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Magnetic-and-powder Method in Diagnostics of Welded Joints in Powered Roof Supports

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Abstract. A possibility of diagnosing the welded joints in the components of powered roof supports used in longwall panels of hard coal mines is analysed. It was found that the magnetic-and-powder method is most useful for that purpose. Devices which facilitate assessment of technical condition of welded joints in canopies and bases are discussed. Design and principles of operation of welded joints liquid detector adapted for operation in industrial conditions are presented. Two ideas of a magnetic inductor for technical diagnosis of powered roof support components by the magnetic-and-powder method is discussed.

1. Introduction

Conditions of the power roof support operation in longwall panels of hard coal mines cause their exposure to intensive destructive interactions, leading to the loss of functional properties and reduction in their technical safety. High load from the rock mass pressure, corrosion and abrasive wear are synergetic, mutually increasing the intensity of destructive processes. This applies in particular to canopies and bases, and especially to their welded joints [1, 2, 3]. The necessity of taking into account the synergy of destructive processes in assessment of the roof support virtual prototype is also emphasised by other researchers [4].

Variability of operational load to the roof support has a typical zero-pulsating character with a high amplitude of force and the main frequency resulting from the roof support operating cycle. These loads generate high strain, leading to formation and progress of fatigue cracks, typical for low-cycle load. Low cycle fatigue is characterized by the occurrence of plastic deformations in the crack zone and high rate of crack progress [5, 6].

The critical crack length at which the rapid acceleration of the crack progress begins, leading to a full fracture, in the case of low-cycle fatigue of steel components is much smaller than the critical crack length in the case of fatigue destruction of the components operating in high cycle ranges. The above applies in particular to the welded joints, which, by their nature, constitute strong constructional and structural notches causing the stress accumulation [7]. In addition, there are high welding stresses in the weld zone, often of unfamiliar distribution and character. In the case of spatially complex components such as canopies and bases, it is very difficult to remove welding stress using known technological procedures [5, 8].

In the described situation for maintaining the technical safety of the roof support, it is necessary to diagnose the technical condition of its components frequently, with special attention to the sensitive welded joints. This diagnosis often takes place in difficult conditions of underground mines. Therefore, the diagnostic methods used in these conditions must be simple and of low labour consumption while maintaining high efficiency, as well as low sensitivity to external operational disturbances. Among many defectoscopic methods of diagnosing the machine components, widely described in [9, 10], the penetrating and the magnetic methods deserve special attention.

Use of penetrants consists in covering the tested zones with special liquid that penetrates fatigue fractures and other surface defects. After a removal of excessing liquid and lighting the tested zone with special ultraviolet lamps, the penetrants remaining in fractures, are clearly visible, revealing the places of defects and cracks. Penetrative methods enable only a detection of defects and cracks occurring on the machine component surface and only in accessible places. This is the main disadvantage of these methods. An additional disadvantage of the methods is a need for a special preparation of the tested surface, which is difficult in the case of intensive corrosion and contamination of the component's surface in mine workings. The penetrants are usually prepared in an aerosol form, where the carriers are combustible solvents, what makes their use in the workings threatened by explosion hazard impossible.

The magnetic methods are free from the described disadvanteges. In particular, magnetic-powder methods are very useful [10]. They use magnetic powder (e.g. magnetite powder or other very fine ferromagnetic particles), which gathers with greater intensity in fatigue fractures of steel components, revealing the cracks or structural defects. The progressing fatigue cracks in the steel components, activate magnetically the fracture zones, so in many cases there is no need to use the external magnetic field. When the external magnetization is induced in the cracks zone or structural defects zone, the described effect of gathering the magnetic powder occurs more intensively, because the cracks and material defects change the lines of magnetic field. The main advantage of the magnetic-powder methods, in addition to their simplicity, is their high efficiency, even in the case of invisible cracks and subsurface defects**.**

2. Liquid detector dedicated to the magnetic-powder method

In magneto-powder defectoscopy, dry and the wet methods are distinguished [10]. With the dry method, a magnetic powder is applied to the tested surface after properly oriented magnetisation of steel component. A high consumption of magnetic powder and a need to prepare the surface by removing contaminants such as varnishes and layers of corrosion, which may be difficult in mine conditions, are the method disadvantages.

