SURFACE STRAIN HARDENING FOR THE PERFORMANCE IMPROVEMENT OF HYDRAULIC ACTUATORS IN POWERED ROOF SUPPORTS

[1]Jarosław MIKUŁA, [2]Stanisław MIKUŁA, [3]Stanisław SZWEDA

[1]*Silesian University of Technology, Faculty of Mechanical Engineering, Gliwice, Poland, EU,* *jaroslaw.milkula@polsl.pl*

[2]*Silesian University of Technology, Faculty of Mining and Geology, Gliwice, Poland, EU,*

[3]*KOMAG Institute of Mining Technology, Gliwice, Poland, EU,* *sszweda@komag.eu*

https://doi.org/10.37904/metal.2019.810

Abstract

In the paper working conditions and requirements for cylinders of hydraulic actuators, used in mining roof supports to protect the roof of workings in underground coal mines are discussed. Significant functional effects that can be obtained by using the surface strain hardening of internal surfaces of cylinders of hydraulic actuators are indicated. A device designed for a dynamic method of percussive burnishing of internal cylinder surfaces with the use of a special hydraulic system is presented. The device enables an implementation of high-efficiency surface strain hardening. This treatment makes it possible to improve the resistance of cylinders to fatigue cracks and to harmful tribological phenomena resulting in a leakage of the working medium, affecting the environment negatively. An application of a strengthening device for cylinders enables a more favourable adjustment of hydraulic cylinders for use in extreme working conditions, in particular in the workings threatened by bumping hazards. Besides, the surface plastic deformation also serves to improve usage conditions of high-pressure sealing nodes and it reduces the leakage of water-in-oil emulsion.

Keywords: Hydraulic leg, percussive burnishing

1. INTRODUCTION

Basic elements of powered roof supports, used to protect the roof of exploitation workings in underground hard coal mines, are hydraulic legs that, together with other actuators, form a hydraulic system transferring rock mass pressure [1]. These actuators, supplied with water-in-oil emulsion, are subjected to big variable loads due to the rock mass pressure. They are used in conditions of high pollution with coal and mineral dust as well as strong corrosive conditions resulting from high air humidity and the presence of, often highly saline, groundwater [2].

Loading of hydraulic actuators in a powered roof support unit is characterised by a pulsating time waveform from zero with high amplitude. The cyclical variability of this load results from a unit operational cycle, determined by the seam mining process. Variable support unit load causes a development of, most often low-cycle, fatigue damages in its components [3-5].

During the mining exploitation, a support section is also subject to impact loads caused by rock bursts and rock bumps. Both the place, time of occurrence and the load rate are very difficult to predict. The occurrence of the impact load results in a damage of the basic load-bearing components of support units, mainly legs and hydraulic actuators [6-8]. A replacement of damaged components in an active working is very difficult, as there is a high risk to occupational safety and a necessity of longer breaks in the mining process, which results in high economic losses. Due to the above, the requirements concerning the reliability of the support unit components, especially legs and actuators, are particularly high [9,10]. These requirements increase with the necessity to conduct mining exploitation in even more difficult conditions, characterised by an increased pressure of the rock mass and dynamic load of high intensity. Such a situation requires a perpetual search of methods for improving the operational properties of support units, taking into account the rationality of costs.

As regards hydraulic actuators, used in the powered roof support units, the highest possible strength, especially fatigue strength and resistance to destructive abrasive and corrosive processes, is required. At the same time actuator cylinders must be resistant to brittle fracture, which in the conditions of rock bursts or bumps, determines the acceptable level of occupational safety [11].

