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TESTS ON HYDRAULIC PROPS EQUIPPED WITH YIELD VALVES AT DYNAMIC LOAD MODELLING A ROCK BURST

BADANIA STOJAKÓW HYDRAULICZNYCH Z ZAWORAMI PRZELEWOWYMI PRZY OBCIĄŻENIU DYNAMICZNYM WYWOŁANYM TĄPNIĘCIEM

The article presents the results of tests on SHC-40 hydraulic props equipped with two types of valve blocks: standard (with spring steel cylinder) and BZG-2FS (with gas spring). The research was conducted using impact mass of 4,000 kg and with extreme dynamic load of free fall impact mass of 20,000 kg released from different heights *h*. The dynamic tests involved a camera with the speed of image capture up to 1,200 frames/sec, which made it possible to register the stream of liquid at the dynamic load and to determine the valve opening time.

The study conducted on SHC-40 NHR10 props equipped with two types of valve blocks: a standard and the BZG-2FS fast acting relief, showed that the prop with the BZG-2FS block is more suitable and more effective in the case of areas with high risk of mining tremors and rapid stress relief of a seam.

Research methodology developed in the Central Mining Institute combines digital recording technique of pressure in a prop and fast registration of the images, and allows to acquire more accurate analysis of dynamic phenomena in the prop during testing.

Keywords: individual roof support; hydraulic prop; yield valves; safety valves

W artykule przedstawiono wyniki badań stojaków hydraulicznych obudowy indywidualnej typu SHC-40 wyposażonych w dwa typy baterii zaworowych: standardową (ze sprężyną stalową walcową) i BZG-2FS (ze sprężyną gazową). Podczas badań stojak obciążany był dynamicznie za pomocą swobodnego spadku bijaka z różnych wysokości. Badania wykonano przy użyciu bijaka o masie 4000 kg i przy maksymalnym obciążeniu dynamicznym za pomocą bijaka o masie 20000 kg. Testy dynamiczne rejestrowane były kamerą z prędkością do 1200 klatek na sekundę, co pozwoliło na zarejestrowanie prędkości propagacji strumienia cieczy i określenie czasu otwarcia zaworu.

Badania przeprowadzono na stojakach typu SHC-40 NHR10 o podporności nominalnej 400 kN. Wykazały one, że stojak wyposażony w baterię ze sprężyną gazową ma lepsze właściwości do dyssypacji energii udaru od stojaka z baterią stalową walcową. Spowodowane jest to tym, że bateria gazowa typu BZG-2FS wykazuje krótki czas otwarcia (8 ms) oraz ma dużą przepustowość (683 l/min).

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Metodologia badań stojaków obudowy indywidualnej typu SHC opracowana w Głównym Instytucie Górnictwa pozwala na dokładną analizę pracy stojaka przy obciążeniu dynamicznym za pomocą tzw. młota spadowego, w połączeniu z cyfrowymi pomiarami ciśnienia w cylindrze stojaka oraz analizą wizyjną filmów zarejestrowanych podczas testów.

Słowa kluczowe: obudowa indywidualna; stojak hydrauliczny; zawór przelewowy; zawór bezpieczeństwa

1. Introduction

An individual mining roof support is a set of elements which support, prop or protect a roof or a sidewall of a drift. The elements do not move or dislocate spontaneously (in contrast to powered roof supports) (Chudek & Pach, 2002).

One of the basic elements of the individual mining support are its props (Jacobi, 1981; The small mining lexicon, 1988) – direct or indirect support of the working's roof (Pytlik, 2013). The props fall into the following categories:

- individual – a construction element in a form of a pillar that carries the pressing pressure,
- with extensions – composed of several structural elements (which can be expanded to a certain height by sliding or fall of an upper prop), i.e.:
  - a lower prop – the bottom part of the prop,
  - an upper prop – the top part of the prop,
  - a lock – used to reinforce the position of the upper prop on the lower prop, adjust the height of the prop and to set its nominal or working load-bearing capacity.

Currently, the most commonly used are SHC centrally powered hydraulic props and SV friction props (two straight sections of a V profile connected by two clamps; or SVt and SVtw types – with three or four clamps) and VALENT props (with a wedge lock). Also widely used are props equipped with locks based on two pipes slid into one another.

These props (VALENT and SHC) are also successfully used to support and stabilization the portal-skeletal support of crossing galery (Rotkegel, 2010) during its execution. This is because of their high carrying capacity and considerable length

Examples of SHC props used in a mining working are shown in Fig. 1.

