructure of the Testing Laboratory, both before obtaining accreditation, as well as its development over 25 years of accreditation.

Streszczenie:

Publikacja poświęcona jest 25-letniej historii akredytacji Laboratorium Badań Instytutu Techniki Górniczej KOMAG w Gliwicach. Przedstawiono w niej proces wdrażania i stosowania systemu zarządzania zgodnie z normami obowiązującymi na przestrzeni lat 1995-2020. W artykule pokazano proces zmian norm dotyczących wymagań akredytacyjnych laboratoriów badawczych. Zasygnalizowano najważniejsze zmiany dotyczące podejścia do działań laboratorium, które obecnie są ukierunkowane na działania procesowe decydujące o ich jakości. Wynikiem zmiany podejścia jest minimalizacja dokumentacji, zaś za kluczowe uznaje się kompetencje personelu. Równolegle przedstawiono zmieniające się wymagania dotyczące samego procesu badawczego, na przykładzie badań górniczych obudów zmechanizowanych.
W artykule opisano zmiany dotyczące bazy badawczej Laboratorium Badań, zarówno przed uzyskaniem akredytacji, jak również jej rozwój na przestrzeni 25 lat akredytacji.

1. Introduction

Accreditation - a term that was only used several decades ago to refer to journalists or diplomats, today is also associated with laboratories. However, in this context, it has a different meaning.

According to the PN-EN ISO/IEC 17000:2020-12 [1] standard, accreditation is "attestation" by a third party, relating to a conformity assessment body, to formally demonstrate its competence in performing the specific tasks associated with conformity assessment.

Accreditation is than a formal recognition, by an authorized organizational unit, of the competence of a certain organization or person operating in the field of conformity assessment.

It is, in a way, a credit of trust granted to an organization, or a testimonial confirming the reliability of an organization offering a given type of service.

In the case of testing laboratories, the term "accreditation" means the procedure in which, on the basis of an assessment made by an authorized body (in Poland - the Polish Centre for Accreditation), a statement (accreditation certificate) that a given entity is competent to perform specific tasks, is issued.

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In the case of laboratories, it involves carrying out tests to show that the tested object meets the requirements for its intended use.

The benefits of accreditation in the case of testing laboratories are presented in the table 1.

Table 1. The benefits of accreditation [2]

Addressee	Benefits
Accredited organization	Confirmation of competences Recognition of results Competitive advantage
Users	Trust in the quality and safety of products and services Reliable and precise results of measurements and tests Reliable information
State administration	Trust in legislation and decisions of state bodies Technical support in notification processes Assurance of public safety
Industry and business	Access to European and world markets Better product quality Lower control and manufacture costs Chance for innovation Effective risk management

Authorizations granted initially by the Central Office of Product Quality, and then by the Polish Centre for Testing and Certification were the basis for granting accreditation to testing laboratories.

Being aware of the benefits of accreditation, the Division for Attestation Tests, as an organizational unit operating within the structures of the Mining Mechanization Centre in Gliwice, submitted in June 1992 an application to the Central Office for Product Quality for the assessment procedure and for granting accreditation for testing the powered roof supports.

In that time the Division for Attestation Tests had the following departments:

– Department for Testing the Powered Roof Supports in the scope of testing the kinematics and functionality as well as fatigue strength of powered roof supports,
– Department for Testing the Hydraulic and Mechanical Systems in the scope of testing the hydraulic cylinders of powered roof supports, hydraulic control and protecting components as well as hydraulic pipes and hoses,
– Department for Physical and Chemical Tests in the scope of testing the material properties and chemical composition of powered roof support components.

In 1994 a proposal was submitted for the pre-audit which included the following stages:

– assessment of advancement in using the quality system in the laboratory in accordance with the requirements of EN 45001:1993 Standard [3] and ISO/IEC No. 25:1990 Guide [4],
– assessment of the quality system documents,
– acquainting with the scope of tests submitted for accreditation.

As a result of the pre-assessment, it was recommended to introduce some changes, especially in the organizational area, consisting in the separation of two areas of the Division's activity, so on January 1, 1995, the following two separate units were established:

a. Testing Laboratory, which conducted research activities and applied for accreditation according to the requirements of the EN 45001:1993 Standard and ISO/IEC No. 25:1990 Guide,
b. Department of Attestation Tests, who conducted the attestation activities and made efforts for accreditation of the certifying body according to the requirements of the EN 45011:1993 Standard [5].

After the organizational changes and the introduction of corrective measures, an accreditation audit was carried out in the Testing Laboratory on June 27-28, 1995, which resulted in the granting the first accreditation certificate for the testing laboratory No. L 39/1/95 for 3 years on October 31, 1995.

The certificate number (39) indicated that the Laboratory was one of the first to be accredited in Poland. Accreditation documents are as follows:

1. Accreditation certificate for the testing laboratory No. 39/1/95 with validity up to 30.10.1998.
2. Contract No. AB/L 39/95
3. Accreditation mark PCBC
4. Rules for using the accreditation mark by the accredited testing laboratory.
5. Scope of accreditation.

Historical certificate and accreditation mark are shown below.

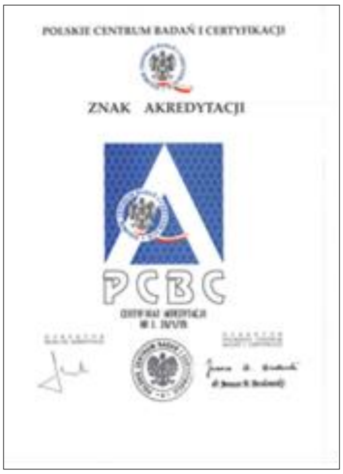

Fig. 1. Certificate and accreditation mark of the Testing Laboratory [1995]

2. Accreditation scope and testing infrastructure

Scope of accreditation granted in 1995 for testing powered roof supports especially:

1. testing the powered roof support's structure,
2. testing the hydraulic components of the powered roof support,
3. physical and chemical tests of the powered roof support components,

which were based on own procedures and testing instructions developed on the basis of the following documents:

1. "Temporary requirements, guidelines for designing and testing in laboratory as well as for in-situ tests of powered supports for issuing the approval of the type for production and use" [6] issued in December 1984 by the Ministry of Mining Industry and Energy, which was in force until November 1998,
2. "Design and strength requirements for powered supports" [7] developed by specialists from KOMAG Gliwice, GIG Katowice and the Silesian University of Technology in Gliwice, which were in force since November 1998,
3. Polish standard PN-G-50041:1994 "Protection of work – Powered roof supports – Requirements for safety and ergonomics" [8].