At present, cylinders of hydraulic legs and actuators are manufactured from thick-walled pipes made of high-quality alloy steel [12]. During the production process, they undergo toughening, turning of the internal diameter and then grinding. In the result of grinding, an unfavourable surface roughness system with a circumferential direction, that is perpendicular to the motion direction of high-pressure polymer seals, is generated. In addition, in the process of inner surfaces grinding, sharp grains drop off the grinding wheels and become an integral part of the cylinder surface layer. These circumstances are conducive to the abrasive wear of the sealing node, causing leakage of the working medium. In hard coal mining, due to the risk of fire, water-in-oil emulsion containing 95 - 97 % of properly prepared water is applied. Other components of the emulsion are: oil, emulsifiers that ensure a permanent preservation of the emulsion properties, corrosion inhibitors and agents protecting the emulsion against a biological degradation. Leakages of the emulsion from the actuators' operating areas, in which the pressure is up to 42 MPa, are very undesirable not only due to the cost of topping up the emulsion in the hydraulic system of powered roof supports. The leaked emulsion enters the water pumped onto the surface, contaminating water courses and reservoirs. The contamination of coal run-of-mine with emulsion leakage is also harmful. In the process of burning coal contaminated with oil and emulsifiers, harmful chemical compounds enter the atmosphere. Therefore, ensuring high efficiency of sealing nodes and limiting their wear is very important due to technical and ecological reasons. A significant improvement in this respect can be generated by properly implemented surface strain treatment applied to the inner surfaces of hydraulic cylinders, especially in their cooperation area with the high-pressure sealing node.

2. SURFACE STRAIN HARDENING OF INNER SURFACES OF THE HYDRAULIC ACTUATOR CYLINDERS

The main purpose of surface strain hardening of machinery components is to improve fatigue properties [13,14]. They are obtained in the result of generating a favourable state of residual compressive stresses in the burnished surface layer. These stresses affect the stress distribution caused by the external load, reducing the value of the maximum tensile stress in the surface area, characteristic for a majority of load cases in the machinery components. Fatigue cracks induced by tensile stresses most often start developing from the surface layer. The surface strain strongly inhibits a nucleation and development of fatigue cracks, which results in a significant increase in the fatigue strength [14].

An important effect of hardening the surface layer with surface strain is an increase in the hardness of the burnished layer of steel components. It has a very big and beneficial effect on a component resistance increase to abrasive wear [13]. The strain-hardened components, in a lot of commonly occurring moderate corrosive environments, including water containing chlorides [2], do not show an tendency to particularly disadvantageous pitting corrosion.

Other beneficial effects of the surface strain are not often appreciated. In many types of the surface strain, favourable surface micro-roughness of elements used under lubricating conditions, including lubrication with water-in-oil emulsion, can be obtained. A formation of lubricating micro-pockets in such elements improves the lubrication conditions. Thus, the tribological life of the surface layer increases as regards both dry erosion wear as well as under lubrication conditions.

In the case of hydraulic actuator cylinders of the powered roof support unit, a difficulty is caused by the length of the cylinders, many times longer than their diameters, and increased hardness of the alloy steel cylinder material after heat treatment. Such a situation requires an application of significantly increased impact energy of the burnishing elements in comparison with the energy of typical surface strain hardening devices [13].

For the purpose of surface strain treatment, it is suggested to apply dynamic burnishing process of the inner surface layer of the cylinder using a device with a special hydraulic system, shown in **Figure 1**. The treatment is preferably performed as the final one, after grinding the inner surface of the cylinder.