In the wet variant, the magnetic-powder method usually consists in applying a thin layer of quick-drying white base coat on the tested component, in a form of aerosol. Then, from the second container, a suspension of black finely dispersed magnetic powder in the liquid carrier is sprayed on the coating layer. However, the use of aerosol pressurised containers with flammable carrier substances cannot be accepted in the workings threatened by methane or coal dust explosion hazard.

In the situation described above, it may be better to use a special liquid detector whose design is shown in figure 1. The detector is a vessel (1) made of thin, flexible polymer (for example rubber) containing a transparent liquid carrier (2) with a small amount of finely dispersed magnetic powder.

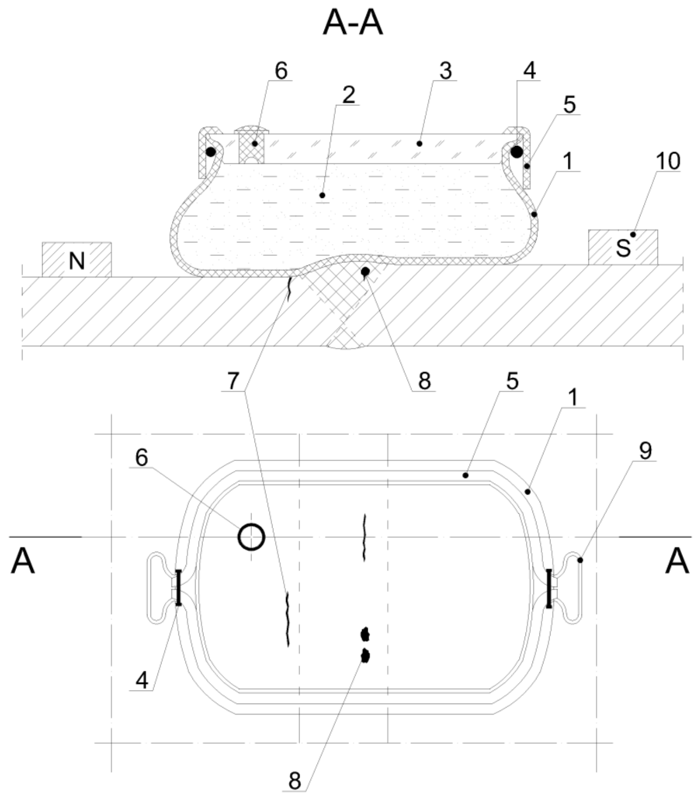

Figure 1. Liquid detector for localization of cracks and structural defects during testing the steel components by the magnetic-powder method (explanation of markings in the text).

The vessel (1) is closed by a transparent lid (3) with a seal (4) and a band (5). The elastomer plug (6) is used to refill the liquid carrier and vent the container inside. The band (5) is connected to the handles (9) for moving and fixing the detector.

Use of the detector requires shaking the container to obtain a homogeneous suspension of the magnetic powder in the liquid carrier. The detector is then placed on the diagnosed zone (e.g. weld). As a result of free sedimentation of the magnetic powder, it falls down to the vessel bottom, gathering with greater intensity within the zones of magnetic field disturbance generated by permanent magnets (10) or special inductors, a sample design of which is described in Chapter 3.

An example of using a liquid detector to assess the technical condition of a butt weld is presented in figure 1. Weld defects, e.g. fatigue cracks (7) in a weld or in a heat affected zone, slagging (8), gas bubbles, short-run castings - are signalled by aggregations of black magnetic powder on the container's white bottom. In the absence of weld defects, the bottom of the container has a uniform grey colour.

The hydrostatic pressure of the liquid carrier enables a good adhesion of the flexible walls of the container to the diagnosed surface. The surface of the tested component does not require any preparation, except for the possible removal of coarse impurities. Surface defects and cracks are best visualized when the magnetic field lines are perpendicular to the extent of defects or cracks. Therefore, it is advisable to diagnose the weld condition at least with two mutually perpendicular magnetization directions.