In the years 1998-2005, the tests of new powered roof supports included the scope presented in the Table 2.

Table 2. Type of powered roof support tests

Item	Type of test
1	Checking the main dimensions of roof supports
2	Assessment of the assembly and disassembly convenience
3	Checking the functionality and kinematics
4	Stability tests
5	Fatigue tests
6	Testing the static strength

7	Testing the dynamic strength
8	Testing the materials

For the new power hydraulic components the scope of testing is given in Table 3.

Table 3. Scope of testing the power hydraulic components

Item	Type of test
1	Leak tightness test
2	Fatigue test
3	Static strength test
4	Dynamic strength test
5	Testing the materials
6	Testing the anti-corrosion protection

The subsequent accreditation periods, covering the years 1998-2001 and 2001-2005, did not introduce significant changes to the scope of the Testing Laboratory activity.

Comprehensive tests of powered supports was possible due to the construction of a state-of-the-art technical infrastructure for testing, which included the following test stands presented in Fig. 2:

1. Stand for testing the strength of powered roof support,
2. Stand for testing the functionality of powered roof supports
3. Stand for testing the hydraulic legs and the components of high-pressure hydraulics,
4. Stand for testing the components of mining machines and equipment,
5. Stand for testing the valves.

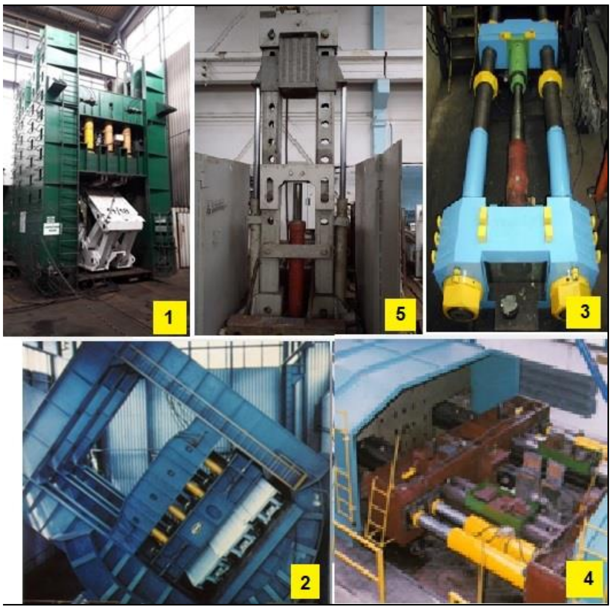

Fig 2. Test stands of the Testing Laboratory [1995]

3. Accreditation after accession to the European Union

The association, and then Poland's accession to the European Union, brought a number of changes both in the accreditation process of testing laboratories as well as in testing methodologies.

Thinking about laboratories developing their quality systems, the Polish Committee for Standardization issued in 2001, the European standard PN-EN ISO / IEC 17025: 2001 [9].

This standard replaced the PN-EN 45001: 1993 document used by the laboratory.

The next edition of the standard containing the requirements for the testing laboratory was the standard issued by ISO/IEC in 2005, which was prepared as the international standard and was issued in Poland as the Polish Standard: PN-EN ISO/IEC 17025:2005.

In June 1998, the European Parliament issued the Directive 98/37/EC, which contained the basic requirements for the safety of machinery and equipment.

Detailed requirements referred to the so-called harmonized standards, drawn up under a mandate from the Commission by CEN and CENELEC, and then incorporated unchanged into national standards.

In the annex to the directive, powered roof supports are listed in the context of type examination for the needs of the notified body.

Regarding the safety requirements for powered roof support, the following two standards were issued:

1. EN 1804-1:2004 – including the requirements for powered roof support design [10],
2. EN 1804-2:2004 – including the requirements for hydraulic components of powered roof support [11].

It should be emphasized that in the case of powered roof supports, the Testing Laboratory was one of two testing laboratories in Europe that performed accredited tests in this scope for the needs of notified bodies.

The previously mentioned harmonized standards fundamentally changed the way of testing the powered roof supports structure and hydraulic components.

In the case of testing the powered roof supports structure, scope of testing was specified in Annex A to EN 1804-1:2004 Standard, which included the following types of tests:

a. testing at static load equal to 1.2 of the nominal force,
b. testing the components hydraulic legs and cylinders at compressing and tensile load equal to 1.5 nominal compressing and tensile force,
c. testing the load-bearing capacity (yield of the powered roof support),
d. cycles of the fatigue test with the amplitude from 1.05 to 0.25 nominal force (26000 load cycles for two-leg roof support and 30000 load cycles for four-leg roof support) for different combined loads,
e. testing the powered roof support at horizontal load,
f. testing the transportation catches for lifting and moving.

The harmonized standards alleviate the requirements for test results acceptance criteria to the criterion that after the tests completion none of the roof support's base material should contain cracks and no cracks in the joints or permanent deformations that would lower the technical parameters of the roof support are allowed.

In testing the actuating components (hydraulic legs, canopy cylinders and auxiliary cylinders), Annex B to the EN 1804-2:2004 standard specifies the scope of tests including the following tests:

a. tests with symmetrical axial load (stroke limiter test, compliance test, overload tests),
b. tests under asymmetric load (bending test and compliance test),
c. durability tests (asymmetric load - 6,000 cycles, axial load - 15,000 cycles, load to the leg in the most extended position - 100 cycles).

Therefore, in 2005, the Laboratory of Tests introduced both standards to its scope of accreditation.

Moreover, the scope of accreditation was extended by including the following groups of tested objects:

- hydraulic transmission pipelines, their components and fittings,
- frictional legs,
- shackles,
- steel sprags,
- lining meshes.

In 2008, the third standard of the EN 1804-3:2008 series [12] was published, containing the requirements for hydraulic control components, which was also included to the scope of accreditation.

4. Development of the testing infrastructure

Growing requirements for accredited laboratories both regarding the quality management system, as well as testing according to specific standards and intensive use of test stands forced modernisation of the Testing Laboratory infrastructure.