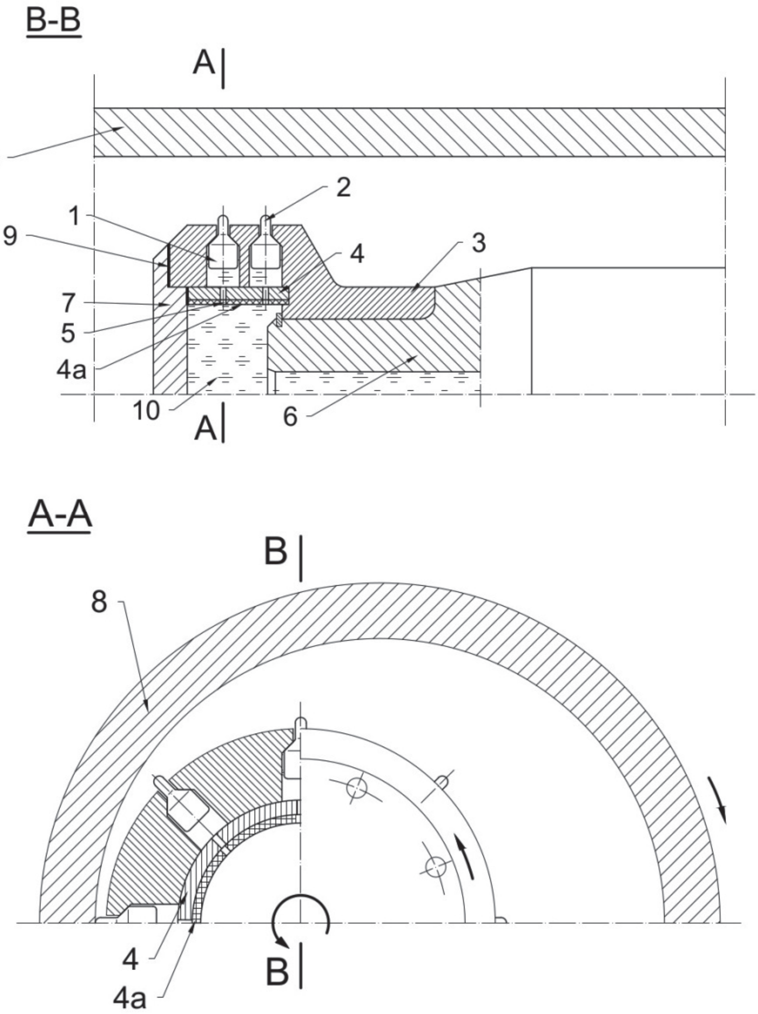

Figure 1 A device for dynamic burnishing of inner surfaces of hydraulic actuator cylinders of the powered roof support (Explanation of designations in the text)

At the end of the rigid drive shaft (6), an interchangeable mounting (3) closed with a cover (7) at the front is mounted with a shape joint (**Figure 2**). There are beaters (1) with working tips (2) mounted radially and loosely in the mounting. The spaces under the beaters are successively filled with a cooling lubricant (10) through the holes (5) made in the rings (4) and (4a). The beaters (1) have spiral grooves (11) arranged symmetrically on their cylindrical side.

A cooling lubricant is continuously supplied under pressure into the mounting (3), for example through a hollow shaft (6) of the device. When the mounting (3) spins, the beaters (1) hit their working tips (2) successively against the inner surface of the machined cylinder (8). In the impact result, the beaters (1) move back into the mounting, causing an instantenous dynamic pressure increase of the cooling lubricant in the space under the beaters. Such an action results in a significant increase in the instantenous burnishing force; at the same time, a dose of the cooling lubricant flows out of the mounting, causing an efficient cooling and lubrication of the machined cylinder area and of the beater working tips. A typical oil-in-water emulsion, used in machining process can be used as a cooling lubricant. The liquid under the beaters acts as a hydraulic spring, whose rigidity depends on the clearance of the beater's seating in the mounting and the hole (5) hydraulic resistance. The hydraulic resistance of all the holes (5) can be adjusted simultaneously by turning the adjustment ring (4a) in relation to the ring (4).

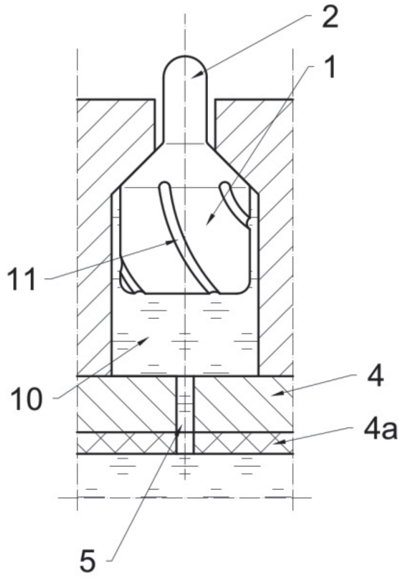

Figure 2 Beater equipped with (1) spiral grooves (11) causing a rotation of beaters around the axis after hitting the machined surface of the cylinder. The hydraulic resistance of the hole (5) connecting the space under the beater with the interior of the mounting filled with the cooling lubricant (10) is adjusted with a ring (4a).

