UDC 622.23.05

V.V. GABOV *(Doctor of Technical Sciences, Professor, Saint-Petersburg Mining University, Saint Petersburg, Russian Federation), gvv40@mail.ru*
D.A. ZADKOV *(Candidate of Technical Sciences, Assistant Professor, Saint-Petersburg Mining University, Saint Petersburg, Russian Federation), dzadkov@yandex.ru*
A.V. STEBNEV *(Chief mechanic, OJSC "SUEK-Kuzbass", Leninsk-Kuznetsky, Russian Federation), StebnevAV@suek.ru*

EVALUATION OF STRUCTURE AND VARIABLES WITHIN PERFORMANCE RATING OF HYDRAULICALLY POWERED ROOF SUPPORT LEGS WITH SMOOTH ROOF CONTROL

The authors analyze variables in the structure of performance rating of powered roof support. The performance data set is composed of varied pressures in the head ends of legs in the course of sequential operations within a production cycle between advances of powered support. Factually, the performance rating represents the control over resistance of hydraulic legs to mine roof convergence. It is shown that the work of modern powered roof supports, with invariable pressures within the performance rating of legs, unavoidably entails static and dynamic impact on immediate roof. These periodic static and dynamic impacts on immediate roof intensify jointing, sags and cascading of roof rocks, and induce loss of touch between the powered roof support and the roof. In the proposed structure for the performance rating of powered support legs, the function of overload protection is separated from the function of roof control. It is suggested to implement regulation of leg resistance to roof convergence gradually, by replacing sequential actuation of pressure relief valve, generating equilibrium resistance, by continuous smooth regulation, which mitigates impact on immediate roof rocks, improves adaptability of powered support sections to gradually changing rock pressure and eliminates dynamic impact of powered support on immediate roof rocks in the mode of roof control. The overload protection function of powered roof support actuates only when the support is overloaded and takes no direct part in the ground control process. The article gives a formula to calculate equivalent resistance of hydraulic legs per production cycle. The new structure and variables of the proposed performance rating for powered support legs both reduce impact on immediate roof rocks, simplify production cycle of powered support section, shorten duration of this production cycle and extend operating period of powered support section in the mode of the controlled resistance. All these factors contribute to better stability of operation of powered support sections in rational modes and to enhanced efficiency of mechanized longwall equipment. The method of smooth pressure regulation enables transmission and efficient use of strata pressure energy in hydraulic system of powered roof support in a fully mechanized longwall.

Key words: *coal, longwall face, rock pressure, regulation, powered roof support section, adaptation, performance rating, hydraulic system.*

DOI: *dx.doi.org/10.17580/em.2016.02.09*

Introduction

Since pioneer engineering of equipment for fully mechanized longwall coal production in the middle of the 20th century, the attempts at improving design of hydraulically powered support units, roof control in longwall faces and hydraulic circuitry both of the support section and powered support as a whole have never stopped [1–3]. Many models of reliable, high capacity and heavy-duty systems of longwalling machines have been designed and manufactured as a result, including hydraulically powered supports with manual, remote, programmable and automated control [4, 5].

It has greatly been succeeded in essential enhancement of efficiency in fully mechanized longwall coal production [6–10]. On the other hand, under complex ground conditions, mechanized longwall heading machines exhibit much worse performance [11, 12].

Currently powered roof supports are manufactured specifically for certain geological and geotechnical conditions. And yet, efficiency of mechanized longwall equipment largely depends on rock pressure and immediate roof strength characteristics, which can vary in a wide range. At the same time, the only control parameters to influence performance of powered support legs have a very rigid structure.

Problem formulation

Operation of sections of modern powered roof supports with rigidly set leg pressures can cause the phenomenon named as “trampling on immediate roof,” which means static and dynamic impacts exerted by the support on the roof rocks. The consequences of this phenomenon are fast jointing and cascading of immediate roof rocks, and loss of touch between the roof and support. Therefore, effectivization of ground control in a longwall face area through improvement of structure and values of control parameters for influencing performance of powered support section legs with the help of new engineering solution was and yet remains of concern.

The aim of this study is to find a method to make ground control more efficient via higher resistance of hydraulic legs of powered roof support to convergence of immediate roof.