In the years 2004-2007, a lot of work was undertaken to modernise the laboratory's testing infrastructure.

The most important projects included the following:

- designing and manufacture of a state-of-the-art oil-water emulsion cooling system supplying the test stands,
- change of the hydraulic system to the electrohydraulic control of the stand for powered roof supports functionality tests and the stand for strength tests,
- manufacture of an automatic monitoring system for fatigue tests on the test stand for testing the strength of powered roof supports,
- modernisation of the valves test stand, extending the possibilities of its use for testing the dynamic loads and tensile static loads,
- modernisation of the stand for testing the strength of powered supports loaded with additional horizontal force,
- modernisation of the system for recording the parameters measured on a testing facility.

At the same time, along with extending the scope of accreditation, actions were taken to build new test stands.

In the years 2008-2011, the technical documentation of the following test stands was prepared at the KOMAG Institute of Mining Technology which then were used in testing:

- a stand for testing hydraulic legs,
- a stand for testing steel sprags,
- a stand for testing lining meshes.

A view of the test stand lining mesh is shown in Fig. 3.

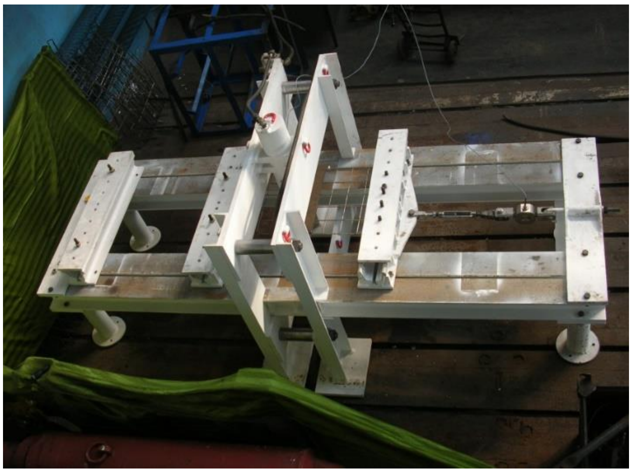

Fig. 3. Test stand lining mesh [2011]

The next stage of extension and modernisation of the testing infrastructure was realized in 2012-2013.

Funds from the European Regional Development Fund allowed for the following:

- modernisation of the stand for testing the functionality of powered roof supports, consisting in the extension of the mechanical equipment of the test stand roof components and replacement of the hydraulic system by this manufactured according the developed technical documentation,
- modernisation of control systems for test stand by changing the control panels and using fatigue test recording systems,
- development a programming environment enabling the collection, analysis and visualization of measurement data and their transfer to customers,
- implementation of an electronic monitoring system for supervising the measuring and testing equipment.

5. Improvement of the management system

The development and modernization of the testing infrastructure ensured meeting the requirements for technical competences in subsequent accreditation cycles covering the years 2005-2009, 2009-2013, 2014-2016 and 2016-2020.

In 2009, integration of management systems, which were in force at the Institute, was completed.

The integration process covered the following three basic levels of management:

- the level of the integrated management policy, which took into account the management of quality, the accreditation system of testing laboratories and the accreditation system of the product certifying body,
- level that takes into account all functions regarding the processes and improvement activities of a different nature (organizational, technical, methodological, IT, etc.) focused on finding the best solutions at various organizational levels in each sphere of the institute activity,
- level of integration of the management system documents.

The quality management system in the scope of R&D projects, designing and author's supervision over the machines and devices as well as expert opinions was the basis of the integrated management system.

This system combined the following management systems resulting from the accreditations granted by the Polish Centre for Accreditation:

- quality management system according to PN-EN ISO 9009:2009 Standard being in force in all Institute's divisions,
- management system according to PN-EN ISO/IEC 17025:2005 Standard valid for accredited tests,
- management system according to PN-EN 45011:2000 Standard valid for products certification processes.

There were the following advantages of the integrated system:

- uniform Quality Policy taking into account the requirements of all standards,
- uniform organization of documentation and no duplication of documents and forms,
- easy supervision of the management system and its improvement through the introduction of common internal audits and management reviews, and the implementation of joint corrective and preventive measures [13].

A positive assessment in 2017 of the competence to manage a flexible scope of accreditation proved the improvement of the management system.

Flexible scope of accreditation by the Laboratory allowed for:

- implementation of own modified testing methods,
- use of updated standard testing methods.

The laboratories with flexible scope of accreditation are obliged to update so-called *List of tests conducted within the flexible scope of accreditation.* The list is an extension of the testing laboratory fixed scope of accreditation [14].

In 2018, the next edition of the PN-EN ISO/IEC 17025:2018-02 standard [15], containing the requirements for a testing laboratory management system, was published.

This standard introduced a number of significant changes compared to the previous edition (including requirements for impartiality, confidentiality and risk).

In accordance with the adopted philosophy of the process management, the new PN-EN ISO/IEC 17025:2018-02 standard identifies the basic processes related to testing, in particular:

- review of inquiries, quotations and contracts,
- method selection, verification and validation,
- sampling,
- handling with the testing objects,
- technical records,
- calculation of measurement uncertainty,
- confirmation of the results usability,
- presentation of test results,

- complaints,
- if the work is inconsistent with the requirements,
- data supervision [16].

The assessment of the Testing Laboratory in 2019 confirmed that the requirements of the new standard were met and allowed for the extension of the scope of accreditation to include test for the construction industry in testing the mechanical properties of steel bars, wires, wire rods and meshes for concrete reinforcement.

The current certificate of the Testing Laboratory is presented below (Fig. 4), and full scope of accreditation can be found at the link http://komag.eu/badania/laboratorium-badan.


