STUDY ON THE SAFETY VALVES FOR THE HYDRAULIC PROPS ON THE ROOF SUPPORTS USED DURING COAL MINING

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ABSTRACT. Supporting of the underground workings and driving the mine pressure are on integrant part of the series of operations comprising coal mining, that provide the safety of the activity and of the deposit.
At present, the hydraulic prop is being used almost exclusively as a carrying element of the supporting equipment used underground and it can be used either as individual supporting element or it can be part of the powered roof support; the hydraulic prop comprises a power cylinder and a sub-assembly made by the hydraulic control apparatus that embeds a safety valve.
The interaction between the roof rocks and the supporting equipment shall give the working resistance of hydraulic props through the personal safety valve. Nevertheless, the operation of safety valves takes place in special conditions and this is the reason why they have to meet particular requirements, not valid in the operation of safety valves used in the industrial hydraulic driven systems.
This paper shows both the requirements for these hydraulic props and constructive and operating information on the safety valves specific to the underground supporting equipment, emphasizing the parameters necessary for a correct and efficient operation of the system of the hydraulic prop.

ИЗСЛЕДВАНЕ НА ПРЕДПАЗНИ КЛАПАНИ НА ХИДРАВЛИЧНИ СТОЙКИ ПРИ ПОВЪРХНОСТНИ КРЕПЕЖИ ЗА НУЖДИТЕ НА ВЪГЛЕДОБИВА
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РЕЗЮМЕ: Укрепването на подземните работи е една от най- съществените дейности при въгледобива , която изисква безопастност на работа и на находища. Към настоящия момент хидравличната стойка е основният носещ елемент на укрепващото оборудване при подземни работи и може да бъде използвано или като самостоятелен укрепващ елемент, или като част от цялостна укрепваща система; хидравличната стойка съдържа носещ цилиндър и подвъзел, състоящ се от контролиращ хидравличен апарат, който укрепва предпазния клапан в грунта. Взаимодействието между скалната повърхност и укрепващото оборудване придава работна устойчивост на хидравличната стойка чрез предпазния клапан. Въпреки това действието на предпазния клапан се реализира при определени условия и изисквания, които не са в сила при работа на предпазните клапани, използвани при традиционни промишлени хидравлично- задвижвани системи. Статията представя от една страна тези изисквания към хидравличните стойки, а от друга- конструктивна и работна информация за предпазните клапани характерни при подземни укрепващи съоръжения. Набляга се върху необходимите параметри за правилна и ефективна дейност на системата за хидравлични стойки.

Introduction

By supporting the face and directing the pressure of the roof, the operation of all coal mining process components is observed, therefore ensuring the safety conditions both for the personnel as well as for the massif.

Although the operation cycles face supports have a relatively reduced life span, the problems related to the support are generally difficult to solve, considering the requirements imposed by the geologic-mining conditions which are extremely variable as well as not knowing the entire basic data; the large variety of natural conditions lead to the development of several structural and technological solutions for supports.

Mine supports are especially used for coal face and meet a series of technologic functionalities, their main functionality being to support the roof of this kind of works. Together with the transportation and cutting equipment, the support, forms a complete longwall package, a machine system ensuring a simple or complex mechanisation of the required works for coal extraction from a longwall face of underground mines.

These days, the hydraulic prop is used almost exclusively as a bearing element of the face support. It can be used either as an individual supporting element or integrated in the metallic construction of the shields which compose the mechanised support.

The interaction between the rocks of the roof and the support created with hydraulic props is the one which, in the formed mechanical system, determines on one hand the load and deformation level of the rock layer found in the superior part of the support and on the other hand the resistance of the hydraulic prop to the descend of the rocks from the roof. One of the most important components of this kind of system, i.e. rock-support system, is the safety valve which constitutes the main element determining the operating resistance of the support hydraulic prop of the rock of the roof.

Structural and functional particularities of hydraulic props and safety valves

The hydraulic prop represents the main support element of each support component (frame with individual props and beams, or mechanised shield support); this realises the bearing function responding with a resistance force, through the superior side of the support (beam), to the lithostatic pressure generated by the rocks of the roof of the face.