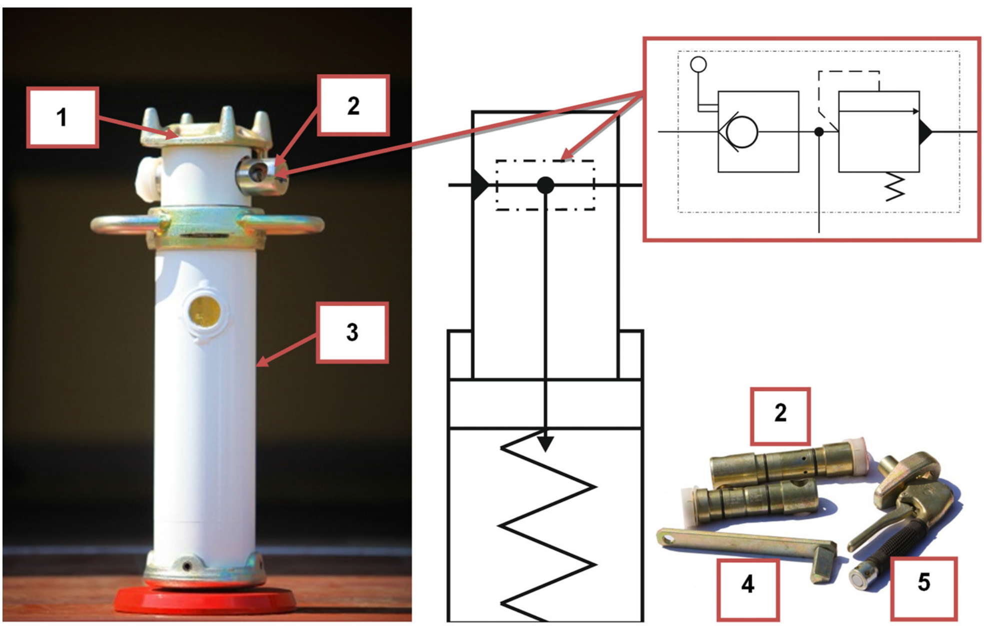
Fig. 1. SHC props supporting a gallery's roof in the area of the intersection of longwall excavation

Frequent cases of damage due to dynamic loading are registered during the operation of SHC props. This phenomenon occurs often due to too small capacity of conventional valve blocks used for SHC props. Requirements and test methods for hydraulic props mounted in an individual roof support are set out in the standard (PN-G-15536:2013-06). PN-G-15535:1998 standard (Mining individual support – Valve blocks of centrally powered props – Requirements) determines the minimum capacity of the valve block (for a yield valve) with a flow rate of 60 l/min. In practice, valve blocks available on the market exceed the standard flow rate by only a few percent.

The valve block's capacity to reduce the pressure in the under piston space is not only determined by its flow capacity, but rather by the opening time of the yield valve, as well as its closing time aimed at preventing an excessive decrease in load-bearing capacity of the SHC prop. These factors are especially significant during the SHC prop operation in terms of mining tremors and rock bursts. The comprehensive analysis of support damages due to rock bursts in conditions of Polish hard coal mines was presented by Prusek and Masny (2015).

Currently, the SHC props, in order to increase the dynamic resistance, are equipped with additional yield valves (e.g. fitted in the bottom of the piston) or fast acting safety valve blocks (Pytlik & Rabsztyn, 2011; Pytlik et al., 2012) installed in place of a traditional valve block, but with increased acting speed and capacity (Gwiazda, 1997; Klishin & Tarasik, 2002). In contrast to the yield valves installed at the bottom of the SHC prop's piston, the fast acting safety valve blocks mounted in the piston or the cylinder (both structures are popular) allow to easily control the tightness of the prop and replace the block with a new one in a case of damage of failure.