POLSKIE CENTRUM AKREDYTACJI
POLISH CENTRE FOR ACCREDITATION
Sygnatariusz EA MLA
EA MLA Signatory
CERTYFIKAT AKREDYTACJI
LABORATORIUM BADAWCZEGO
ACCREDITATION CERTIFICATE OF TESTING LABORATORY
Nr AB 039
Potwierdza się, że: / This is to confirm that:
INSTYTUT TECHNIKI GÓRNICZEJ KOMAG
ul. Pszczyńska 37, 44-101 Gliwice
LABORATORIUM BADAŃ
ul. Pszczyńska 37, 44-101 Gliwice
spełnia wymagania normy PN-EN ISO/IEC 17025:2018-02
Akredytowana działalność jest określona w Zakresie Akredytacji Nr AB 039
Akredytacja pozostaje w mocy pod warunkiem przestrzegania wymagań jednostki akredytującej określonych w kontrakcie Nr AB 039
Akredytacji udzielono dnia 31.10.1995 r.
DYREKTOR POLSKIEGO CENTRUM AKREDYTACJI
LUCYNA OLBORSKA
Warszawa, dnia 23 maja 2019 roku

Fig. 4. Current accreditation certificate of the testing laboratory [2019]

This year, another accreditation cycle ended in May, and therefore in February this year the Polish Centre for Accreditation re-assessed the competences of the Testing Laboratory.

6. Conclusions

Over 25 years of accreditation; The Research Laboratory has performed approximately 3,500 accredited tests of all types of construction products, contributing to the improvement of work safety both in the underground of mines as well as in other industries.

Initially, mainly powered supports and their components were tested, while in recent years the scope of testing is not limited to tests for the mining industry, but also covers other areas, e.g. construction industry.

References

[1] PN-EN ISO/IEC 17000:2020-12 Ocena zgodności – Terminologia i zasady ogólne (Conformity assessment – Vocabulary and general principles)

[2] pca.gov.pl/akredytacja/akredytacja/korzyści-z-akredytacji [accessed: 28.10.2020]

[3] EN 45001:1993 General criteria for the operation of testing laboratories

[4] ISO/IEC GUIDE 25:1990 General requirements for the competence of calibration and testing laboratories

[5] EN 45011:1993 General requirements for bodies operating product certification systems

[6] Tymczasowe wymagania, wytyczne konstruowania oraz prowadzenia badań laboratoryjnych i prób eksploatacyjnych obudów zmechanizowanych dla dopuszczenia typu do produkcji i stosowania, Katowice, grudzień 1994

[7] Wymagania konstrukcyjne i wytrzymałościowe dla obudów zmechanizowanych, Gliwice, listopad 1998

[8] PN-G-50041:1994 Ochrona pracy – Obudowy ścianowe zmechanizowane – Wymagania bezpieczeństwa i ergonomii (Work protection in mining industry – Powered roof supports – Safety and ergonomics requirements)

[9] PN-EN ISO/IEC 17025:2001 Ogólne wymagania dotyczące kompetencji laboratoriów badawczych i wzorcujących (General requirements for the competence of testing and calibration laboratories)

[10] EN 1804-1:2004 Machines for underground mines - Safety requirements for hydraulic powered roof supports - Part 1: Support units and general requirements

[11] EN 1804-2:2004 Machines for underground mines - Safety requirements for hydraulic powered roof supports - Part 2: Power set legs and rams

[12] EN 1804-03:2008 Machines for underground mines - Safety requirements for hydraulic powered roof supports - Part 3: Hydraulic control systems

[13] Zając R., Zintegrowany system zarządzania Instytutu Techniki Górniczej KOMAG, Maszyny Górnicze 2010 nr 3-4

[14] Zając R., Akredytacja laboratoriów badawczych w zakresach elastycznych, Zarządzanie Jakością 2010 nr 3-4.

[15] PN-EN ISO/IEC 17025:2018-02 Ogólne wymagania dotyczące kompetencji laboratoriów badawczych i wzorcujących (General requirements for the competence of testing and calibration laboratories).

[16] Zając R., Podejście procesowe w zarządzaniu laboratorium badawczym w świetle zmienionych wymagań normy PN-EN ISO/IEC 17025: 2018-02, Maszyny Górnicze 2019 nr 2; DOI: 10.32056/KOMAG2019.2.8

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DOI: 10.32056/KOMAG2020.4.8

Innovative techniques and technologies for the mining industry – conclusions from the KOMTECH-IMTech 2020 Conference

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Keywords: conference, mining industry, work safety, innovativeness, mining machines, cyber-security, internationalization

Słowa kluczowe: konferencja, górnictwo, bezpieczeństwo pracy, innowacyjność, maszyny górnicze, cyberbezpieczeństwo, internacjonalizacja

Abstract:

A review of selected papers, presented during the 21st International Scientific-and-Technical Conference KOMTECH-IMTech "Innovative techniques and technologies for the mining industry in the aspect of safety, efficiency and reliability" are described in the article. During twelve conference sessions forty-four papers, concerning work safety in the mining industry, minerals' extraction systems, state-of-the-art control, monitoring and diagnostic systems of machines and equipment, cyber-security, new solutions of hydraulic systems, new generation, highly efficient haulage assemblies for longwall systems, hoisting machines, a recovery of minerals, preparation systems, an improvement of mining personnel's qualifications and an internationalization of the Polish circum-mining sector, were presented. Special attention should be paid to the special session oriented onto a presentation of information about a roadway driving technology with use of a Bolter Miner, and also onto debates concerning the mining industry in future as well as a demand for innovations from the future mining industry.

Streszczenie:

W artykule przedstawiono przegląd wybranych referatów wygłoszonych podczas 21. Międzynarodowej Konferencji Naukowo-Technicznej KOMTECH-IMTech „Innowacyjne techniki i technologie dla górnictwa w aspekcie bezpieczeństwa, efektywności i niezawodności". Podczas dwunastu sesji konferencyjnych zaprezentowano czterdzieści cztery referaty dotyczące bezpieczeństwa pracy w górnictwie, systemów wydobywczych, nowoczesnych systemów sterowania, monitoringu oraz diagnostyki maszyn i urządzeń, cyberbezpieczeństwa, nowych rozwiązań układów hydraulicznych, nowej generacji systemów posuwu wysokowydajnych kompleksów ścianowych, maszyn wyciągowych, odzysku minerałów, systemów przeróbczych, poprawy kwalifikacji pracowników górnictwa oraz internacjonalizacji polskiego sektora okołogórniczego. Na szczególną uwagę zasługuje tematyka sesji specjalnej, ukierunkowanej na prezentację technologii drążenia z zastosowaniem kombajnu urabiająco-kotwiącego Bolter Miner, a także debaty na temat górnictwa przyszłości oraz potrzeby innowacyjności w aspekcie przyszłości górnictwa.