The structure of the prop contains a force hydraulic cylinder HC acting together with a pilot controlled pressure retention check valve CCV, a safety (relief) valve SV and a manometer M, usually composing a hydraulic system and connected to a circuit as shown in Figure 1.
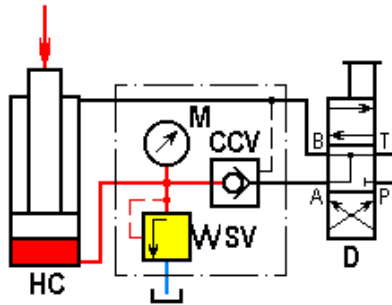

Fig. 1 Face hydraulic prop. Hydraulic basic diagram

The supply with operational liquid from the distributor (directional control valve) D ensures the extension of the prop with the opening force F_o and lifts the superior support beam of a G_B weight:

$$F_o = G_B = p_{PP} \cdot \eta_{hPP-P} \frac{\pi D_C^2}{4} \eta_{mC}, \qquad (1)$$

fastening it to the roof of the face with the pretension force:

$$F_p = p_{PPmax} \cdot \pi D_C^2 / 4, \qquad (2)$$

where: p_{PP} is the pressure developed by the supply hydraulic power pack inside the cylinder of the prop, under a piston; D_C- is the interior diameter of the cylinder; η_{hPP-P}- is coefficient of hydraulic efficiency of the circuit between the power pack and the prop; η_{mC}- is the coefficient of mechanic efficiency of the cylinder.

After the supply with liquid has ended (the centre position of the distributor) the cavity under the piston remains closed by the retention valve CCV.

In time, mining pressure rises as an effect of the rocks from the roof pressing on the superior beam, leading to the increase of liquid pressure under the piston of the prop, when reaching the input pressure, the safety valve opens allowing the discharge of a certain amount of liquid from the interior of the cylinder, therefore limiting the force of resistance of the prop to a constant value – bearing capacity of the prop:

$$F_b = p_{maxSV} \cdot \pi D_C^2 / 4. \qquad (3)$$

Operating according to this constant resistance regime is important considering the mining technology and the safety of the support during operation and it depends on the good operation of the safety valve.

The amount of liquid discharged through the safety valve considering this operational regime may be released either in the surrounding space or in the return circuit of the support.

In the first case, a simplification of the system is observed, and the operation of the valve becomes visible, however, there will be certain liquid losses ending up on the floor of the mine. The pressure in the return circuit does not by any means influence the correct operation of the safety valve.

If the outlet of the safety valve is connected to the return circuit, the influence of the pressure in this system is different depending on its construction.

Figure 2 represents the two main safety (relief) valves: a – fitted with a classical pneumatic element and b – fitted with mechanical spring.
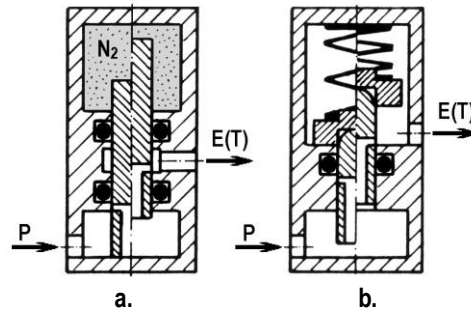

a.   **b.**

Fig. 2 Safety (relief) valves for hydraulic props. Main types

The safety valves using as an elastic element a compressed nitrogen cushion, enclosed in a tight cavity (figure 2,a), does not modify its operational characteristics in proportion with the pressure of the outlet circuit, thus, this pressure does not influence the changing capacity of the valve. The disadvantage of this kind of valves is the need of periodically loading them with compressed nitrogen as it is lost in time.

Considering the safety valves fitted with a coiled spring as a pressure regulating element, the outlet circuit is chained with the chamber of the spring (figure 2,b). The pressure on the return circuit generates a force over the shutter in the same direction as the force of the spring, leading to the increase of opening pressure and reduces the transition (discharge) capacity of the valve.

