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Selected technologies for destruction of rocks cohesion by using their tensile strength properties

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Keywords: failure of the rocks cohesion, pulling out rock fragments, rescue operations in mines, unconventional mining technologies, rock strength tests

Słowa kluczowe: niszczenie spójności skał, wyrywanie fragmentów skał, akcje ratownicze w kopalniach, niekonwencjonalne techniki urabiania, badania wytrzymałościowe skał

Abstract:

Basic mechanical properties of rock material, crucial for its destruction, and the basic condition for its destruction - the Mohr-Coulomb criterion, are presented at the beginning. The basic strength feature of rocks is their low tensile and shear strength. In practice, this first property is used for mining and processing of rock materials. The article presents selected technologies of rock destruction based on this feature, such as: rock splitting by the expanding method (mechanical wedging, expanding materials, EDH electrohydraulic method). An innovative technology of rock loosening using a fixed bolt is presented as an alternative solution. This technology has been tested and developed at KOMAG for several years, under the projects. The selected results of research work and literature analysis of the problem are given.

Streszczenie:

Na początku artykułu przedstawiono podstawowe własności wytrzymałościowe materiału skalnego, kluczowe dla jego zniszczenia oraz podstawowy warunek ich zniszczenia – warunek Coulomba-Mohra Podstawową cechą wytrzymałościową skał jest ich niska wytrzymałość na naprężenia rozciągające i ścinające. W praktyce, ta pierwsza własność wykorzystywana jest do realizacji procesów urabiania i przeróbki materiałów skalnych. W artykule przedstawione zostały wybrane technologie niszczenia spójności skał wykorzystujące tę właściwość, takie jak: rozłupywanie calizny skalnej przy wykorzystaniu *rozpierania* (klinowanie mechaniczne, materiały ekspansywne, metodą elektrohydrauliczną EDH). Jako rozwiązanie alternatywne przedstawiono innowacyjną technologię odspajania za pomocą utwierdzonej kotwy. Technologia ta jest badana i rozwijana w ITG KOMAG od kilkunastu lat, m. in. w ramach realizacji projektów badawczych. W artykule przytoczone zostały wybrane wyniki prac badawczych i podana szersza analiza literaturowa przedstawionego zagadnienia.

1. Introduction

Significantly lower rock tensile strength than its compressive strength (and shear strength) is the main feature of the rock material. This feature is used in rock mining technologies. This article reviews these technologies, together with an assessment of their scope of application.

One of the least studied and described in the literature methods of using low tensile strength of rocks is the technology of mechanical rock loosening with the use of a bolted string; this method is constantly being extended to include other force input variants.

The concept of a method for mechanical rock loosening and the tests aimed at assessing its applicability were developed for the first time within the INREQ project, for designing the portable device for driving the rescue tunnels [1].

The project presented the main advantages of this method, that is its safe use in the conditions of rock outburst hazard, methane hazard and unstable rock mass. This technology enables the mining of solid rock pieces without destroying the rock mass, even in the case of hard rocks. Simple mechanization of the technology ensures its reliability, however, the slow progress of the roadway development can currently provide satisfactory results only in the case of driving small-size rescue tunnels. The method intended for solid rock driving is based on the use of lightweight and easy to transport manual tools. Due to the degree of mechanization, this method of roadway development has no restrictions concerning the methane concentration. Moreover, it cause destruction of the rock mass only in a strictly defined area and allows for mining the hard rocks [2, 3]. This method has potential for wider application, e.g. rock mining, as an alternative to blasting technology. Its development depends, however, on the basic tests determining empirical models of destruction of various rocks types, which will allow to determine geometry of the pulled off solid and the critical force P causing the material destruction.

Such work was carried out as part of the next RODEST project, the results of which allowed to undertake the development of technology and equipment intended to use in drilling by this method and to evaluate the efficiency of the process comparing to the conventional methods.

Work carried out so far and planned in the future within the framework of the projects financed, among others, by NCBiR, allow to replenish the knowledge on the strength properties of rocks in the complex conditions of stresses, when using this innovative technology. In practice, the developed models of the destruction of rock materials will be used for the development and popularization of the innovative mining technology of mechanical rock loosening by a fixed bolt method [4].

2. Main constants of rock materials determining their strength properties

A rock is a natural concentration of several minerals resulting from various geological processes, such as flooding and solidifying of volcanic lava, deposition of salt or the formation of gravel and sand in river beds. Rocks can be composed of one mineral (simple) or composed of several different minerals (complex). Due to the genesis of the formation, the rocks can be divided into the following three groups [5]:

- igneous (they are a product of magma freezing)
- sedimentary (they are formed on the surface of the lithosphere from the remains of older rocks or from the remains of plant and animal organisms, a characteristic feature is their layered structure (usually parallel to each other)
- metamorphic (these are rocks of igneous or sedimentary origin, which get into deeper parts of the earth as a result of high pressure and temperature, where they change in their original structure and mineral composition).

The mechanical and physical properties of rocks largely depend on the following factors [6, 7]:

- type of rock and their origin,
- rock tectonics (faults, crevices, scratches, cracks, cleavage),
- rock porosity and water content,
- grain size, shape and strength,
- binder properties,
- the direction of force in relation to the foliation.