A diagram of the SHC prop, valve block and prop components are presented in Fig. 2.



a b c

Fig. 2. A diagram of a SHC prop, a valve block and prop components: a – a SHC prop; b – a diagram of a SHC prop and a valve block; c – prop components

Explanations for Fig. 2:

1. A piston rod (upper prop) with a crown head
2. A valve block
3. Prop's cylinder (lower prop)
4. A lever for opening the yield valve
5. A supply gun

The Central Mining Institute developed a BZG-2FS fast acting safety valve block equipped with a gas spring, which operates faster, and has greater flow capacity than typical valve blocks (Pytlik & Rabsztyn, 2011; Pytlik et al., 2012; Pytlik, 2015). The new block design is based on the original structural solution submitted by GIG for patent protection, based on the so-called gas spring, which unlike conventional cylindrical steel springs (prone to rapid corrosion that affects the change in their characteristics) allows to significantly improve performance characteristics of valves and millisecond opening times of the safety valve. With the new method of sealing of a cone-seat system of the valve for varying clamping force in proportion to an increase in load, the research team was able to acquire very good and satisfactory level of tightness of the valve. The design of the valve block is protected by patents registered at Polish Patent Office, no. P.388584, titled: "Valve block for the hydraulic prop" and P.387582 titled: "Gas spring".

The article presents the results of tests on SHC-40 hydraulic props equipped with two types of valve blocks: standard and BZG-2FS. The research was conducted using impact mass of 4,000 kg and with extreme dynamic load of free fall impact mass of 20,000 kg released from different heights *h*.

Dynamic resistance tests were carried out on SHC-40 NHR10 props with nominal load-bearing capacity of 400 kN. The dynamic tests involved a camera, using a computer program TRACKER (Michalak et al., 2012), with the speed of image capture up to 1,200 frames/sec, which made it possible to register the stream of liquid at the dynamic load and to determine the valve opening time.

The test stand for the dynamic load (Fig. 3) allows to examine various elements with maximum dimensions of 5×2×6 m (height×width×length) by direct impact of mass (450÷20,000 kg). The maximum impact energy is 500 kJ, and the initial spreading force of hydraulic props can be up to 2 MN. The test facility is equipped with cross-bars of 200, 1,600, 3,300 and 6,600 kg, which allow the initial and static load test during the test. The tests in the test facility include both hydraulic props of the powered roof support as well as hydraulic and friction props of the individual roof support. With additional frames and tools, mining anchors and chains can be examined and tested in the test bench. The research also included development of a new methodology of research in the form of a "box of rocks" test with dynamic load, which enables to specify dynamic load rating and formability of membranes, spray coatings and various mining linings, i.e. steel welded mesh and plastic mesh. The test method for shotcrete, membranes and mesh linings as proposed in the box of rocks test, is closer to the actual operation in the mining excavation, compared with the tests set out in the standards. This method also provides the opportunity to investigate the cooperation of the membranes or spray coatings with rock substrate. Simulations of such cooperation using various advanced computational algorithms were presented by Prusek et al. (2014).

2. Methodology and resarch results

Tests on the SHC hydraulic prop dynamically impacted were conducted at the dynamic test facility (direct impact of mass) presented in Fig. 3.

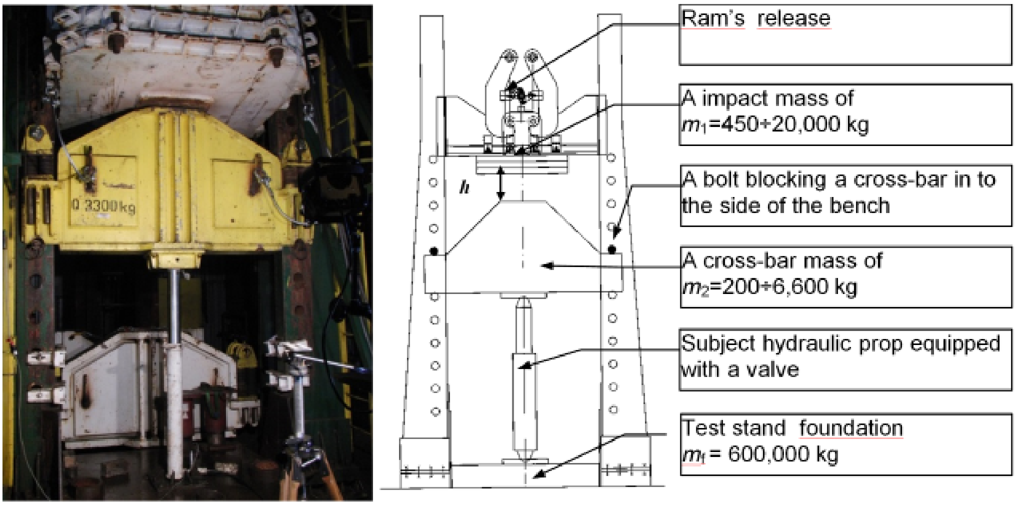


Fig. 3. Dynamic test facility

Dynamic test facility were carried out on SHC-40 NHR10 props with nominal load-bearing capacity of 400 kN. The prop before the test was spread between the base of the test stand and a cross-bar to a height of 2 m. The tests included cylinders of the props with internal diameter of ϕ = 120 mm.

