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IMPROVEMENT OF PERFORMANCE INDICATORS OF HYDRAULIC DRIVE OF PROPS OF POWERED SUPPORT UNITS OF HEADING COMPLEXES

Aleksandr V. STEBNEV[1], Vladimir V. BUEVICH[2]
[1] *OJSC «SUEK – KUZBASS», Leninsk-Kuznetsk, Russia*
[2] *JSC «VNII Galurgii», Saint-Petersburg, Russia*

The method of reducing the dynamic loading of the support unit and the immediate roof rocks resulting from the successive operation of the safety valve during operation of the props in the regime of «equal resistance» is considered. In the developed working characteristic of hydraulic props of supporting units their overload protection is singled out into an independent function and is separated from the function of rock pressure control. The resistance of the hydraulic props of the support units to the roof rocks subsidence is regulated in a non-pulsed manner, and the movement of the support units can be carried out in a «non-unloading» mode. As a result, the static «trampling» of the intermediate roof is reduced, and in the regime of controlling the rock pressure, the dynamic impacts of the mechanized support on the intermediate roof are excluded. In this case, the protection of the support unit from overloads works only when the support is overloaded and does not directly participate in the formation of the process of rock pressure rock. The proposed non-pulse method provides controlled transmission of hydraulic energy with a small pressure drop from the head ends of the hydraulic props to the pressure line of the hydraulic system of the heading mechanized complex and its subsequent useful use.

Key words: coal, longwall face, roof support, hydraulic system, rock pressure, regulation, performance indicators, «trampling» of the roof, adaptation

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Introduction. From the moment of their creation in the middle of the twentieth century the first coal face mechanized systems (CFMS) for underground coal mining in complex fully mechanized longwalls (CFML) there have been attempts to search for the best constructions of the roof support units [6, 7] and ways of controlling the mining pressure in the faces, hydraulic roof support systems and hydraulic systems for controlling mechanized roof support of complexes have been improved [5, 9, 14]. During this time, numerous types of reliable powerful high-performance heading complexes with hydroficated props with manual, remote, program and automated control have been invented [8, 12].

There are significant successes in increasing the intensity of wastewater treatment in the CFMS of coal mines, mainly during the development of high-tech coal seams [6, 7, 16-20]. However, during development of coal seams occurring in difficult mining and geological conditions, the efficiency used mining complexes was significantly reduced [13].

At present, the manufacturing of mechanized roof support is, as a rule, carried out for specific mining, geological and technological operating conditions. But even in this case, the rock pressure and the strength properties of the rocks of roof are changing, as a rule, in a wide range, which significantly affects the efficiency heading complexes. One of the reasons for this situation is the operating performance of hydraulic control of roof support units, which is invariable, rigid in structure, form and values of its parameters.

Formulation of the problem. The work of modern units of mechanized supports (UMS), with their strict characteristics of hydraulic force value for hydraulic drive of props, is accompanied by static and dynamic «trampling» of the roof. The consequences of these processes are manifested in the intensity of the cracking in the roofs, its accidental release into the bottomhole space, in asymmetrical loads on the supports and in the loss of contact of the roof slabs with the roof. Therefore, the increase in the efficiency of the process of controlling the mining pressure in the face by improving the structure and parameters of the UMS, their performance and hydraulic props have been and remain relevant.

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The aim of the work is to increase the effectiveness of controlling the resistance of UMS hydraulic props to subsidence of the rocks of the immediate roof with the exception of the process of static, with a large range of value changes, and the dynamic force effects of the UMS on the roof when performing all operations of the cycle.