After a short time and after shaking it, the detector can be used again to test another weld. An observation of the vessel bottom (1) can be facilitated by the use of an optical magnifying glass in place of the transparent lid (3) and additional battery lighting. The detector facilitates a photographic recording of the weld damage condition for keeping the archieves of the damage or, for example,

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tracking the progressing fatigue crack. The described liquid detector enables a good assessment of the crack size or structural defect of the weld. To some extent, it is also possible to use foe an estimation of the depth of the subsurface defects**.**

3. Magnetic inductors adapted for assessments of welds in powered roof supports by the magnetic-powder method

Fully reliable results of diagnosing the technical condition of welds, especially for monitoring the development of fatigue cracks during the use of the powered roof support, are conditioned by the retention of repetitive magnetization parameters in subsequent weld condition evaluation cycles.

It is difficult to obtain the required repeatability of the magnetisation state of the tested roof support zones using the standard inductors with rigid permanent magnets or electromagnets with rigid pole pieces because the surfaces of the roof support components, especially welds, are usually exposed to intensive corrosive interactions, plastic deformations and abrasive wear. In addition, in the conditions of many mines, the powered roof support components are often covered by difficult-to-be-removed crust of mineral impurities. Such a condition of the roof support surface causes for example that the Solver inductors with four flat joints [9], or Pascal type DFN flaw detector [10], are of little use due to their inability for ensuring repeatable adhesion of their terminals to the tested surfaces. Besides, inductors with flat joints, at the connections of their segments, show a big loss of magnetic flux. These losses are also dependent on the angle of the joints bending.

Non-articulated inductor, presented in figure 2, is free from the disadvantages described above [11].

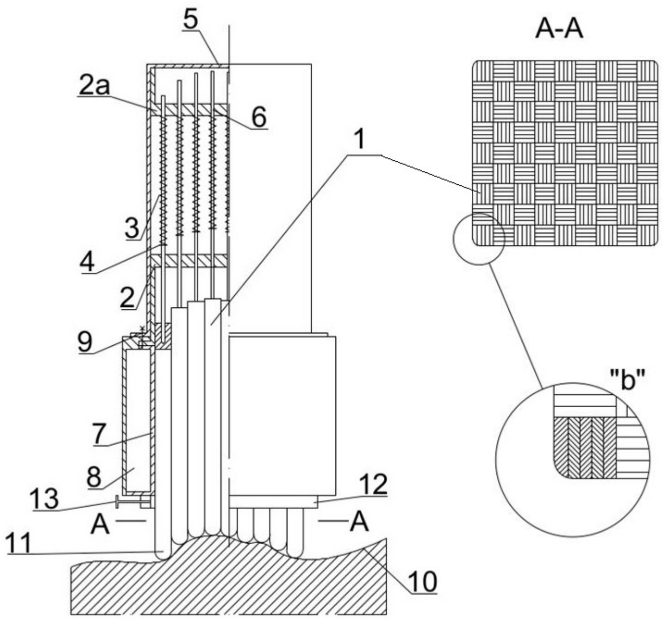

Figure 2. Non-articulated inductor for the components magnetization in magnetic-powder method [11] (expalnation of markings in the text).

The inductor core is made of a pack of loose rods (1) of the square or regular hexagon cross-section.

Each rod has a possibility of independent, free movement along its axis. The rods (1), made of transformer silicon steel, are loosely mounted in guides (2) and (2a) and held in starting position by individual springs (3), supporting one end with support plates (4), and the other end with internal guide bar (2a). The thrust plates (4) are clamped on the rods (1) guides (6). The cover (5) is permanently connected to the guide (2) and the coil bobbin (8) by screws (9).

Core rods can be monolithic or made of transformer sheets glued together (figure 2, fragment “b”). The side surfaces of rods (1) are covered by low-friction coating (e.g. Teflon) to reduce the friction force and to isolate from eddy current induced in rods after switching on the inductor electric power supply system.

Under pressure exerted on the tested surface (10) each rod slides partially to the inductor interior and the springs (3) secure a permanent contact with the tested surface. The current direction in the coil (8) should be selected in such a way that an electromagnetic force, acting on the core, is directed to the tested surface (10). After the test completion and removing the inductor from the tested object, all rods return to the starting position automatically. If necessary, there is a possibility to fix all the rods in a fixed or removable clamp (12) by the screw (13). That can be useful e.g. during testing the numerous identical components. The inductor can be used in combination with another the same inductor or with permanent magnets.

The method of using non-articulated inductors for testing welds is given in figure 3 [11]. A sample position of a crack or other flaw is marked by “x”.