Basic technical parameters of the BZG-2FS valve block are shown in Table 1.

TABLE 1

Technical parameters of the tested valve blocks

Type	Nominal (average) capacity Q_N, l/min	Maximum flow capacity (momentary) Q_{MAX}, l/min	Opening time of the valve, ms	Nominal pressure p_N, MPa
BZG-2FS	350	680	8	35
standard block	60	no data	10	35

The test of the prop with the valve block was based on its dynamic load by a direct impact of mass, the prop was spread between a cross-bar and post's base. The record of the pressure p of the fluid in the space under the piston was carried out with sampling frequency of 9.6 kHz, using a P3MBP pressure sensors (accuracy class 0.2) and a MGCplus amplifier system (accuracy class 0.03) produced by HBM.

V_o velocity of the impact mass freely falling from height h on a cross-bar in the time of the impact is calculated by the following formula:

$$v_o = \sqrt{2gh} \tag{1}$$

where:

g — gravitational acceleration, m/s^2,
h — impact mass release height, m.

Velocity v_u of m_1 (impact mass) and m_2 (cross-bar mass) is calculated applying the Momentum Principle:

$$m_1 \cdot v_o = (m_1 + m_2) v_u \tag{2}$$

therefore:

$$v_u = v_o \frac{m_1}{m_1 + m_2} \tag{3}$$

Velocity v_u is adopted as an initial velocity of prop's load, therefore, it is applied to the formula of kinetic energy E_k of combined masses m_1 and m_2:

$$E_k = \frac{1}{2}(m_1 + m_2) v^2{}_u \tag{4}$$

Finally, after substituting the formula (4) by (1) and (3) the amount comes to:

$$E_k = \frac{m_1^2}{(m_1 + m_2)} g \cdot h \tag{5}$$

The momentum M (the traditional symbol for momentum was changed in order to distinguish it from pressure p) of combined masses m_1 and m_2 that load the prop at the time of the impact, amounts to:

$$M = (m_1 + m_2) \cdot v_u \tag{6}$$

The impulse of force J was calculated by the following formula:

$$J = S \int_{t_0}^{t_1} p(t) dt \tag{7}$$

where:

S — surface area of the cylinder of the SHC-40 NHR10 prop equals to 0.01131 m^2,
t_0, t_1 — the time of beginning and end of the impulse of the pressure, s (Fig. 4),
p — pressure, MPa.

Table 2 shows the results in the form of performance characteristics of the SHC-40 NHR10 prop at the dynamic load (direct impact of mass).

Figures 5 to 8 shows the pressure pulses occurring in the space under the piston in tests.

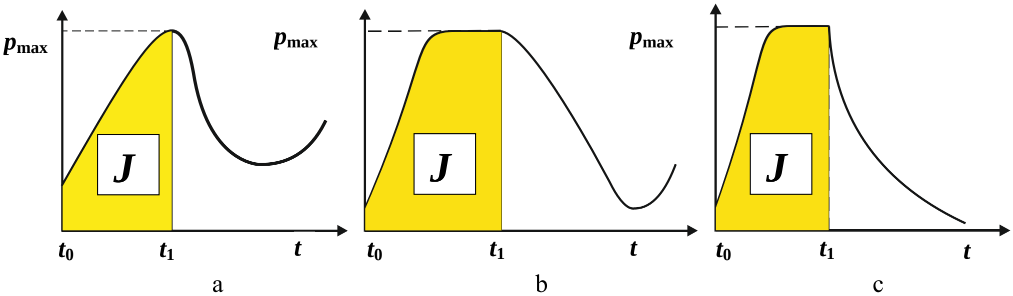


Fig. 4. The time of beginning (t_0) and end (t_1) of the impulse of the pressure:
a – tests with impact mass 4,000 kg; b – tests with impact mass 20,000 kg; c – destructive testing

TABLE 2

The results in the form of performance characteristics of the SHC-40 NHR10 prop at the dynamic load