1. Introduction

Since 1999 the KOMAG Institute of Mining Technology has organized international scientific-and-technical conferences from the KOMTECH cycle, oriented onto innovative techniques and technologies for the mining industry in the aspect of safety, efficiency and reliability. For two years the conference name has been KOMTECH-IMTech. Due to severe pandemic restrictions, caused by the SARS-CoV2, the conference organizers decided to implement an electronic form and offer all the presentations and debates on line. The conference covered a broad spectrum of scientific, research and technical subjects, enabling an exchange of knowledge and professional experience among representatives of academia, research institutes, producers of mining machines and equipment as well as end-users from mines. In total about 4000 viewers participated in the conference, watching presentations and asking many interesting questions. Such a big number of participants can be regarded as a real success, considering the circumstances and a new form of this cyclic conference. The conference was bilingual: in Polish with a simultaneous translation into English. It is worth mentioning that 830 people followed the sessions in the English version. Foreign participants were from Australia, Chile, India, Romania and Slovenia. The conference co-organizer was Jastrzębska Spółka Węglowa S.A. (Jastrzębska Coal Company J.S.C) which was responsible not only for the technical side of this challenging undertaking at a big scale, but its representatives also gave an extremely valuable scientific input in a form of interesting and stimulating presentations. One of the sessions concerned widely understood hydraulic issues. The main presenters from the INOE 2000 – Subsidiary Hydraulics and Pneumatics Research Institute in Bucharest (Romania) concentrated on predictive maintenance of hydrostatic drive systems, tests of flow and pressure pulses in oscillating hydraulic intensifiers, monitoring proportional directional valves in hydraulic drive systems and on a modernization of the Fluid Power field through an integration of intelligent equipment.

The KOMTECH-IMTech 2020 Conference was initially planned as one of the key events, enabling to celebrate the 70th Anniversary of the KOMAG activity. Two papers, included in the Conference programme, presented the role of the Institute in shaping work safety in hard coal mines and its achievements in the field of environmental protection over the years 1950-2020. Special attention was paid to the research projects' results oriented onto a creation of safe, reliable design solutions of mining machines and equipment as well as of safe work environment. There was also some information about innovative technical solutions, which obtained awards and were distinguished by domestic and foreign experts at fairs, exhibitions and competitions in Poland and abroad.

2. Review of papers

2.1. Session 1 – Technology of driving roadway workings with use of a Bolter Miner

The subject-matter of this inaugural session concerned roof-bolting technology – a case study at the Budryk Mine. The presentations were oriented onto a design of the roof-bolting supports, a summary of a research project with special attention paid to challenges, experience and conclusions as well as to a presentation of experience, resulting from using a roof-bolter for cutting hard rock.

The other part of the session consisted of two debates on mining in future and also on the demand of innovations and the future of the mining industry. It was very interesting to hear opinions of experts representing Jastrzębska Spółka Węglowa S.A., Tauron Wydobycie S.A., Wyższy Urząd Górniczy, Lubelski Węgiel BOGDANKA S.A., Główny Instytut Górnictwa, Politechnika Śląska, FAMUR S.A., CARBOAUTOMATYKA S.A., Polska Technika Górnicza S.A. and Instytut Chemicznej Przeróbki Węgla. The debates were moderated by Prof. Dariusz Prostański and Dr. Bartosz Polnik from the KOMAG Institute of Mining Technology.

2.2. Session II – Cyber-security

In this session the papers and presentations covered the IT/OT cyber-security system based on CP4S Qradar and the system of PAM class, the Journey to Cloud containing a question, if it is a must to migrate to a public cloud, the IBM Cloud Pack for Applications – the platform of innovativeness and the system Ewidencja EX as a state-of-the-art tool of an efficient aid in the Asset Management Process at the Jastrzębska Spółka Węglowa S.A.

2.3. Session III – State-of-the-art control, monitoring and diagnostic systems of machines and equipment

The main subjects of the session included a replacement of control systems due to an implementation of digital inverter drive technology in opencast mining machines, principles of using simple electrical equipment in intrinsically safe circuits and also a dissipated monitoring and diagnostic system to be applied in photovoltaic power-stations. In the case of digital inverter drive technology the issues concerned problems with starting opencast machines supplied with AC drives equipped with frequency converters and voltage inverters, built on the basis of IGBT transistors controlling induction motors [11, 12]. The control algorithms implemented digital structures of control systems with PID controllers. Incorrect settings caused vibrations during a machine operation, which were the reasons of cracks in machine components, forcing downtimes due to mechanical damages. The presentation on using simple electrical equipment in intrinsically safe circuits enabled to get acquainted with conditions and requirements which these devices must meet, if they are to be used in intrinsically safe systems [7, 8, 25]. The experience of the KOMAG Division of Attestation Tests, Certifying Body confirmed problems with incomplete or incorrect documentation which is supplied in the case of simple electrical equipment.

2.4. Session IV – Work safety in the mining industry

The session started with a paper on the role of the KOMAG Institute of Mining Technology in shaping work safety in hard coal mines [6, 15, 16, 17, 22]. Then the subject of an improvement of work safety and a communication of small working groups, using the VR environment network, was presented and the information about the AutoInvent – an innovative system, aiding mine surveyors, increasing work safety and efficiency, was given.

The role of the KOMAG Institute in shaping work safety in hard coal mines was highlighted. Special attention was paid to the results of scientific, research and development projects concerning safe, reliable and operator-friendly solutions of machines and equipment for extracting and processing minerals, mainly hard coal. A creation of safe work environment due to an implementation of diagnostic and monitoring devices as well as sophisticated trainings of machinery operators contributed to an awerness increase as regards work safety. It should be highlighted that work safety in mines has always been one of the Institute's top priority objectives. An indicator of fatal accidents for one million tons of extracted coal, reflecting the safety level was 8.64 in 1945. For a comparison it is worth giving these indicators for the Polish mines in the years: 2018 and 2019, i.e. 0.24 and 0.21 respectively.

2.5. Session V – New solutions of hydraulic systems

This session was dominated by scientists and researchers from the INOE 2000 – Subsidiary Hydraulics and Pneumatics Research Institute in Bucharest, Romania. Their presentations were oriented onto a modernization of Fluid Power field through an integration of intelligent equipment, monitoring proportional directional valves in hydraulic drive systems, predictive maintenance techniques enabling a reduction of hydrostatic drive systems' wear and an assessment of flow and pressure pulses in oscillating hydraulic intensifiers.