Main part

The primary supporting element of any section of powered roof support is hydraulic leg that cyclically comes to force interaction, through platform and shielding, with rocks

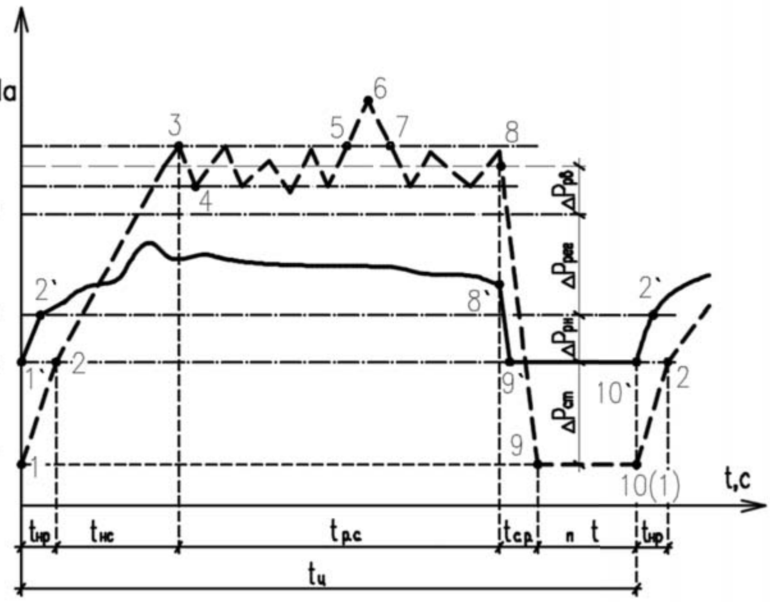

Fig. 1. Ideal control parameters for performance of legs of powered roof support

in mine floor and roof in accordance with the rated performance (**Fig. 1**). The quality of supporting of mine roof and shielding of face area from rock falls and sags depends on how each support section and the powered roof support as a whole perform all sequential operations and on how these operations influence roof control efficiency.

The roof control process in **Fig. 1** is marked with points 3–8 representing successive steps after actuation of pressure relief valve and onset of transient (dynamic) processes in the powered roof support–immediate roof system. The dynamic processes intensify origination and rate of growth of joints in rocks of immediate roof.

The modern powered roof supports have increased characteristics of strength and pressure, and higher metal consumption. Hydraulic legs of such powered roof supports operate mainly in the mode of progressive resistance (branch 2–3 in **Fig. 1**) without reaching the mode of equilibrium resistance within a production cycle. From evidence of numerous data captured within the years of operation of powered roof supports, legs in the case described experience nonuniform loading, and actuations of pressure relief valves actually represent emergency situations [13].

Damage of roof rocks (cutters, schistosity, falls) is, in one case, the consequence of excessive resistance of support, being higher than strength of rocks composing immediate roof, and, in another case, is the result of successive actuations of pressure relief valve, which exert dynamic impacts on immediate roof rocks [14, 15].

Considerable contribution to damage of immediate roof rocks is made by the change in effective forces in hydraulic legs at the production cycle stages of setting pressure (branch 1–2 in **Fig. 1**), progressive resistance (branch 2–3) and relief (branch 8–9). Considerable difference in the fluid pressures in head ends of hydraulic legs (thrust force) at the beginning and at the close of each operation induces extensive jointing of immediate roof rocks [16, 17].

The integral estimates of operating regimes of powered support sections are the duration t_c of a production cycle of successive operations, equivalent resistance F_e per cycle, maximum static pressure difference ΔP_{st} in head ends of legs (**Fig. 1**) and the degree of irregularity of loading per cycle.

The cycle duration of a powered roof support section is composed of durations of individual operating stages within a cycle:

$$t_c = t_{sp} + t_{pr} + t_{cr} + t_{rel} + t_a,$$

where t_{sp} is the setting pressure time; t_{pr} is the progressive resistance time; t_{cr} is the controlled resistance time; t_{rel} is the pressure relief time; t_a is the advance time. The time of the powered support section function in the mode of the controlled resistance (ΔP_{cr}) is only and exclusively conditioned by the duration of coal production cycle at a longwall face.