No.	Type and line of a prop / a valve block	m_1 / m_2, kg	p_{max}, MPa	E_k, kJ	M, kg·m/s	h, m	Remarks
1	SHC-40 NHR10 block type BZG-2FS	4000/ 3300	45.0 57.3 58.0 71.1 78.4 87.7	2.2 4.3 4.3 6.5 8.6 10.8	5603 7924 7924 9704 11206 12528	0.1 0.2 0.2 0.3 0.4 0.5	The prop was not damaged
2	SHC-40 NHR10 standard block	4000/ 3300	46.7 61.9 77.7 90.5 95.1	2.2 4.3 6.5 8.6 10.8	5603 7924 9704 11206 12528	0.1 0.2 0.3 0.4 0.5	The prop was not damaged
3	SHC-40 NHR10 standard block	20000/ 3300	58.8 82.6 94.1	8.4 16.8 25.3	19809 28014 34310	0.05 0.10 0.15	The prop was not damaged
4	SHC-40 NHR10 block type BZG-2FS	20000/ 6600	49.5 91.8 97.6 101.5	7.4 29.5 29.5 44.3	19809 39618 39618 48522	0.05 0.2 0.2 0.3	Damage to the prop at h = 0.3 m Damaged sealing of the piston; buckling of the prop

3. Result analysis

Fig. 9 summarizes the results of the research in the form of $p_{max} = f(E_k)$ characteristics obtained from all tests.

The analysis of the velocity of the rise in pressure in the space under the piston of subject props showed that the pressure in the props equipped with the standard block valve increases the fastest. This applies to the tests with m_1 = 4,000 kg impact mass as well as the mass of m_1 = 20,000 kg.

This is due to the fact that the standard block has smaller capacity than the BZG-2FS block and it acts slower (the opening time is approx. 10 ms).