The decrease, up to zero, of the discharge capacity of the safety valves by increasing the pressure in the main return pressure pipeline is one of the main causes of cylinder shirt swelling of the hydraulic props therefore leading to taking them out of operation.

The operation of the safety valves of the hydraulic props, happens therefore in special conditions, reason for which certain requirements are imposed, which cannot be met during the operation of other valves used in hydraulic systems.

The operation regime characterising the long time operation of the safety valve and of the hydraulic prop is the one that ensures the smallest drop of the rocks of the roof with an average speed of several millimetres per hour; therefore

determines the smallest flow through the valve, for opening pressures usually regulated between 30 – 60 MPa.

The connection of the safety valve to the hydraulic prop is made differently according to the type of hydraulic prop used: individually or for mechanised support. Figure 3 represent the general design of the shutter assembly of the hydraulic prop for individual support, while Figure 4 represents a section of the nitrogen safety valve used in mechanised support hydraulic props. Both figures also represent the basic diagram of the hydraulic circuit of the prop comprising as well the safety valve. As liquid, an oil in water fluid with 3 to 5% oil, for the hydraulic props, is used.
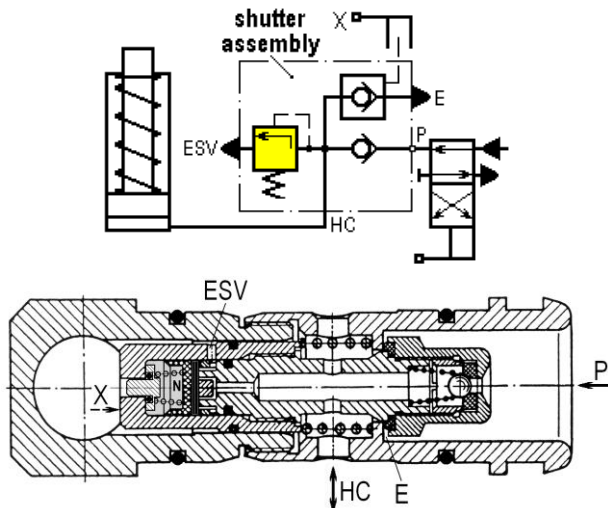

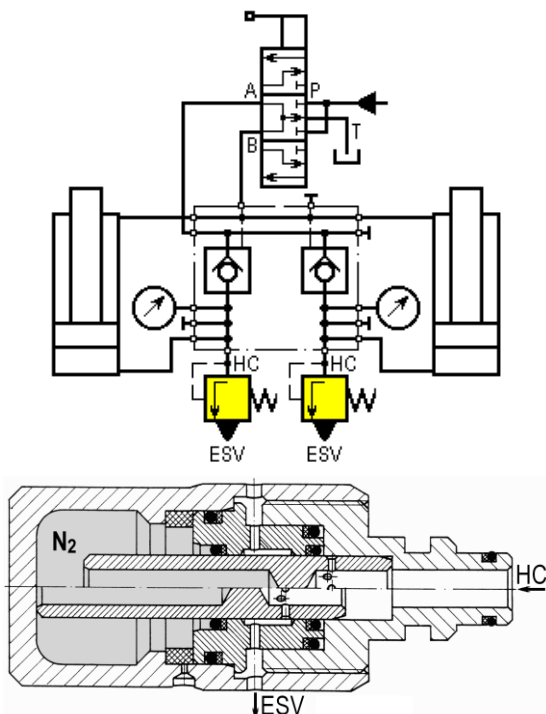**Fig. 3 Individual hydraulic prop shutter for open circuit**

Fig. 4 Safety valve for the hydraulic props for mechanised support

Considering these conditions, the most important indexes of the operation capacity of the support when interacting with the rocks of the roof are the degree of tightness of the working cavity of the hydraulic prop and the establishment of its resistance to the hanging of the rocks of the roof. In the case of total micro-losses of liquid through the pilot controlled retention check valve or through the seals of the piston, the hydraulic prop will not be able to develop its nominal resistance, and could lead to the disturbance of the rocks of the roof and their sudden caving, therefore generating dangerous situations in the face.