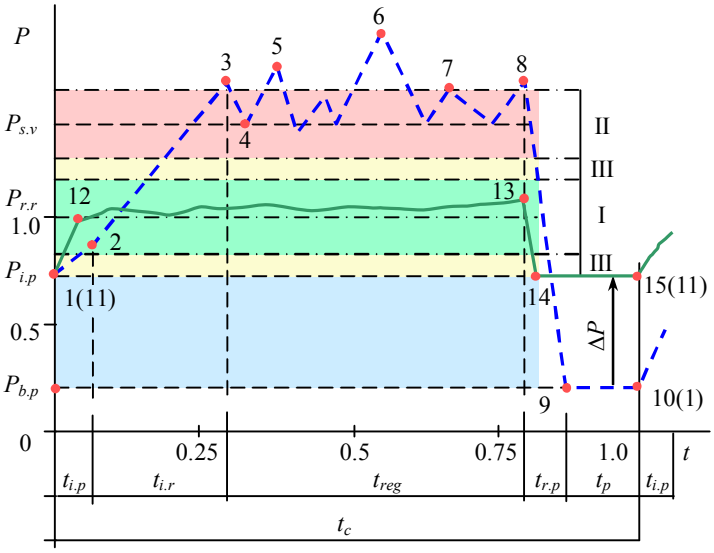


Fig.1. Working characteristics of hydraulic prop of UMS
I – resistance regulation zone ($P_{r.r}$); II – safety valve set up zone (protected zone); III – separating zones

Results and its discussion. The main power support element of any unit of the mechanized support is a hydraulic prop. In accordance with the specified operating characteristic, it cyclically performs the functions of force interaction with the soil and roof rocks through the base and canopy of the power support unit. The quality of the process of supporting the roof, protecting the bottomhole from accidental releases and rock falls depends on the quality of the complex performed by each power unit and the mechanized support of the whole operation of the cycle and their indirect influence on the process of controlling the rock pressure. The process of interaction of UMS with the roof, in accordance with its typical performance, is marked on the graph (Fig.1) by points 1-10. The change in pressure in the head end of the hydraulic prop and the time in the cycle of operations are presented in relative units.

The cycle of functioning of the unit of the mechanized support reflects the working characteristic of its hydraulic prop, they also show slowly varying (static) values of the pressure of the working fluid in the head end of the hydraulic props. The basic operations of the cycle are as follows: the initial prepressing with the pressure $P_{i.p}$ reflects the line 1-2 in time $t_{i.p}$, the work in the regime of increasing resistance is shown by the line 2-3 in time $t_{i.r}$, the work in the constant (equal) resistance mode is reflected by the line 3-8 (P_{reg}) and the control time t_{reg} with characteristic points are 3 and 4 (3 is the opening of the safety valve when reaching the set point pressure $P_{s.v}$ and 4 is the closing of the safety valve), points 5-8 show different overpressures, line 8-9 represents the removal of the pressure ($P_{r.p}$) for moving the power unit and the line 9-10 reflects the backup pressure ($P_{b.p}$) during movement of the unit.

In the process of convergence of wall rocks in the elastically deformable units of the system «mechanized support – immediate roof» (working fluid in the head ends of the hydraulic props, covers of the cylinders of props, roof rocks), the potential energy accumulates [9]. As I.V.Antipov noted in his study under the static «trampling» of the roof he means a state where «... the system «support – rock mass» does not come to a state of equilibrium even in the absence of external influences, which is the movement of the support unit. During the movement of the support, a dynamic «trampling of the roof» is observed, which is caused by the removal of the pressure when the section of the mechanized support is moved to the face, which also negatively affects the lower layer of the roof» [1, p.16]. Thus, the section of characteristic 3-8, or work in the regime of constant resistance, shows the negative effect of static «trampling», and the static force drop caused by the removal of the pressure during the movement of the support reflects the negative effect of the dynamic «trampling» of the rocks of the immediate roof.

A significant difference in the pressures of the working fluid in the head ends of the hydraulic props (thrust forces) at the beginning and end of these operations leads to activation of the process of formation of «systemic» technogenic cracks in the rocks of the immediate roof, which are directed predominantly parallel and perpendicular to the face plane [9].

In production conditions, they use the power support units designed for the maximum predicted loads in specific operating conditions, the pressure level of the safety valves ($P_{s.v}$) is set up

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according to these values. Therefore, the hydraulic props of the support units in the process of controlling the rock pressure operate mainly in the regime of increasing resistance (section 2-3, Fig.1), without going to the constant resistance mode 7. As the numerous data accumulated over the years of operation of the mining complexes, in this case the power support units, as a rule, are loaded unevenly, and the release of pressure in the safety valves reflects, in fact, emergency situations [3].

Therefore, violations of the integrity of the roof rocks (skips, falls and loose rocks) in one case are the result of an overestimated roof resistance value that exceeds the strength of the rocks of the immediate roof, in the other is the consequence of successive releases of the safety valve, which are accompanied by dynamic forces on the rocks of the immediate roof [4, 15].