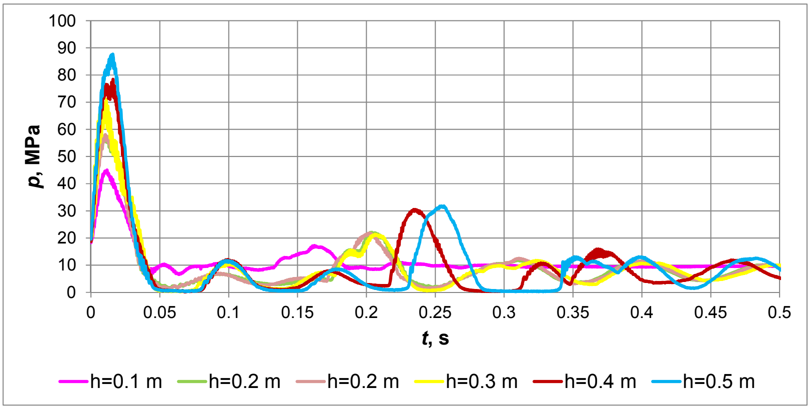


Fig. 5. Characteristics $p = f(t)$ in test no. 1

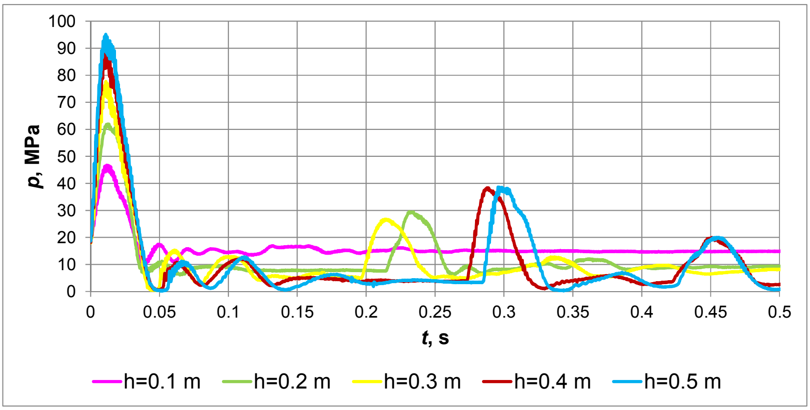


Fig. 6. Characteristics $p = f(t)$ in test no. 2

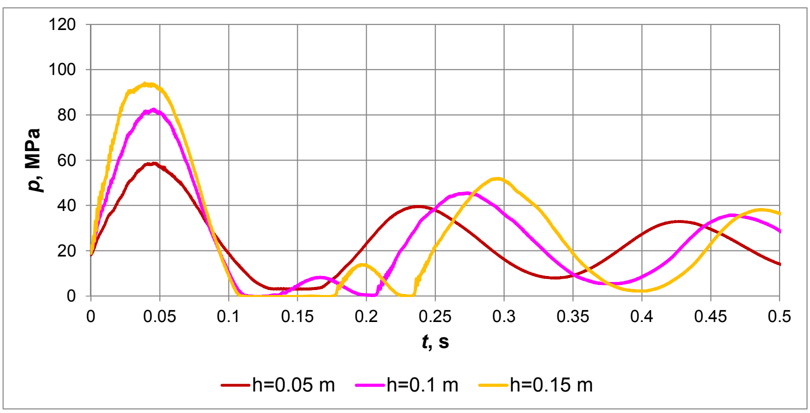


Fig. 7. Characteristics $p = f(t)$ in test no. 3

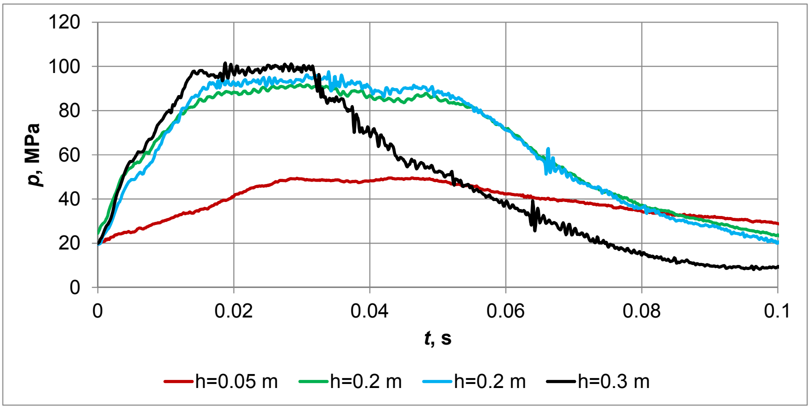


Fig. 8. Characteristics $p = f(t)$ in test no. 4

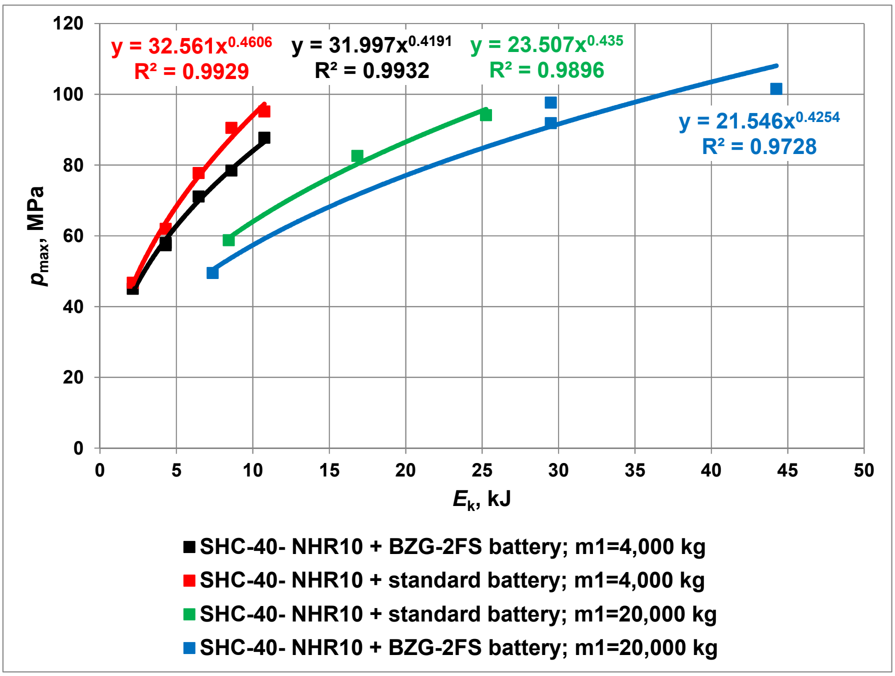
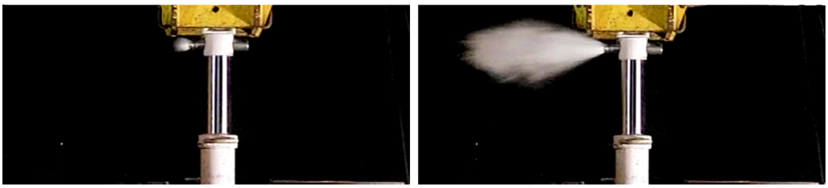


Fig. 9. Summary of results showing the p_{max} maximum pressure of a valve, as a function of the kinetic energy E_k

Conducted tests including impact mass of $m_1 = 4{,}000$ kg showed that BZG-2FS valve blocks have higher efficiency than standard blocks mounted in the SHC-40 NHR10 prop. The pressure in the prop was reduced by ~7 MPa (with kinetic energy $E_k = 10.8$ kJ). Each time the prop was not damaged, and it remained leak-proof and functional. This type of research is the most effective simulation method of a prop, and particularly its seals, operating in the area where occurring mining rock bursts mostly caused by rapid destruction of the coal seam caused by exceeding its allowable stress.