The increment in the pressure in the head ends of legs in the course of a production cycle depends on the difference in the pressures at the beginning and at the close of each operation (refer to **Fig. 1**) and is given by $\Delta P_{sp1} = P_{sp} - P_a$ for the mode of setting pressure; by $\Delta P_{pr1} = P_{pr} - P_{sp}$ in the mode of progressive resistance and by $\Delta P_{rel1} = P_{rel} - P_a$ during pressure relief.

The upper pressure P_a during the powered support advance (**Fig. 1**) is set as a function of stability of immediate roof rocks.

The equivalent resistance of hydraulic legs to roof convergence per production cycle can be found from the formula below:

$$F_e = \sqrt{\frac{F_{sp}^2 t_{sp} + F_{pr}^2 t_{pr} + F_{cr}^2 t_{cr} + F_r^2 t_r + F_a^2 t_a}{t_c}},$$

where F_{sp}, F_{pr}, F_{cr}, F_{rel} and F_a are the leg resistances in the modes of setting pressure, progressive resistance, controlled resistance, pressure relief and the powered support advance, respectively; the leg resistance in any *i*-th mode of production cycle is conditioned by the product of fluid pressure in the head end of the leg and the area of the leg piston:

$$F_i = \frac{P_i \pi D^2}{4},$$

where P_i is the fluid pressure in the head end of a leg in the given mode of operation and D is the diameter of the leg piston.

The degree of dynamic loading of a powered support section in the period of roof control or within the entire production cycle can be estimated in terms of EMS, room mean square deviation or coefficient of variation in loading.

To eliminate static and dynamic impact on mine roof, it is suggested to reduce the structure of the control parameters that influence performance of powered support legs to the shape of the curve 1′–10′ in **Fig. 1**. The features of this structure of the control parameters are:

— separation of the overload protection function and roof control function of a powered support section;

— roof control through continuously adjustable flow rate of fluid from the head end of a leg, via fluid converter, to pressure line of the hydraulic system of the powered support and not as a consequence of actuations of relief valve as is provided in the standard performance rating;

— feasible advance of powered support sections in the regimes of no touch between the support and the mine roof, with upward thrust and in no-relief mode, depending on the condition of the roof and on the type of the powered support section.

Modern pumping stations are capable of ensuring thrust of legs up to the setting pressure P_{sp}. This value can be assumed the lower limit of permissible pressures in the performance rating of a powered roof support section.

The upper limit of the pressure range is assumed from the maximum permissible loads on support with respect to the strength of the powered support section and from the forecasted loads on support with regard to the strength of immediate roof rocks in the course of extraction. This pressure limit is set as the pressure relief P_{rel} of unloading valve. Under such conditions, the pressure relief valve will only perform the protective function.

The pressure control range is between the limit fitting the setting pressure and the limit of the relief valve actuation. To eliminate false response of pressure relief valve in the transient operating modes, the pressure control zone is isolated by the protective zones of lower limit ΔP_{ll} and upper limit ΔP_{ul} (**Fig. 1**). Eventually, when implementing strata pressure control, actuations of relief valve as well as dynamic impact on immediate roof due to these actuations will be avoided. In the work pressure range (controllable pressure) ΔP_{ll}–ΔP_{ul}, in case of accelerated convergence of mine roof, the control arrangement [18, 19], which switches a valve flow rate regulator with a comparison element, fluid converter and a back valve, ratably increases the work fluid flow rate from the head ends of legs to the pressure line of hydraulics of powered roof support [20]. An increase in the thrusting force is limited by an increase in the leg yield. Accordingly, ground control will be executed in the quasi-static regime of loading exerted on hydraulic legs and pressures on immediate roof. The energy of roof convergence will be transmitted to the hydraulic system of powered support.

Sections of powered support can be advanced with the relief of legs down to the setting pressure pressure P_{sp}. Such mode of advance is implemented, e.g. in walkway sections of powered supports used at junctions of longwalls and roadways. When sections of support are advanced in the no-relief mode, the static impact on the roof rocks is eliminated owing to small pressure difference.