Integral estimation of the power support unit modes of operation are the following: the cycle duration (t_c) of successively performed operations; weighted average resistance per cycle resistance ($F_{w.a}$) of a hydraulic prop or power support unit; pressure drops in the head ends of hydraulic props in static and dynamic modes during the execution of cycle operations.

The duration of the work cycle of the power support unit is composed of the duration of the individual operations:

$$t_c = t_{i.p} + t_{i.r} + t_{reg} + t_{r.p} + t_m ,$$

where $t_{i.p}$ – time of initial pressure; $t_{i.r}$ – time of increasing resistance; t_{reg} – time of regulated resistance of the unit (hydraulic prop); $t_{r.p}$ – time of pressure removal from power unit; t_m – time of power support unit movement.

The operating time of the power support unit in the regime of controlled resistance ($P_{c.r}$) does not depend on the operating mode of the unit and is determined solely by the duration of the coal extraction cycle in the CFMS.

The increment of the pressure values in the head ends of the props during the execution of the cycle operations is determined by the pressure difference at the beginning and at the end of each operation (Fig.1) and will be equal when the stage of initial pressure $\Delta P_{i.p_1} = P_{i.p} - P_{b.p}$; increasing resistance $\Delta P_{i.r_1} = P_{s.v} - P_{i.p}$; unloading of props (removal of pressure) $\Delta P_{r.p_1} = P_{s.v} - P_{b.p}$. The level of pressure $P_{b.p}$ in the mode of pressure removal from the power support unit (Fig.1) is set up in relation to the level of rigidity degree of initial roof rocks.

The mode of functioning of the UMS is carried out in a short-time mode. For such a regime, the resistance should be evaluated by its weighted average value, taking into account the forces and time of their action per cycle. The weighted average resistance is determined taking into account the load action for individual time intervals t_i during the cycle:

$$F_{wa} = \frac{\sum_1^n F_i \cdot t_i'}{\sum_{i=1}^n t_i'},$$

where F_i – averaged pressure values for hydraulic props during the execution of cycle operations: $\overline{F}_{i.p}$ – initial pressure, $\overline{F}_{i.r}$ and $\overline{F}_{r.r}$ – increasing and regulated resistances, $\overline{F}_{r.p}$ – removal of pressure; $\sum_{i=1}^n t_i = t_c'$ – UMS working time per one cycle.

In this case, the magnitude of the force will be equal to the multiplication of the corresponding pressure of the working fluid in the head end per area of the hydraulic piston of the prop:

$$F_i = P_i \pi D^2 / 4 ,$$

where P_i – working fluid pressure in piston of the prop in the investigated mode of operation; D – hydraulic prop piston diameter.

The degree of dynamic loading of the power support unit during the regulation of the rock pressure, or in general for the cycle of operations, can be estimated by variance, root-mean-square deviation or coefficient of variation of loads.

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Technical solutions. To increase the stability of the process of controlling the rock pressure, preventing the falling of the roof rocks, increasing the adaptation of the UMS to changing mining and geological conditions, we propose the UMS and a mechanical characteristic of the hydraulic drive of its props having a more effective structure. The basis of technical solutions are the following principles:

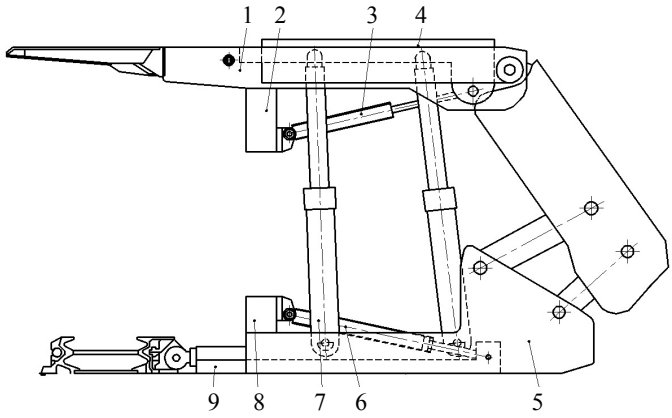


Fig.2. General view of power support unit

– stepping way of UMS movement process from the fixed contacts of the pressure elements of the support unit to the roof and the floor (Fig.2) with compensation transfer of the pressure forces from the canopy 1 to the hold-down beam 4 and from the base 5 to the guiding beam 9 [11];

– a significant decrease in the pressure drop in the head ends of the hydraulic props during the stage of the initial pressure, the increasing resistance and the movement of the unit with the power support (see Fig.1, points 11-15);

– separation of the function of rock pressure regulation from the function of protecting the UMS from overloads;

– non-pulse method for regulating the resistance of hydraulic props of UMS to subsidence of roof rocks [2, 10];

– adaptive to the changes of rock pressure mechanical characteristic of hydraulic drive of UMS props.