As regards a modernization of Fluid Power field it was possible to get detailed information about two smart devices designed by the IHP, i.e. a proportional directional valve and a digital actuator as well as about two smart laboratory stands, one of servo-valves and one of digital hydraulic cylinders. An introduction of sensors, electronic blocks and software algorithms contributed to an improvement of functional performance of machines. In the case of an incorrect operation the local smart device provides error codes using various communication protocols: RS 232, CAN, Fieldbus and Modbus. The paper concentrated on a structure of a monitoring and diagnostic module for monitoring proportional directional valves in hydraulic drive systems [3, 5]. It should be highlighted that predictive maintenance techniques play a very important role in the process of identifying wear of technical systems, enabling to avoid failures [4]. Using three methods of predictive maintenance, namely infrared tomography, vibration analysis and oil analysis, the authors presented the results of their research work and tests on an example of hydraulic pumps [10]. In the case of an assessment of flow and pressure pulses in oscillating hydraulic intensifiers (miniboosters) the authors presented a test stand construction, enabling to determine flow and pressure pulse characteristics, their impact on a uniform displacement of hydraulic cylinders' load as well as functional characteristics in dynamic and stationary operational modes of pumping units with embedded miniboosters [20, 27].

The latest paper in this session concerned an optimization of a hydraulic system for a briquetting machine.

2.6. Session VI – Mining systems

The programme of this session included five papers on various mining and geological subjects such as temporary powered roof supports to be used in a development of roadway workings, a system for a withdrawal of a powered roof support unit from the row and its transportation from the working in the process of a longwall liquidation, an analysis of wear of powered roof support elements after a long period of operation in the aspect of their technical condition assessment, an analysis of mining-and-geological conditions in longwalls from the point of view of introducing pressure monitoring of powered roof supports and a strength analysis of cycloidal gear wheels system with a new concept of power transmission. In the case of temporary powered roof supports, applied in the process of roadway development, the author presented some reasons which cause that they are not commonly used worldwide [9, 14]. However, there are attempts to develop new solutions of temporary powered roof supports, to be used in roadways, as they give a chance for increasing efficiency of roadway development operations.

An innovative system for a withdrawal of powered roof support units from a row and their transportation from the working during the longwall liquidation was presented. Three variants of this system were discussed in detail [2]. Two protective roof support units, connected to a special platform, using the beams of the advancing system, are used in this solution. The platform enables a rotation of the withdrawn roof support. Some advantages and disadvantages of the system are shown [13]. In the case of wear of powered roof support units, after a long period of operation, some information was given about methods of technical assessments, used at the KOMAG Laboratory of Tests [18, 21]. The results of thickness measurements of metal sheets, of thicknesses of canopy brace, of gob shield and base are presented. The measurements of openings diameters of the main articulated pairs were analyzed as well. The percentage loss of metal sheets thicknesses in the result of corrosive and abrasive wear was determined. It was found that despite the loss in metal sheets thicknesses and an increase in sizes of bolt connections, the roof support units passed the strength and fatigue tests at the KOMAG accredited laboratory [24, 26].

2.7. Session VII – KOMTRACK – a new generation haulage assembly of highly productive longwall systems

The session consisted of seven presentations, six of them concerned the KOMTRACK system. Detailed information about the design of an innovative haulage assembly of highly productive longwall systems, in the result of the KOMTRACK research project, was given by researchers from the KOMAG Institute who developed this solution. Then the results of functional tests were discussed. It was interesting to get acquainted with analyses of kinematic and dynamic cooperation of a friction pair in the case of the KOMTRACK assembly. The information about the material, manufacturing technique, tooling and casting of the haulage segments of a shearer was also given. This block of presentations was ended with a programme of tests in underground conditions of the Piast Mine.

The seventh paper in this session concerned a review of methods for a recognition of coal and rock interfaces to automatize a longwall shearer operation [23, 28]. One of the key issues, faced by mines at present, is how to increase productivity of longwall faces. It is obvious that R&D projects should be focused on a shearer which plays a crucial role in the production process of coal. An accurate recognition of the shearer’s cutting pattern is an indispensable condition enabling to develop a system for automatization of coal extraction from a longwall face [1]. A review of the methods of coal and rock interface identification, together with a presentation of advantages and disadvantages of each method, was an interesting contribution to the subject-matter of the KOMTECH-IMTech Conference.

2.8. Session VIII – Internationalization of the Polish circum-mining sector

This session was oriented onto a presentation of the Polish mining sector expansion possibilities. Representatives of the KOMAG Institute developed a concept of a small opencast gold mine and they shared their experience with the Conference participants.

2.9. Session IX – Hoisting machines

The session was started with metrological aspects of measurements of an elevator installation in a mine shaft. It was indispensable to select an appropriate method for measuring real stresses in the shaft reinforcements, generated by the elevator cabin. Implemented technical solutions and operational parameters of built-in transportation devices for a vertical men-riding in the Regis Shaft of the Wieliczka Salt Mine were discussed [29]. Then a use of magnetometry for diagnostics of electric elevators, used in the mining industry on the example of the Regis Shaft, was presented.

Innovative solutions of the MWM Elektro Company, for use in mine shaft winders, attracted an attention of a big number of the Conference participants. The session ended with a presentation of technological hoisting machines used for an execution of specialistic shaft operations.

2.10. Session X – Recovery of minerals

This session was dominated by researchers from the KOMAG Institute of Mining Technology who shared their knowledge and scientific experience related to a recovery of coal small grains from post-mining waste, using a technology of an autogenous suspension bed, to a determination of contents of rare earth elements in hard coal and in power station waste, to a new design solution of the radial thickener Ø30 of KOMAG type and to tests of rare earth elements contents in selected materials.

2.11. Session XI – Preparation systems

The session started with a presentation of 70-year activity of the KOMAG Institute of Mining Technology for the benefit of environmental protection [6,15]. Special attention was paid to the projects oriented onto dust and noise control, but in particular onto an environmental protection of post-mining sites and other areas badly affected by the industry. A review of research projects included KOMAG achievements in the scope of reducing noise emissions to the environment such as acoustic baffles and active acoustic silencers. The awards and distinctions, obtained by KOMAG and its researchers at various exhibitions, fairs and competitions, confirm an innovative character of these technical solutions.