The most important mechanical properties of rocks include: cohesion c, angle of internal friction φ, uniaxial compressive strength σ_C (or R_c), tensile strength σ_T (or R_r) and shear strength τ [6].

A commonly used material constant for rocks is the uniaxial compressive strength σ_C (or R_c). Uniaxial compression tests are the most popular as they are easy to perform and there is a large database on compressive strength of rocks.

Rocks are granular materials. Mineral grains are bound together to form aggregates. The failure of rocks, despite the compressive forces applied from the outside (and compressive stresses), occurs as a result of exceeding the shear and/or tensile strength. Also, the samples subjected to uniaxial compression tests are generally sheared in one or two planes (Fig. 1).

The bonds between mineral grains and grain aggregates are broken as a result of exceeding the tensile strength.

The uniaxial tensile strength σ_T (or R_r) is the material constant that describes the strength properties of rocks in a best way. Unfortunately, uniaxial (direct) tensile tests are difficult to perform so they are very rarely used. In accordance with the recommendations of the International Society of Rock Mechanics, these tests should be carried out on cylindrical specimens with a slenderness of h:d = 4, glued to the holders of the testing machine, performed with appropriate accuracy and test regimes [8].

The relatively few results of the tests carried out in this way show the specific behaviour of rocks under tension (Fig. 2) for example:

- nonlinearity of the stress σ - deformation ε characteristics in the entire range of tensile stresses (as opposed to compression tests),
- variability of deformation properties, i.e. modulus of longitudinal elasticity E and Poisson's ratio ν together with an increase in tensile stress σ,
- plastic deformations (permanent, irreversible), which are also experienced by rocks under tension.

The analysis of the results of uniaxial tensile, mono- and multicyclic tests and a discussion of the tests conducted so far by Polish and foreign researchers are presented in a few studies. In Poland, Tomiczek dealt with this problem more widely [9, 10, 11, 12].

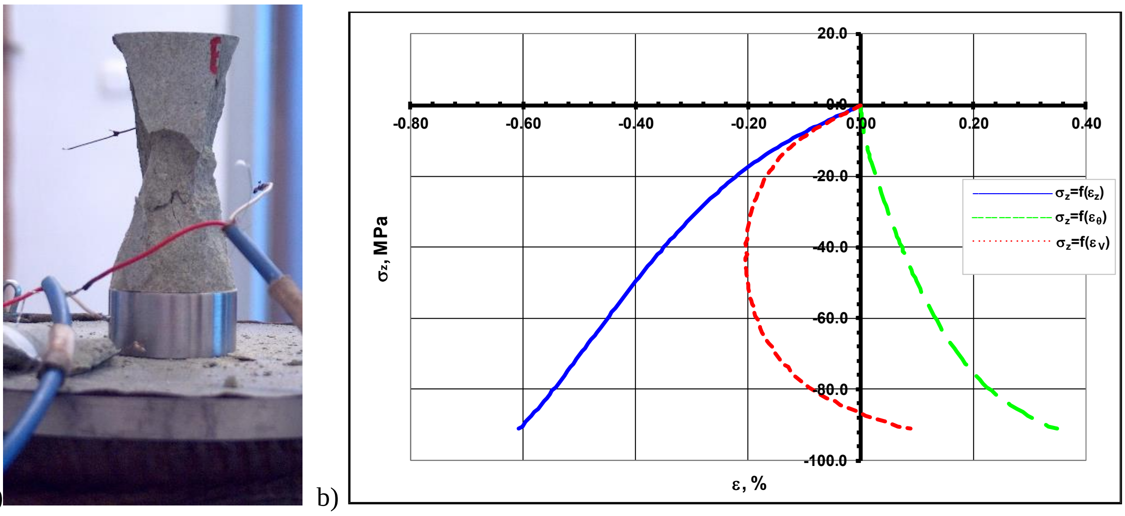

Fig. 1. Typical view of the failured sample (a) and stress σ - strain ε characteristics for rocks (b) in uniaxial compressing test; *Brenna* sandstone [9]