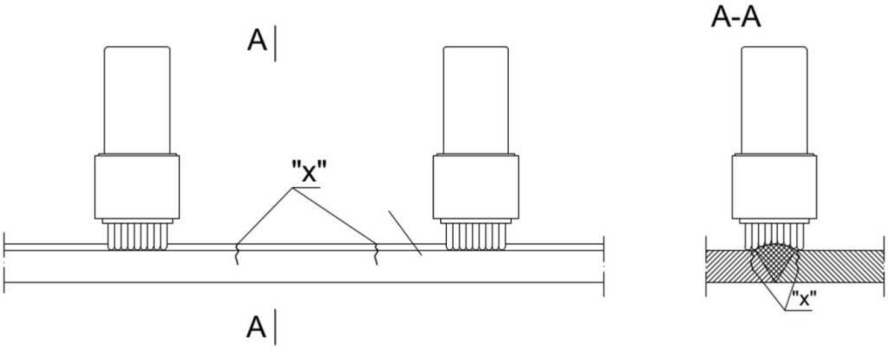

Figure 3. Example of using two non-articulated inductors for diagnosing the weld [11] technical condition. "x" – position of cracks.

The inductor ensures a permanent contact of all the rods with the tested surface securing a constant magnetization conditions despite a change in shape of the surface. Lack of articulated joints, eliminating a loss of a magnetic flux, enables supply the inductor with a current of lower voltage, what increases the work safety and reduces the power consumption. A non-articulated magnetic inductor (figure 2) can be used for a demagnetization of the tested object at the proper power supply, if necessary.

Another suggestion of an inductor design, intended for diagnosing the components, such as welds in powered roof support parts, is presented in figure 4. This inductor can be used in a version with permanent magnets (1a) or in a version with a coil (1b). An exchangeable and movable segment (2) is attached to one of the fixed parts of the inductor core (1), connected by the screw (12) with a pack permanent magnets (1a) or the coil (1b). Its position is fixed by a clamp (8) with a screw pressing (4). Strong tightening of the screw (4) enables good contact of the inductor’s core components resulting in small magnetic flux losses. Pole pieces (5) are made of loose steel balls (9) of small diameter, installed in a flexible enclosure (6), made of, for example, thin rubber. The pole pieces are attached to the ends of the core by clamps (8) with clamping screws (7).

A small amount of oil lubricating the balls (6) was added to the enclosure interior for an anticorrosion protection and for a better adaptation of pole pieces to the tested surface (10), (11).

In the case of using the coil (1b) an adaptation of pole pieces to the tested components is enhanced by electromagnetic forces generated after switching on the electric feeder. The components (1) and (2) of the core are made of transformer sheet packs connected with glue and additionally with rivets. Clamps, screws and rivets are made of paramagnetic materials such as brass.

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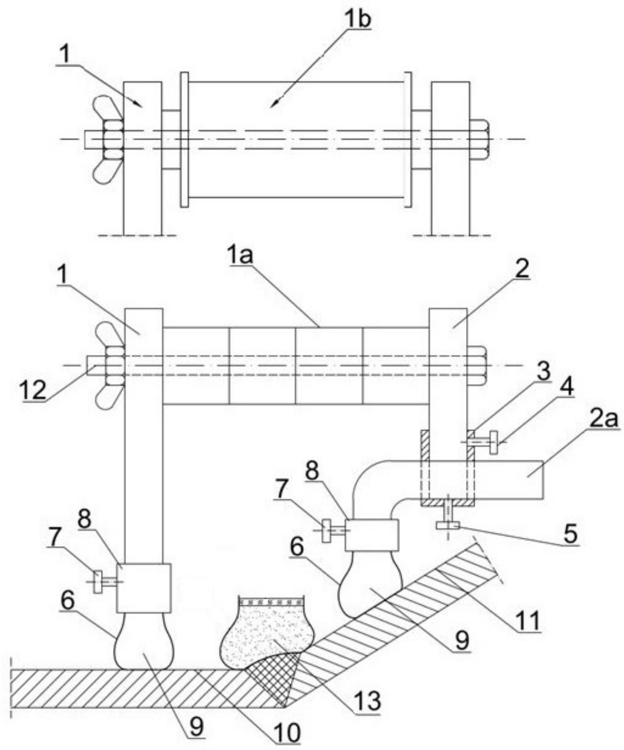

Figure 4. Inductor with a pack of permanent magnets (1a) or a coil (1b) for the components magnetization in the magnetic-powder method (explanation of markings in the text).