A very interesting presentation concerned new implementations of jigs for coking and steam coal, developed in a collaboration with Carbo-Eco and Fugor Companies. The Company Nord Napędy Polska gave a presentation on its activity in the domain of preparation systems and the BEFARED J.S.C. presented its solutions of preparation machines and equipment.

2.12. Session XII – Development of qualifications in the mining industry

The last session of the Conference was dedicated to the state-of-the-art training systems offered by JSW Szkolenie i Górnictwo (JSW Training and Mining), Ltd.

The first presentation in this session concentrated on the sectoral frame of qualifications in the mining industry. Then a role of Virtual Reality in a process of employees' professional development was discussed in the aspect of market qualifications for the mining sector.

The session was finished with a summary of the KOMTECH-IMTech 2020 Conference made by Prof. Dariusz Prostański, Director of KOMAG Institute of Mining Technology and Dr. Artur Dyczko, Vice-President of Jastrzębska Spółka Węglowa S.A. (Jastrzębska Coal Company, J.S.C.)

3. Summary and conclusions of the KOMTECH –IMTech 2020 Conference

The summary and conclusions were expressed not only by the Conference organizers, but also by two distinguished experts: Prof. Stanisław Prusek, Director of GIG – Central Mining Institute and Mr. Artur Wasil, Director of Bogdanka Mine.

Prof. Prostański thanked all the Conference participants, but in particular the presenters of the submitted papers. He expressed his gratitude to Dr. Dyczko and his Team for such a fruitful collaboration in organizing the Conference. Everybody spoke highly about the session on Bolter Miner technology. Prof. Prusek gave some information about mining and geological problems experienced during an implementation of this technology in the Budryk Mine. Prof. Prostański declared that KOMAG was ready to solve problems related to mechanical aspects of this technology. Mr. Wasil expressed an opinion that it was a very good idea to have one session dedicated exclusively to a Bolter Miner. Dr. Dyczko highlighted the fact that the Conference presented the state-of-the-art mining knowledge offered in an electronic, convenient and safe form. Prof. Prusek mentioned the achievements of the Bogdanka Mine in implementing the plow technology. Afterwards Mr. Wasil expressed his interest in implementing innovative technologies, including a Bolter Miner technology. This interest also concerns electromobility as in his opinion a mine is a logistic enterprise. All these actions will contribute to an increase of a production efficiency. Both KOMAG and GIG offered their assistance and support in implementing innovative technologies; GIG as regards rock mechanics and KOMAG in the scope of mechanical, mechatronic and hydraulic issues.

Mr. Wasil thanked for the words of appreciation, addressed to him and to his employees. He said that Bogdanka was ready to follow the steps, undertaken by the JSW S.A. as regards innovative technologies and a vision of a future development. Unfortunately, the pandemic of SARS-CoV2 obstructed a realization of ambitious development plans, concerning a search of methods for increasing the production efficiency, following the example of the British mining industry. Looking for best practices, it is indispensable to eliminate physical work to the biggest possible extent and to test a behaviour of the rock mass in a more precise way. So far there has been insufficient information, so an installation of monitoring devices seems to be essential. Horizontal pressure is a real issue as well as the issues of bed separation. Hazardous situations should be avoided any time. A serious engineering work is required to change an approach to the rock mass. It is absolutely necessary to strengthen the rock mass to increase a functionality of roadways. Some problems with a horizontal deformation are experienced. In the case of a multi-seam extraction with use of bolting supports, there is no experience in the world. There are plans to apply a Bolter Miner in a 400-meter longwall face. It is also a challenge as regards a ventilation system. The participants of the discussion highlighted the role of collaboration from Lubin to Lublin via Jastrzębie. The Bogdanka Mine will announce its development strategy in a couple of days. Prof. Prusek expressed his opinion about testing the rock mass. So far these tests have been underestimated. Sometimes only one hole is drilled and general conclusions are drawn as regards the whole panel. In the JSW S.A. measurements of the stress tensor were taken and such measurements are planned for the Bogdanka Mine, too. According to the experience, gained in Poland so far, it has not been possible to achieve an advance similar to that in the USA or in Australia due to the faults in the seam. Roof bolting technology gives extremely positive effects in the case of a longwall face development, when a single seam extraction is conducted. One roadway can be developed with use of the roof-bolting technology and the other one- with use of standing supports.

The project at the Budryk Mine included testing of the rock mass, training, use of best materials and a precise execution of the jobs. Monitoring played a very important role. Plow faces have already been mentioned by the participants of this panel discussion. Both the Bogdanka Mine and the JSW S.A. are experienced in using this technology.

Prof. Prostański mentioned two devices, designed at the KOMAG Institute, the PCA haulage unit and the GAD suspended locomotive, both having very good operational parameters. Discussing the issue of increasing production efficiency, he informed about the project, realized by KOMAG in collaboration with the Central Mining Institute, concerning a transportation of workers with increased speed to achieve a longer effective work-time of miners.

Dr. Dyczko and Prof. Prostański thanked the participants of the discussion, all the presenters and such a big group of viewers.

References

[1] Alehossein H. Poulsen B.A.: Stress analysis of longwall top coal caving. International Journal of Rock Mechanics and Mining Sciences, 2010, 47.1: 30-41.

[2] Chase F., Worley P., Mc Comas A.: Longwall Shield Recovery Using Mobile Roof Supports. Lakeview Scanticon Resort and Conference Center, Morgantown, WV, USA, July 31-August 2007.

[3] Drumea P., Dumitrescu I.C., Hristea A., Chirita C.: Methods of Diagnosing Malfunctions in Hydraulic

Actuations. Proceedings of International Conference on Hydraulics and Pneumatics HERVEX 2016, pp. 212-217.

[4] Duffuaa S.O., Raoul A.: Planning and control of maintenance systems. Modelling and analysis. 2nd Edition, Springer 2015.

[5] Dutu I., Dumitrescu C., Matache G.: Diagnosis of Proportional Electro-Hydraulic Equipment Using Specific Virtual Instruments, The Romanian Review Precision Mechanics, Optics & Mechatronics, No. 43. 2013. pp. 98-101.

[6] Dyrektywa 2003/10/WE Parlamentu Europejskiego i Rady z dnia 6 lutego 2003 r. w sprawie minimalnych wymagań w zakresie ochrony zdrowia i bezpieczeństwa dotyczących narażenia pracowników na ryzyko spowodowane czynnikami fizycznymi i hałasem.