The features of the structural construction of the power support unit are (Fig.2, see the table):

– the presence of a symmetrically located guiding beam 9 with respect to the base 5, the beam with the hydraulic jack 6 moving through the cross-beam 8 with the support mechanism ensures the base lifting when movement of the unit;

– the presence of a hold-down beam 4 located in the longitudinal groove of the canopy 1 with the possibility of a step-by-step movement of the hydraulic jack 3 with respect to the canopy [11];

– the base and the canopy of the unit are equipped with support mechanisms fixed to the cross-beam 2 and 8, providing special hydraulics for compensating the pressing forces of the props 7 through the bearing sliding unit on the guiding and the hold-down beams.

Comparison of performance indicators values

Parameters of operation modes of hydraulic props of UMS at different stages	Performance indicators		
	I (typical)	II (proposed)	III (typical vs. proposed)
1. Prop pressure during movement	$P_{b.p\,\mathrm{I}} = \begin{cases} 0 \\ P_{b.p} \end{cases}$	$P_{b.p\,\mathrm{II}} = \begin{cases} 0 \\ P_{b.p} \\ P_{i.p} \end{cases}$	$\frac{P_{b.p}}{P_{b.p}} = 1.0$ $\frac{P_{i.p}}{P_{b.p\,\mathrm{I}}} \gg 1.0$
2. Increase of initial pressure in the prop	$\Delta P_{i.p\mathrm{I}} = P_{i.p} - P_{b.p}$	$\Delta P_{i.p\mathrm{II}} = P_{i.p} - P_{b.p}$	$\Delta P_{i.p\mathrm{II}} \ll P_{i.p\mathrm{I}}$
3. Increase of pressure during the stage of increasing resistance	$\Delta P_{i.r\mathrm{I}} = P_{s.v} - P_{i.p}$	$\Delta P_{i.r\mathrm{II}} = P_{r.r} - P_{i.p}$	$\Delta P_{i.r\mathrm{II}} \ll P_{i.r\mathrm{I}}$
4. Pressure drops during the stage of regulated resistance	$\Delta P_{reg\mathrm{I}} = \Delta P_{s.v}$	–	Dynamic force action
	–	$\Delta P_{reg\mathrm{II}} = \Delta P_{r.r}$	Static force action
	–	–	$\Delta P_{reg\mathrm{II}} < \Delta P_{reg\mathrm{I}}$
5. Removal of pressure before movement	$\Delta P_{r.p\mathrm{I}} = P_{s.v} - P_{b.p}$	$\Delta P_{r.p\mathrm{II}} = P_{reg\mathrm{II}} - P_{i.p}$	$\Delta P_{r.p\mathrm{II}} \ll \Delta P_{r.p\mathrm{I}}$

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The structure of the developed (proposed) unit performance indicators is shown in Fig.1 (points 11-15) and its comparison with the typical characteristic is given in the table. Among the indicators there are pressure levels for head ends of the props, providing an initial pressure of the unit sufficient to eliminate the immediate roof rock lamination; the required supporting force of the unit during its movement and we also allocated special zones I-III. In the table, the line 3-8 corresponds to the regulation in the existing support props ($\Delta P_{reg\text{I}}$), which is determined by the pressure ($P_{s.v}$) of the safety valve, and in the proposed scheme the control pressure ($\Delta P_{reg\text{II}}$) corresponds to the line 12-13 (Fig.1). Zone I reflects the limits of the resistance control ($P_{r.c}$) of the support section (the zone of adaptation of the UMS to the rate of roof rocks subsidence). Zone II shows the limits of the setting of safety valves, which perform only the function of protecting the section from overloads. Zones III divide functional zones I and II to avoid false activation due to their mutual influences.