Examples of using the fluid detector (13), described in Section 2, for testing welds in powered roof support components of different spatial configuration and cooperating with the inductor with flexible pole pieces are presented in figure 4 and 5.

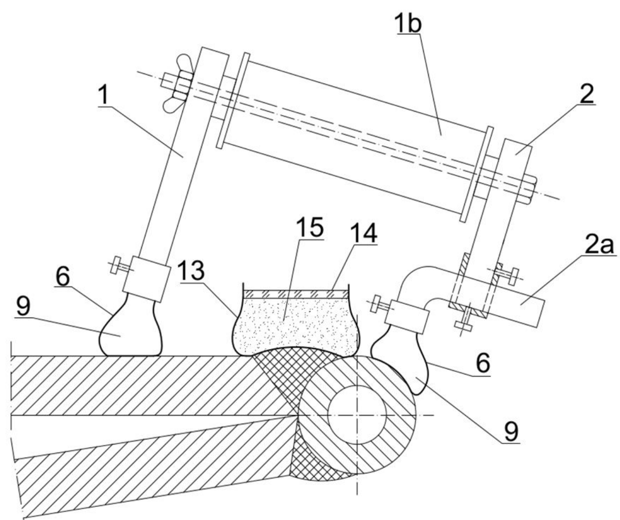

Figure 5. Example of using the inductor with flexible pole pieces and the liquid detector for diagnosing welds. (expalnation of markings in the text).

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A new design of the inductor gives a good repeatability of a roof support magnetization during diagnosing of welds technical condition. Due to small losses in magnetic flux, the inductor ensures a high magnetization level at reduced voltage of power supply.

A liquid detector and magnetic inductors, described in this article, can be used for testing different components to detect cracks or structure flaws.

4. Conclusions

From a number of methods applied for technical diagnostics of powered roof support components, especially those realized in underground mine conditions, the magnetic-powder method in the wet variant is most useful.

The article describes a design of the fatigue cracks and structural defects liquid detector to be used for diagnosing the condition of powered roof supports components, with special emphasis on welded connections.

The described inductors, used for magnetization of roof support components, have many advantageous functions especially for diagnosing machine components in conditions of underground hard coal mines.

References

[1] Jaszczuk M and Markowicz J 2011 *Parametryczna metoda oceny stanu technicznego sekcji obudowy zmechanizowanej* ed. M Jaszczuk and J Markowicz (Gliwice: Wydawnictwo Politechniki Śląskiej)
[2] Szurgacz D 2017 Stress analysis of the powered roof support caving shield *Proc. XXV-th. Int. Conf. TEMAG Trwałość Elementów i Węzłów Konstrukcyjnych Maszyn Górniczych* Ustroń 19-21.10.2017 (Gliwice: Wydawnictwo Politechniki Śląskiej) pp 199-208
[3] Szweda S, Szyguła M and Mazurek K 2016 *Czynniki wpływające na postać konstrukcyjną i parametry techniczne sekcji ścianowej obudowy zmechanizowanej. Część 1* (Gliwice: Monografia Instytut Techniki Górniczej KOMAG)
[4] 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* **2** pp 1149-53
[5] Gurney T R 1999 *Zmęczenie konstrukcji spawanych* (Warsaw WNT)
[6] Wyrzykowski J, Pleszakow E and Sieniawski J 1999 *Odkształcanie i pękanie metali* (Warsaw WNT)
[7] Robakowski T 1991 *Projektowanie złączy i zespołów spawanych* (Instytut Spawalnictwa Gliwice)
[8] Myśliwiec M 1972 *Cieplno- mechaniczne podstawy spawalnictwa* (Warsaw WNT)
[9] Kubiński W 2016 *Wybrane metody badań materiałów* (Warsaw PWN)
[10] Lewińska- Romicka A 2001 Badania nieniszczące – podstawy defektoskopii (Warsaw WNT)
[11] Szweda S 2017 Wzbudnik transformatorowy do badań magnetycznych elementów maszyn i urządzeń. Polska. Patent P 421490 z dn. 04.05.2017