[7] Dyrektywa Parlamentu Europejskiego i Rady 2014/32/UE z dnia 26 lutego 2014 r. w sprawie harmonizacji ustawodawstw państw członkowskich odnoszących się do urządzeń i systemów ochronnych przeznaczonych do użytku w atmosferze potencjalnie wybuchowej. OJ Nr 96 z dnia 29.03.2014 r.

[8] Figiel A.: Wymagania dotyczące systemów sterowania. Maszyny Górnicze 2016. 3, pp. 45-53.

[9] Galvin J.M.: Ground Engineering – Principles and Practices for Underground Coal Mining. Springer International Publishing. Switzerland 2016.

[10] Hajianto M.R., Yulianto A.: Vibration analysis for monitoring the condition of hydraulic powerpack for underground mining supporting simulation at education and training unit of underground mining (ETUUM). American Journal of Engineering (AJER) 2017 6(5). pp. 123-129 e-ISSN: 2320-0487 p-ISSN: 2320.

[11] Jabłoński M., Anuszczyk J.: Współczesne algorytmy sterowania maszyn górnictwa odkrywkowego na przykładach aplikacyjnych. VII Międzynarodowy Kongres Górnictwa Węgla Brunatnego 2011 „Węgiel Brunatny-Energia-Rozwój".

[12] Jabłoński M.: X Konferencja Naukowo-Techniczna: Innowacyjne Maszyny i Technologie – Efektywność 2014: Rozwój innowacyjnych technik sterowania systemów napędowych, monitorowania bezpieczeństwa i użytkowania maszyn a trendy rozwojowe maszyn górnictwa odkrywkowego w Polsce.

[13] Kania J., Szweda S., Szyguła M.: Analiza procesu wybudowy sekcji obudowy zmechanizowanej z wyrobiska ścianowego w aspekcie bezpieczeństwa. Maszyny Górnicze 2018. 3, pp. 24-34.

[14] Korski J.: Zastosowanie kombajnów typu Bolter Miner w warunkach polskich kopalń. Innowacyjne techniki i technologie – bezpieczeństwo – efektywność – niezawodność. Instytut Techniki Górniczej KOMAG 2018.

[15] Lutyński A.: Zagrożenia metanem, pyłem i hałasem występujące w zakładach przeróbki mechanicznej kopalń węgla kamiennego. Instytut Techniki Górniczej KOMAG 2016. ISBN 978-83-60708-96-5.

[16] Malec M., Stańczak L.: A Generation of Innovative Technical Ideas and Solutions as an Important Component of the KOMAG Strategy. MAPE 2020, Volume 3, Issue 1. pp. 248-262.

[17] Malec M., Stańczak L.: Innovative Mining Techniques and Technologies – Review of Selected KOMTECH-IMTech 2019 Conference Proceedings – Part 2. Mining Machines 2020. 2, pp.13-25.

[18] Markowicz J.: Analysis of impact of welded joint damages and corrosion in powered roof support components on their operational safety. Archives of Mining Sciences 2010. 55(4), pp. 799-826.

[19] Mobley R.K.: Maintenance Engineering Handbook. 7th Edition. McGraw-Hill. Section 7. Instruments and Reliability Tools 2008.

[20] Popescu T.C., Chirita P.A., Popescu A.: Increasing Energy efficiency and flow rate regularity in facilities, machinery and equipment provided with high operating pressure and low flow rate hydraulic systems. Proceedings of 18th International Multidisciplinary Scientific GeoConference SGEM 2018. 18, pp. 401-408. DOI: 10.5593/sgem2018/4.1.

[21] Praca zbiorowa pod red. Jaszczuk M., Markowicz J.: Parametryczna metoda oceny stanu technicznego sekcji obudowy zmechanizowanej. Wyd. Pol. Śl. 2011. ISBN 9788373358206.

[22] Prostański D.: Development and research work in the air-water spraying area for reduction of methane and coal dust explosion hazard as well as for dust control in the Polish mining industry. September 2018. IOP Conference Series: Materials Science and Engineering 427 (1): 012026. DOI: 10.1088/1757-

899X/427/1/012026.

[23] Ralston J.C., Strange A.: An Industrial Application of Ground Penetrating Radar for Coal Mining Horizon Sensing, Conference ISAP 2015, Hobart, Austraila.

[24] Szweda S., Szyguła M., Mazurek K.: Czynniki wpływające na postać konstrukcyjną i parametry techniczne sekcji ścianowej obudowy zmechanizowanej. Część 1. Czynniki naturalne, techniczne i konstrukcyjne, ITG KOMAG, Gliwice 2016. ISBN 978-83-65593-01-6.

[25] Ustawa z dnia 12 grudnia 2003 r. o ogólnym bezpieczeństwie produktów (tj. Dz. U. z 2016 r., poz. 2047).

[26] Winkler T., Tokarczyk J.: Multi-Criteria Assessment of Virtual Prototypes of Mining Machines. Proceedings of the World Congress on Engineering and Computer Science 2010, vol. 2, WCECS 2010, October 20-22 2010, San Francisco USA. ISSN 2078-0958. pp. 1149-53.

[27] Zardni B., Cillo G., Zavadinka P., Hanusovsky J., Borghi M.: Design and modelling of a cartridge pressure amplifier. Proceedings of the ASME/JSME/KSME Joint Fluids Engineering Conference 2019, vol. 1, article No. UNSP Voo1ToAo43, DOI: 10.1115/AJK Fluids 2019-5474.

[28] Zhang G., Wang Z., Zhao L.: Recognition of rock-coal interface in top coal caving through tail beam vibrations by using stacked sparse autoencoders. Journal of Vibroengineering 2016. 18(7). ISSN 1392-8716.

[29] Zuski Z., Czyżowski J.: Transport pionowy dźwigami osobowo-towarowymi w Kopalni Soli Wieliczka – Zabudowa i uruchomienie dźwigów osobowo-towarowych w górniczym szybie „Regis”. VIII Międzynrodowa Konferencja; Bezpieczeństwo Pracy Urządzeń Transportowych w Górnictwie. Ustroń 2012. pp. 45-61. ISBN 978-83-929335-9-5.