The duration of the production cycle of a powered support section in case of using the new performance rating makes:

$$t'_c = t'_{sp} + t'_{pr} + t'_{cr} + t'_{rel} + t'_a,$$

where, as against the standard performance, the progressive resistance time $t'_{pr} < t_{pr}$; the controlled resistance time $t'_{cr} > t_{cr}$; the pressure relief time $t_{rel} < t_{rel}$; the advance time $t'_a > t_a$ and the setting pressure time $t'_{sp} = 0$.

The equivalent resistance of legs per cycle in case of the proposed performance rating can be given by:

$$F_e = \sqrt{\frac{F'_{ir}t'_{ir} + F'_{cr}t_{cr} + F'_r t'_r + F'_a t'_a}{t_c}},$$

where F'_{pr}, F'_{cr}, F'_{rel} and F'_a are the averaged leg resistances over the time of the i-th operations in the cycle (F_{pr}, F_{cr}, F_{rel} and F_a — respectively, leg resistances in the modes of progressive resistance, controlled resistance, pressure relief and the powered support advance); t_{ip}, t_{cr}, t_{rel} and t_a — durations of the periods of progressive resistance, controlled resistance, relief and section advance time, respectively.

Based on the aforesaid, the new structure and variables within the performance rating of legs of powered roof support not only reduce static and dynamic impacts on immediate roof, but simplify structure of operations within a production cycle of a powered roof support section, shorten the rated duration of the production cycle and extend the relative duration of the powered support section operation in the mode of the controlled resistance, which enhances the stability of operation of powered roof support sections in rational regimes and the efficiency of the entire mechanized longwall coal production machinery.

Conclusions

The new performance rating offered for hydraulic legs of sections of powered roof support, with the separated functions of protection and control, smooth regulation of resistance of powered support legs to roof convergence and with no-relief advance of support sections enables:

— reduction in static impact induced on immediate roof;

— improvement of adaptability of support sections to gradually varying rock pressure;

— elimination of dynamic impact exerted by powered roof support on immediate roof in the mode of overburden pressure control;

— transmission and efficient use of overburden pressure energy in hydraulic system of powered roof support.

References

1. Yu. A. Korovkin, Yu. L. Khudin. *Mekhanizirovannye krepi ochistnykh zaboev* (Mechanized supports of breakage faces). Moscow : Nedra, 1990. 413 p.
2. R. Slusage, S. Falat. Lavnye krepi proizvodstva zavoda gornykh mashin «GLINIK» dlya ugolnoy promyshlennosti Rossii (Face supports of production of mining machines "GLINIK" plant for Russian coal industry). *Ugol = Russian Coal*. 2006. No. 4. p. 21.
3. V. I. Klishin, W. Kissling, M. Reuter, A. O. Wessel. Sistema avtomaticheskogo upravleniya krepyu (SAUK) kak sredstvo adaptatsii krepi k razlichnym gorno-geologicheskim usloviyam shakht Kuzbassa (Automatic control system as means of roof supports adaptation to different mining and geological conditions of Kuzbass mines). *Vestnik Kuzbasskogo gosudarstvennogo tekhnicheskogo universiteta = Vestnik of Kuzbass State Technical University.* 2014. Iss. 1(101).
4. Linnik Yu. N., Krashkin I. S., Merzlyakov V. G. et al. Kontseptsiya razvitiya ochistnogo, prokhodcheskogo, konveyernogo i burovogo oborudovaniya na period do 2020 goda (Concept of development of purification, sinking, conveyor and drilling equipment for the period to 2020). *Gornoe*

CONTENTS

oborudovanie i elektromekhanika = Mining equipment and electromechanics. 2006. No. 2. pp. 2–12.