The movement of the power support unit (without beams), depending on the conditions, can be carried out in three different modes: in an unloading mode, with partial compensation of the pressing force and with a break in the unit canopy contact with the immediate roof. In this case, the operation in each of the three modes includes the sequential execution of operations: unloading the hydraulic props (removing the pressure $P_{r.p\text{II}}$, points 13, 14 in Fig.1), movement of the unit (points 14, 15) and the subsequent pressure of the hydraulic props (points 11, 12) 5 (Fig.2) into the floor and canopy 1 into the roof. The reduction of cyclical repetitive force impacts on the immediate roof during movement of the supporting unit is provided by compensating the pressing forces on the hold-down and guiding beams (Fig.2). At the same time, the movement of the support units is carried out with the fixed contacts of the hold-donwn beam 4 with the roof and the guiding beam 6 with the floor.

With mobile UMS in the unloading and supporting modes the bearing units provide a reduction in frictional forces when they slide along the hold-down beams. The device of pulse-free control of resistance of a hydraulic prop as a function of the rate of intermediate rock subsidence changes the rigidity of its performance indicators. The rigidity of the hydraulic props is ensured by a metered increase or decrease in the indirect flow of working fluid from its head ends with a small differential pressure through the reduction device to the heading machine hydraulic line. The limits of self-regulation of pressures in the head ends of hydraulic props (adaptation limits, zone I, Fig.1) are established depending on the type of roof.

From the comparison of the performance indicators of the typical support section with the operating characteristic I and the developed adaptive unit with its operating characteristic II (see table), it follows that the pressure drops are significantly reduced during the movement of the unit and initial pressure stage, control of the rock pressure in the regime of increasing resistance and during removal of the unit prop. Consequently, the static «trampling» of the immediate roof rocks is reduced. The impulse regulation of the resistance of the hydraulic props to the roof rock subsidence not only excludes the dynamic force impacts on the roof rocks (the dynamic «trampling» of the roof), but also provides the possibility of transferring some of the energy of the rock pressure to the hydraulic system of the heading machine and its further useful use.

Conclusions

The changed structure and parameters of the proposed performance indicators of the hydraulic drive of the unit props with the separation of the functions of protection and control of the rock pressure, the pulse-free regulation of the resistance of the hydraulic props, the movement of the support units with the preservation of the contacts of the supporting elements with the floor and the roof of the formation provide the following:

1) reduction of static and dynamic «trampling» of the immediate roof rocks and, as a result, increasing the stability of the heading process;

2) increase of static adaptability of the support unit to the randomly changing rock pressure;

3) transfer of a part of the energy of the rock pressure appearing in the support unit to the hydraulic line of the heading complex and its useful use.

The proposed criteria for performance indicators of operation modes of powered support units provide more objective assessment and selection of the most advanced methods and equipment for rock pressure control.

REFERENCES

1. Antipov I.V. Geomechanical and technological foundations for the creation of a new level of support units for heading thin sloping layers: The autor ... Doctor of Engineering Sciences: 05.15.02. Donetsk: Donetskii nauchno-issledovatel'skii ugol'nyi institut, 1996, p. 39 (in Russian).

2. Buevich V.V., Gabov V.V., Zadkov D.A., Kabanov O.V. Non-pulse control of the operation mode of the hydraulic props of powered support units of the mechanized heading complex. *Gornoe oborudovanie i elektromekhanika*. 2015. N 3, p. 26-30 (in Russian).

3. Bykov S.V., Myshlyaev B.K. Determination of the resistance of mechanized units of the supporting type. Voprosy gornogo davleniya. Novosibirsk: IGD SO AN SSSR, 1985. Iss. 43, p. 108-117 (in Russian).

4. Kiyashko I.A., Saratikyants S.A., Ovchinnikov N.P. et al. Interaction of mechanized supports with wall rocks. Moscow: Nedra, 1990, p. 128 (in Russian).

5. Zyara A., Slyusazh R., Kret A., Dzik K. Plant of mining machines "Glinik" - a comprehensive supplier of equipment for longwall mining faces. *Glyukauf*. 2008. N 1(2), p. 74-80 (in Russian).

6. Klishin V.I. Adaptation of mechanized supports to conditions of dynamic loading. Novosibirsk: Nauka, 2002, p. 200 (in Russian).

7. Klishin V.I., Matviets Yu.V. Increase the adaptation of single-row mechanized support to loading conditions. *FTPRPI*. 1993. N 2, p. 23-29 (in Russian).