After leaving the impact zone, due to the centrifugal force and the pressure of the cooling lubricant, the beaters automatically move to their outermost position. In this beater position the outflow of liquid outside the mounting (3) is blocked.

Taking advantage of the described control possibilities, choosing the spinning speed of the mounting, moving it closer to the machined surface, the cylinder rotational speed and longitudinal rate of feed, it is possible to control the beaters' impact force in a wide range, and thus also the intensity of hardening the cylinder surface layer. Additional control possibilities of the burnishing effect are obtained due to changing the weight of beaters. Beaters should be made of high hardness steel or tungsten and cobalt cemented carbides, additionally taking advantage of their higher density compared to the steel density.

Due to the spiral grooves (11) on the beater (1) side surface, after each hit of the surface under machining the beater rotates slightly around its axis due to the outflow of the cooling lubricant outside the mounting (3). This arrangement facilitates an efficient cooling and lubrication of the machining area and, due to the continuously changing contact area of the working tip (2) with the surface under machining, ensures its uniform wear. The outflowing liquid is collected at one end of the cylinder, while the other end should be plugged with a rubber stopper. After a filtration and possible cooling, the collected liquid is returned to the device in a closed loop system. An efficient cooling of the machining area prevents against unfavourable phenomena of recrystallisation of cylinder material structures subjected to strain and relaxation of residual stresses. These phenomena may occur in the strain area due to a work conversion of plastic deformations into heat. A lathe with a sufficiently long bed can be used with the described hardening device. The cylinder is rotated by the lathe chuck, and the device together with its drive can be mounted in the lathe saddle with a mechanical longitudinal feed. In the case of particularly long cylinders, the treatment can be performed in stages from both sides of the cylinder or it can be limited to the operation area of the cylinder and sealing nodes.

In the result of the burnishing process conducted with the use of the described device, the treated surface is covered with a very dense system of oval plastic micro-indentations. This results in a formation of a favourable state of residual stresses in the surface layer, improving the fatigue strength, without causing any significant changes in the mechanical properties of the whole cylinder cross-section. The surface hardness and its contact stiffness significantly increase, which considerably improve the resistance of the cylinder inner surface to abrasive wear. Lubricating micro-pockets, generated due to the treatment, enable a more efficient impact of oil particles from the water-in-oil emulsion in the lubricating function of the surfaces having contact with the sealing rings. Due to the higher oil viscosity, its particles suspended in the emulsion, have a greater ability to group and attach to the surface micro-cavities generated in the result of the treatment using the described device. A dynamic impact of the beaters on the surface under treatment enables to remove hard and sharp grains deposited there while grinding the cylinder inner surface.

In the result of the strain hardening the resistance to abrasive and corrosive wear of the cylinder is increased, the resistance of the actuator movement decreases, and a possibility of the working medium leakage outside the sealing node is significantly reduced.

3. SUMMARY

The strain hardening of the inner surface of the hydraulic cylinders used in the units of the mine powered roof supports, enables to obtain a number of advantageous effects improving a performance of the actuators at small costs. The device, presented in this publication, is used for applying the surface strain method, whose parameters can be selected in a wide range, thus shaping the depth of strain hardening, increasing the hardness of the surface layer and the type of the surface relief. It is possible, therefore, to optimise the treatment parameters to obtain the most desirable properties of the surface layer for a given application of the actuator.

In the case of leg cylinders and actuators in the powered roof support units, an increase in both the hardness of the hardened layer as well as the contact stiffness and the highly favourable relief of the cylinder inner surface significantly improve the resistance to abrasive wear and are used to limit the working medium leakage through the sealing nodes. Favourable tribological properties of the cylinder surface layer, obtained in the result of burnishing, depend, to a small extent, on the heat treatment parameters of the steel from which the cylinders of the powered roof support are made. That is why, it is possible to optimise a selection of the material for cylinders and a selection of their heat treatment parameters due to other important properties of the cylinders. This is particularly essential in the case of selecting strength properties, in particular fatigue properties, of the material for actuator cylinders intended for use in the workings where rock burst hazards occur. The criterion for the material selection and heat treatment of the cylinder legs and actuators, used in these conditions, is oriented onto achieving the biggest possible plastic deformation ability, which due to the planned extremely high impact load of the actuator in these conditions, increases the safety of its use. In addition, the application of the surface strain treatment increases the safety of the actuator use due to simultaneous obtaining favourable tribological properties of the cylinder surface layer.