Requirements for the safety valves of the hydraulic props

The most vulnerable element of all the elements of a hydraulic system of the prop from the point of view of liquid leakages is the safety valve, therefore the basic requirement is that during operation the valve to be perfectly tightened for different operating pressures in the operational cavity of the hydraulic prop – from a minimum to a maximum pressure determined by the opening of the safety valve.

The sagging character of the rocks of the roof determines the operation of the support:

- in the case of a monotonous development process, the sagging of the roof is periodical, measured in millimetres, and controlled slides of the props by the safety valves;

- if the layer above the support is formed of hard displacing rocks, and above the rocks of the roof there are heavy sandy or lime layers, a sudden sagging of the roof may appear (roof breaking phenomenon), highly increasing the speed of the roof's descent, reaching in some cases 0.5 m/s.

Therefore, considering the inertia and the limits of the safety valve, dangerous increase of pressure appear in the cavity under the piston, leading to the exceeding of the superior limit of the bearing of the prop, the swelling phenomenon of the cylinder and to remnant deformities of the mobile components of the prop or of the support.

That is why, when the support is destined for operation in roofs with hard displacing rocks and with block displacement, valves of high discharge capacity are chosen in order to avoid the dangerous increase of pressure inside the operating cavity of the cylinder, respectively its loading.

Another condition imposed for the safety valves of the hydraulic props is that the difference between the pressure opening and closing value to be as small and as stable during the entire operation; it is also implied that the difference not modify significantly when high speed variations of the rocks of the roof occur (when the flow through the valve increases)

Figure 5 represents the operating characteristics of the safety valves, and two operating regimes may be distinguished:

- regime no I (OA) – the increase of the resistance of the hydraulic prop: the valve remains closed, and the effect of the rocks of the roof produces an increase of pressure in the cavity of the prop; a perfect tightness of the safety valve is imposed;

- regime no II (AB) – constant resistance of the hydraulic prop: under the continuous action of the rocks of the roof the prop operates in an elastic guidance regime; repeated opening and closing of the safety valve, the repeated opening and closing of the safety valve is produced, with a variable frequency and periodic discharge of a quantity of liquid from

the cavity under the piston. The operating resistance of the hydraulic prop (depending on the pressure in the cavity of the cylinder) varies within the limits $p_{minSV} - p_{maxSV}$, appearing several differences of the opening and closing pressures of the safety valve depending on the way the rocks of the roof manifest themselves.

In this operating regime of the safety valve, if the rocks of the roof are hard displacing, sudden displacements of the rocks may occur: therefore, momentary high flows should go through the valve corresponding to pressure p^*_{maxSV}, superior to the normal pressure p_{maxSV}; if this resistance is higher, it can lead to the appearance of remnant deformities, with consequences already mentioned.
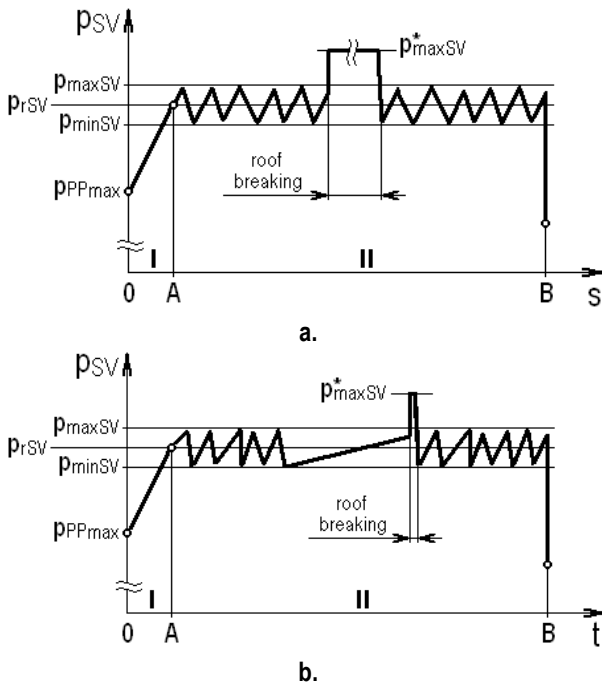

a.

b.