Moreover, the research also included the test of the same type of the SHC prop equipped with the standard block, and with the BZG-2FS block at impact mass of m_1 = 20,000 kg. This kind of test of props is more suitable for simulation conditions of rapid stress relief of a seam, which involves a large mass of rock.

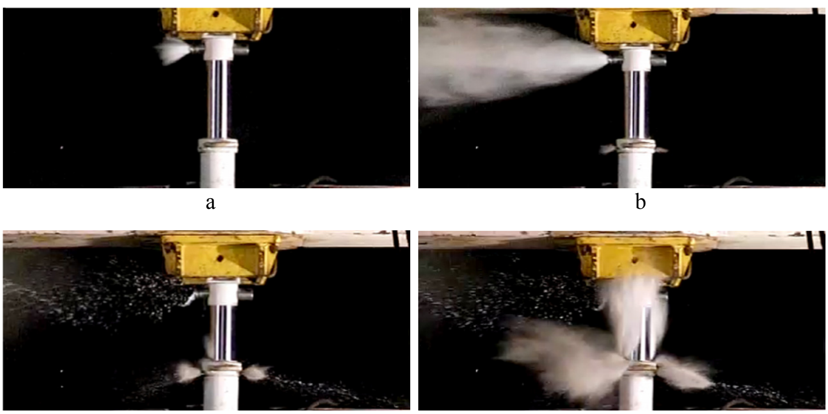
The prop carried without any damages the impact load of E_k = 29.5 kJ kinetic energy. Fig. 10 shows two photographs of a hydraulic fluid stream flowing out of the BZG-2FS fast acting safety valve mounted in the SHC hydraulic prop. A time-lapse analysis of photos showing the opening moment of the safety valve indicates that its opening took place 8 ms after the moment when the prop had been impacted, and indicates the propagation of the hydraulic fluid stream's front with maximum velocity of about 60 m/s, and maximum momentary intensity of fluid flowing through a safety valve amounted to $Q_{c\,\max}$ = 683 l/min.



a b

Fig. 10. The tests on the SHC prop at E_k = 29.5 kJ, M = 39618 kg·m/s; the prop was not damaged;
a – the moment of opening of the safety valve; b – the maximum capacity of the safety valve

The SHC prop equipped with the BZG-2FS block, which was damaged during the test at h = 0.3 m is presented in Fig. 11.



a b c d

Fig. 11. The tests on the SHC prop at E_k = 44.3 kJ; M = 48522 kg·m/s; the prop was damaged;
a – the moment of opening of the safety valve; b – the maximum capacity of the safety valve and the apparent leak in the cylinder; c – the pressure drop in the prop by subsequent leakage in the cylinder;
d – damage of the seal of the cylinder

Fig. 12 shows the pressure pulses occurring in the space under the piston of the prop with the standard block and the BZG-2FS block, during the test with impact of m_1 = 4,000 kg.

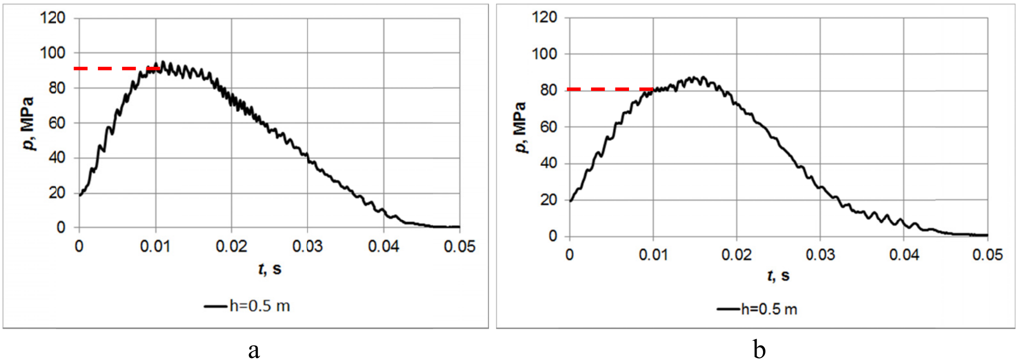


Fig. 12. Research using impact mass m_1=4000 kg, SHC-40 NHR10 prop with the valve block: a – standard, p_{max} = 95.1 MPa, J=26.14 kN·s; b – BZG-2FS, p_{max} = 87.7 MPa, J = 23.04 kN·s