REFERENCES

[1] PENG, Syd S. *Longwall Mining.* 2nd ed. Morgantown: Department of Mining Engineering West Virginia University, 2006. p. 621.

[2] KOTWICA, K., FURMANIK, K. and BRUKHARD, S. Wpływ warunków pracy na zużycie i trwałość cięgien łańcuchowych zgrzebłowych przenośników ścianowych w wybranych kopalniach węgla kamiennego. In: *TUR 2011: Międzynarodowa konferencja Nowoczesne metody eksploatacji węgla i skał zwięzłych.* Cracow: Akademia Górniczo-Hutnicza im. St. Staszica in Cracow, 2011, pp. 397-408.

[3] KOCAŃDA, S. *Zmęczeniowe niszczenie metali*. Warsaw: Wydawnictwo Naukowo-Techniczne, 1972. p. 385

[4] WYRZYKOWSKI, J., PLESZAKOW, E. and SIENIAWSKI, J. *Odkształcanie i pękanie metali* Warsaw: Wydawnictwo Naukowo-Techniczne, 1999. p. 406.

[5] POLAK-MICEWICZ, M. and ŁAGODA, T. Badanie zmechanizowanych obudów górniczych ze względu na trwałość zmęczeniową. *Transport Przemysłowy Maszyny Robocze.* 2013. no. 4, pp. 47-52.

[6] SZYGUŁA, M., CIEŚLAK, Z. and GERLICH, J. Identyfikacja trwałości stojaków i siłowników wykonawczych stosowanych w sekcjach obudowy zmechanizowanej. *Maszyny Górnicze.* 2012. No. 1, pp. 14-18.

[7] JASZCZUK, M., and MARKOWICZ, J. *Parametryczna metoda oceny stanu technicznego sekcji obudowy zmechanizowanej.* Gliwice: Wydawnictwo Politechniki Śląskiej, 2011. p. 272.

[8] STOIŃSKI, K. *Obudowy górnicze w warunkach zagrożenia wstrząsami górotworu.* Katowice: Wydawnictwo Głównego Instytutu Górnictwa, 2000. p. 191.

[9] WINKLER, T. and TOKARCZYK, J. 2010 Multi-Criteria Assessment of Virtual Prototypes of Mining Machines. *Proc. of the World Congress on Engineering and Computer Science.* San Francisco, USA, WCECS, 2010. vol. 2, pp. 1149-1153.

[10] SZWEDA, S., SZYGUŁA, M. and MAZUREK, K. *Czynniki wpływające na postać konstrukcyjną i parametry techniczne sekcji ścianowej obudowy zmechanizowanej. Część 1* Gliwice: Instytut Techniki Górniczej KOMAG, 2016. p. 157.

[11] PN-EN 1804-2+A1 *Machines for underground mines Safety requirements for hydraulic powered roof supports - Part 2: Power set legs and rams*.

[12] ZIARA, A., ŚLUSARZ, R. and KRET, A. Kierunki rozwoju hydrauliki siłowej i sterowniczej w obudowach zmechanizowanych. In: PALCZAK, E. ed. *Badanie, konstrukcja, wytwarzanie i eksploatacja układów hydraulicznych Cylinder 2006* Gliwice: Mining Mechanization Center KOMAG, 2006, pp. 63-72.

[13] PRZYBYLSKI, W. *Technologia obróbki nagniataniem.* Warsaw: Wydawnictwo Naukowo-Techniczne, 1987. p. 465.

[14] ŁUNARSKI, J.(ed.) *Wytrzymałość zmęczeniowa części maszyn po wybranych sposobach obróbki powierzchniowej [Fatigue strength of machine parts after selected surface treatment methods].* Rzeszów: *Zeszyty Naukowe Politechniki Rzeszowskiej,* 1988. no. 17, p. 118.