Fig. 5. Operating characteristics of safety valves for hydraulic props: a – opening pressure dynamics $p_{SV} = f(t)$; b – the dependence of the opening pressure on the stroke of the piston of the prop $p_{SV} = \varphi(s)$.

The pressure drop of the liquid inside the hydraulic system of the prop and the increase of volumetric losses depend on the operating pressure, the roughness and precision in execution of the tight surface of the valve, the wear degree, the elasticity of the hydraulic system of the prop, viscosity as well as on other physical properties of the operating liquid.

Testing the performance of the safety valves of the hydraulic props

Starting from the utmost importance of supporting mining works, from the point of view of a normal development of the technological process and in full labour safety conditions, it results the need of correct operation of hydraulic props in all possible conditions of the face.

As the safety valve is the main component of the hydraulic prop, the operation of which determines its behaviour in contact with the rocks of the roof of the face, it results the need for the safety valves to be verified according to a maintenance schedule which establishes if certain operating parameters are

within the limits of the values mentioned in specific norms and regulations.

The main parameters of the safety valves and the verification conditions are:

1. Opening p_{maxSV} and closing p_{minSV} pressure values of the safety valve are determined on a testing prop foreseen with the possibility of locking its extension: a flow of 40 cm³/min at a temperature comprised between 20 and 25 ºC is used.

The operating pressure is gradually increased inside the working cavity of the prop until it is fixed between the bearers, continuing with the increase of pressure until the safety valve opens and the flow passes; then, the supply circuit is closed and the variation of pressure is constantly checked after a certain waiting time.

The norms foresee that the operating regime (opening - closing) if the safety valves does not, during the first year of operation, surpass 10% of the regulating pressure p_{rSV}. There is the need, as well, for the effective difference between the opening p_{maxSV} and closing p_{minSV} pressures not to be more than 15 % of the regulating pressure, established for the bearing capacity if the prop.

2. In order to verify its behaviour when a variable flow passes through the valve, the pressure is increased until the valve starts its operation, then the flow of the liquid is increased until it reaches the recommended nominal value; then, a decrease of the flow follows until the safety valve closes. Considering the regulating pressure, an increase of the opening pressure with 7.5 MPa, the most, for an outlet flow comprised between 0 and 15 L/min.

Conclusions

The operation of the safety valves of the hydraulic props is made in special conditions, reason for which it is imposed for them certain requirements which have never been met during the operation of other safety valves used for other hydraulic operated systems.

The operating regime characterising the long operation of these valves is the one ensuring the slightest and uniform sagging of the rocks of the roof, with an average speed of several millimetres per hour, determining the lowest flow through the valve for opening pressures regulated within the limits 30 – 60 MPa.

When the destination of the support is that of working with roofs of hard falling rocks and block falls, valves with a high discharge capacity are chosen, which are able to avoid the dangerous increase of pressure in the working cavity of the prop and ensure its efficient protection.

The liquid discharged through the valve following this operation regime may be discharged either in the surrounding space or into the return circuit of the support. Considering the latter case, the return counter pressure generates an extra force over the closing organism, leading to the increase of the opening pressure and to the decrease of the discharge capacity of the valve; the decrease of the discharge capacity is one of the main causes for which the encasings of the cylinders of the hydraulic props swell and therefore removing them of operation.

The following technical requirements are very important for the evaluation of the quality of safety valves for the hydraulic props:

- absolute tightness until the reach of the opening pressure;

- the establishment of the regulating pressure and a minimum dispersion of the operating pressures (i.e. opening and closing pressures);

- an increased safety and sustainability degree.

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