5. Podkolzin A. A. Sovershenstvovanie gidrosistemy sektsii mekhanizirovannoy krepi (Improvement of hydrosystem of mechanized support section). *Izvestiya Tulskogo gosudarstvennogo universiteta. Tekhnicheskie nauki = News of the Tula State University.* Technical sciences. 2014. Iss. 2.
6. S. S. Peng. Longwall Mining. 2nd edition. October 2006. p. 621.
7. Cheng Jingyi, Wan Zhijun, PengSyd S., 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.doi.org/10.1016/j.ijmst.2015.03.006.
8. 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.
9. Jonathon C. Ralston, David C. Reid, Mark T. Dunn, David W. Hainsworth. Longwall automation: Delivering enabling technology to achieve safer and more productive underground mining. International Journal of Mining Science and Technology. November 2015. Vol. 25, Iss. 6. pp. 865–876.
10. Petr Novak, Jan Babjak. Roof support control in longwall technology. 4th Coal Operators Conference, University of Wollongong, The Australasian Institute of Mining and Metallurgy & Mine Managers Association of Australia, 2014. pp. 34–41.
11. Remezov A. V., Klimov V. V. Issledovanie vliyaniya opornogo davleniya ot ochistnogo zaboya i zon PGD na gornye vyrabotki (Research of abutment pressure influence of production face on mine workings). *Vestnik Kuzbasskogo gosudarstvennogo tekhnicheskogo universiteta = Vestnik of Kuzbass State Technical University*. 2011. Iss. 4.
12. Gorodilov N. N. Osobennosti rezhimov raboty mekhanizirovannoy krepi s uchetom veroyatnostnogo kharaktera vzaimodeystviya ee s trudnoobrushayushcheysya krovley ugolnogo plasta (Features of operating modes powered support with account statistically distributer of character of her interaction with complicated handing wall of the coal layer). *Gornyy Informatsionno-Analiticheskiy Byulleten = Mining Informational and Analytical Bulletin.* 2012. No. 3. pp. 234–239.
13. Bykov S. V., Myshlyaev B. K. Opredelenie soprotivleniya mekhanizirovannykh krepey podderzhivayushchego tipa (Definition of resistance of mechanized supports). *Voprosy gornogo davleniya = Issues of rock pressure.* 1985. Iss. 43.
14. Kiyashko I. A., Saratikyants S. A., Ovchinnikov N. P. et al. *Vzaimodeystvie mekhanizirovannykh krepey s bokovymi porodami* (Interaction of mechanized supports with country). Moscow : Nedra, 1990. 128 p.
15. Cheremenskiy B. G. Energeticheskiy kriteriy vybora ratsionalnogo soprotivleniya krepi (Energetic criteria of the choice of rational resistance of support). *Fizicheskie protsessy gornogo proizvodstva: Vsesoyuznyy mezhvuzovskiy sbornik* (Physical processes of mining: All-union inter-university collection). Leningrad : Leningrad Mining Institute named after G. V. Plekhanov, 1979. Iss. 7. pp. 81–84.
16. Klishin V. I., Matviets Yu. V. *Povyshenie adaptatsii odnoryadnoy mekhanizirovannoy krepi k usloviyam nagruzheniya* (Increasing of adaptation of single-range mechanized support to the loading conditions). Novosibirsk : Institute of Mining (Siberian Branch RAS), 9/XI 1992.
17. Klishin V. I. *Adaptatsiya mekhanizirovannykh krepey k usloviyam dinamicheskogo nagruzheniya* (Adaptation of mechanized supports to the conditions of dynamic loading). Novosibirsk: Nauka, 2002. 200 p.
18. Buevich V. V., Gabov V. V., Zadkov D. A., Kabanov O. V. Bezimpulsnoe upravlenie rezhimom raboty gidrostoek sektsiy gidrofitsirovannoy krepi ochistnogo mekhanizirovannogo kompleksa (Non-Pulse Control of the Operating Mode of Hydroracks of Sections Hydraulic Powered Support the Clearing Mechanized Complex). *Gornoe oborudovanie i elektromekhanika = Mining equipment and electromechanics*. 2015. No. 3. pp. 28–34.
19. Buevich V. V., Gabov V. V., Zadkov D. A., Vasileva P. A. Adaptation of the mechanized roof support to changeable rock pressure. Eurasian Mining. 2015. Iss. 2. pp. 11–14. doi: 10.17580/em.2015.02.03
20. Buevich V. V., Gabov V. V., Babyr N. V., Zadkov D. A., Stebnev A. V. Adaptatsiya sektsii mekhanizirovannoy krepi sovershenstvovaniem mekhanicheskoy kharakteristiki gidroprivoda ee gidrostoek (Adaptation of Powered Roof Support Section to Improve the Mechanical Characteristics of the Hydraulic Drive of her Legs). *Gornoe oborudovanie i elektromekhanika = Mining equipment and electromechanics.* 2016. No. 3. pp. 28–34.

CONTENTS