8. Linnik Yu.N., Krashkin I.S., Merzlyakov V.G. et al. The concept of development of heading, tunneling, conveyor and drilling equipment for the period up to 2020. *Gornye mashiny i avtomatika*, 2006. N 2, p. 2-12 (in Russian).

9. Korovkin Yu.A., Khudin Yu.L. Mechanized support of longwall faces. Moscow: Nedra, 1990, p. 413 (in Russian).

10. Buevich V.V., Gabov V.V., Kabanov O.V. RF Patent 2510460, MPK E21D23/16. Hydrophobic support with adjustable resistance and energy recovery. Zayavitel' i patentoobladatel' FGBOU vysshego professional'nogo obrazovaniya «Natsional'nyi mineral'no-syr'evoi universitet «Gornyi». N 2012131355/03. Zayavl. 20.07.2012. Publ. 10.01.2014. Bul. N 1 (in Russian).

11. Gabov V.V., Zadkov D.A., Buevich V.V., Babyr' N.V., Stebnev A.V. Patent for utility mode 169381 RF, MPK E21D 23/04, E21D 23/06. Mechanized support unit with guiding and supporting beams. Patentoobladatel' FGBOU VO «Sankt-Peterburgskii gornyi universitet». N 2016142172. Zayavl. 26.10.2016. Publ. 16.03.2017. Bul. N 8 (in Russian).

12. Podkolzin A.A. Improvement of the hydraulic system of the mechanized support unit. *Izvestiya Tul'skogo gosudarstvennogo universiteta. Tekhnicheskie nauki*. 2014. Iss. 2, p. 49-54 (in Russian).

13. Remezov A.V., Klimov V.V. Investigation of the influence of the reference pressure from the working face and ORP zones on the mine workings. *Vestnik Kuzbasskogo gosudarstvennogo tekhnicheskogo universiteta*. 2011. Iss. 4, p. 40-43 (in Russian).

14. Klishin V.I., Kissling U., Roiter M., Vessel A.O. Automatic roof support system control (ARSSC) as a means of adapting the support to various mining and geological conditions of the Kuzbass mines. *Vestnik Kuzbasskogo gosudarstvennogo tekhnicheskogo universiteta*. 2014. N 1, p. 34-39 (in Russian).

15. Cheremenskii B.G. Energy criterion for choosing rational resistance of roof support. Fizicheskie protsessy gornogo proizvodstva: Vsesoyuz. mezhvuz. sb. Leningr. gorn. in-t im. G.V.Plekhanova. Leningrad, 1979. Iss. 7, p. 81-84 (in Russian).

16. Novak Petr., Babjak Jan. Roof support control in longwall technology. 14th Coal Operators' Conference, University of Wollongong, The Australasian Institute of Mining and Metallurgy & Mine Managers Association of Australia, 2014, p. 34-41.

17. Peng S.S. Longwall Mining, 2nd edition, 2006. Published by: Society for Mining, Metallurgy, and Exploration. Inc. (SME), p. 621.

18. Ramesh Kumar B., Siva Sankar U., Prasad V.N.S. Selection of Powered Roof Supports – 2-Leg Shields vis-à-vis 4-Leg Chock Shields. International Conference on Underground Space Technology, 17-19 January 2011, Bangalore, India, p. 1-20.

19. Vatavu Sorin, Vatavu Niculina. Constructive and Calculus particularities for the hydraulic props of powered roof support. Annual of the University of Mining and Geology «St. Ivan Rilski». Sofia, Bulgaria. Vol. 49. Part III. Mechanization, electrification and automation in mines. 2006, p. 7-10.

20. Cheng Jingyi, Wan Zhijun, Syd S. Peng, Liu Sifei, Ji Yinlin. What can the changes in shield resistance tell us during the period of shearer's cutting and neighboring shields' advance. *International Journal of Mining Science and Technology*. 2015. Date Views 15.08.2015 dx, p. 1-7. doi.org/10.1016/j.ijmst.2015.03.006.

***Authors*: Aleksandr V. Stebnev,** *Chief mechanic*, *stebnevav@suek.ru* (*OJSC «SUEK – KUZBASS»*, *Leninsk-Kuznetsk*, *Russia*), **Vladimir V. Buevich,** *Leading engineer*, *buevich.v@bk.ru* (*JSC «VNII Galurgii»*, *Saint-Petersburg*, *Russia*).

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