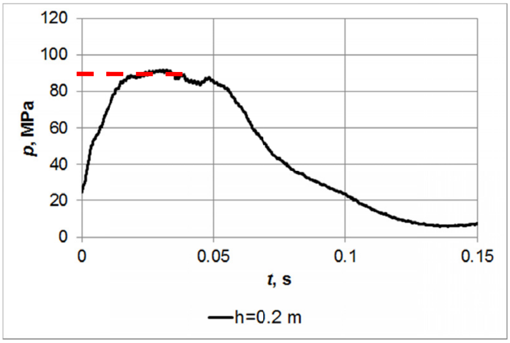
Based on the analysis of the two graphs shown in Fig. 12 and the time-lapse analysis of the recorded video, it can be concluded that too low level of capacity of the standard valve block and slower acting of the yield valve caused the blockade of the valve, and a full opening of the valve occurred at a pressure of about 95 MPa. The full opening of the BZG-2FS block occurred at a pressure of approx. 80 MPa, and as a result of its blockade due to increasing loads, the pressure increased in the prop to a maximum value of approx. 88 MPa. The research also included calculation of the impulse of the force J impacting the prop using impact mass of m_1 = 4,000 kg. The calculations were carried out using CATMAN software by HBM, which was also used to gather, prepare visualization and store acquired data. The calculations showed that thanks to the use of the BZG-2FS block, the load impulse impacting the prop was of J = 23.04 kN·s, and was reduced compared to the impulse of the load impacting the standard block by approx. 12%.

The research also included calculation of the impulse of the force J impacting the SHC-40 NHR10 prop equipped with the BZG-2FS block, at impact mass of m_1 = 20,000 kg. The comparison of the impulse of the load of the SHC-40 NHR10 prop with the BZG-2FS block with impact mass of m_1 = 20,000 kg is shown in Fig. 13.

The tests proved that the prop carried, without any damages, the maximum value of the kinetic energy E_k = 29.5 kJ of the load. The damages occurred during the test at E_k = 44.3 kJ and caused an increase in pressure in the prop to p_{max} = 101.5 MPa, and its sudden decline after approx. 30 ms, resulting in leakage, buckling and distension of the cylinder.

4. Conclusion

The study conducted on SHC-40 NHR10 props equipped with two types of valve blocks: a standard (with spring steel cylinder) and the BZG-2FS (with gas spring), showed that the prop with the BZG-2FS block is more suitable and more effective in the case of areas with high risk of mining tremors and rapid stress relief of a seam.



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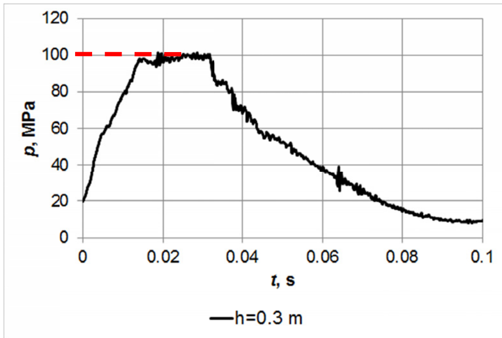

b

Fig. 13. Comparison of the pressure impulse in the under piston space of the SHC-40 NHR10 prop equipped with the BZG-2FS block with impact mass of m_1 = 20,000 kg:
a – no damages, p_{max} = 91.8 MPa; b – damaged, p_{max} = 101.5 MPa

Research methodology developed in the Central Mining Institute combines digital recording technique of pressure in a prop and fast registration of the images, and allows to acquire more accurate analysis of dynamic phenomena in the prop during testing.

Obtained results enable to further optimize the structure of the BZG-2FS fast acting safety valve in order to decrease the valve opening time and to minimize the flow resistance.

Moreover, works on increasing the dynamic resistance of the prop's structure itself has continued, which, in combination with a valve block, should have a greater resistance to dynamic impact.

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