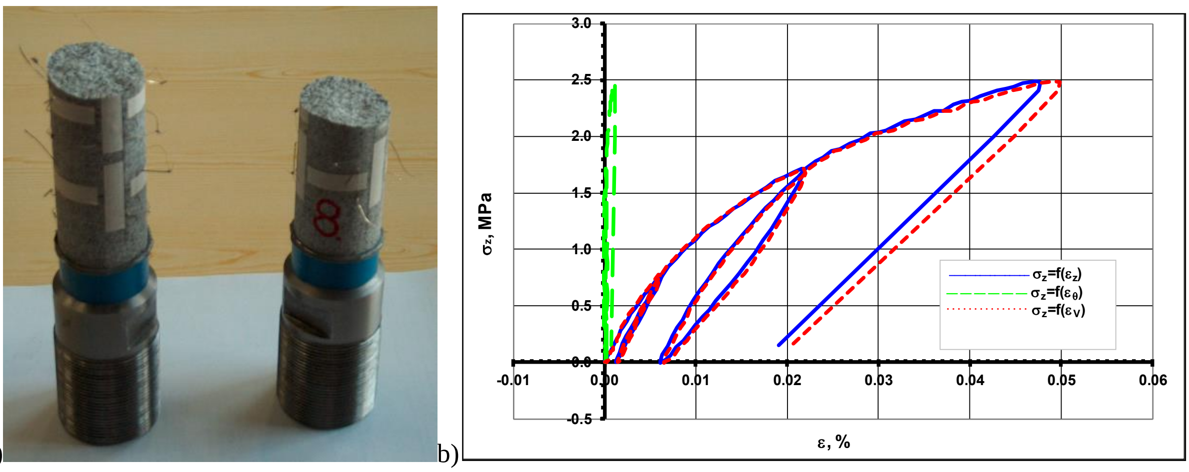

Fig. 2. Typical view of the failured sample (a) and stress σ - strain ε characteristics for rocks (b) in uniaxial tensile test; *Brenna* sandstone [9]

As already mentioned, uniaxial tensile tests are technologically difficult, therefore usually the strength (and deformation) properties of rocks under tensile conditions are determined by indirect methods, e.g. the Brazilian method [13] or the three bending point test [14]. It should be emphasized, however, that the constants determined by indirect methods are different from those determined by the uniaxial tensile method, and the latter are the exemplary values of the constants for rocks in the field of tensile stress (e.g. Tomiczek [9, 10, 11, 12]).

Coulomb-Mohr criterion is one of the basic strength criteria used to describe rock behaviour and failure. It combines all the basic constants characterizing the strength properties of rocks such as: cohesion c, uniaxial tensile strength σ_T (and compression strength σ_C), angle of internal friction φ and shear strength τ.

Coulomb in 1776 suggested the relationship (1) in which he assumed that rocks (also soils and some granular materials) are failured after exceeding the shear strength.

$$\tau = c + \tan\varphi\sigma \tag{1}$$

where:

- τ shear strength,
- c cohesion,
- φ angle of internal friction
- σ normal stress.

This equation was completed by Mohr in 1900 (Fig. 3), Paul in 1968 as well as described, among others, by Labuz and Zang in 2012 [15].

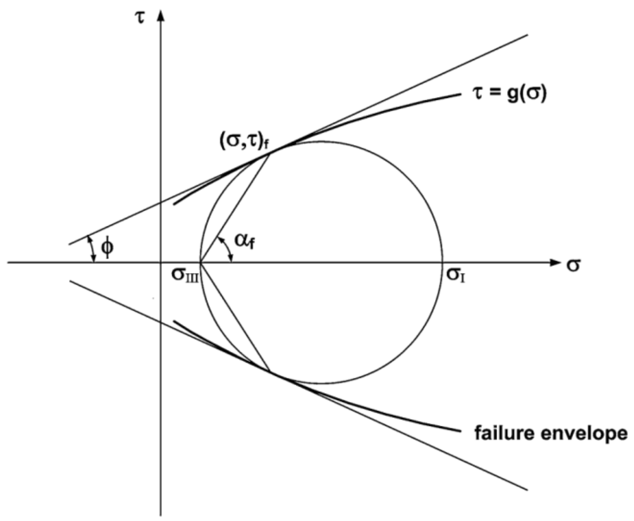

Fig. 3. Mohr circle and envelope; τ – static stress, φ (or ϕ) angle of internal friction, σ_I and σ_{III} – the highest and the lowest main stress [14]

Equation (1) can be written as [14]:

$$(\sigma_I - \sigma_{III}) = (\sigma_I + \sigma_{III})\sin\phi + 2c\cos\phi \tag{2}$$

Coulomb-Mohr criterium in the convention of principal stresses can be written as [14]:

$$\pm\frac{\sigma_1-\sigma_2}{2} = a\frac{\sigma_1+\sigma_2}{2} + b, \pm\frac{\sigma_2-\sigma_3}{2} = a\frac{\sigma_2+\sigma_3}{2} + b, \pm\frac{\sigma_3-\sigma_1}{2} = a\frac{\sigma_3+\sigma_1}{2} + b \tag{3}$$

while:

$$a = \frac{m-1}{m+1}, \qquad 0 \le a < 1$$

$$m = \frac{C_0}{T_0} = \frac{1+sin\emptyset}{1-sin\emptyset},$$

$$b = \frac{1}{m+1},$$

$$C_0 = \frac{m}{m+1},$$
$$T_0 = \frac{C_0}{2}(1 - sin\emptyset),$$

where:

c	Cohesion
C_0	Uniaxial compressive strength (σ_C, R_c),
T	Uniaxial tensile strength (σ_T, R_r),
T_0	Theoretical *MC* uniaxial tensile strength,
ϕ	Angle of internal friction (φ),
$\mu=tan\phi$	Coefficient of internal friction,
σ	Normal stress on plane,
τ	Shear stress on plane,
σ_1, σ_2, σ_3	main stresses (refer to σ_I, σ_{II}, σ_{III})

Coulomb-Mohr envelope in the convention of normal stresses σ and tangential stresses τ is presented in Fig.4.

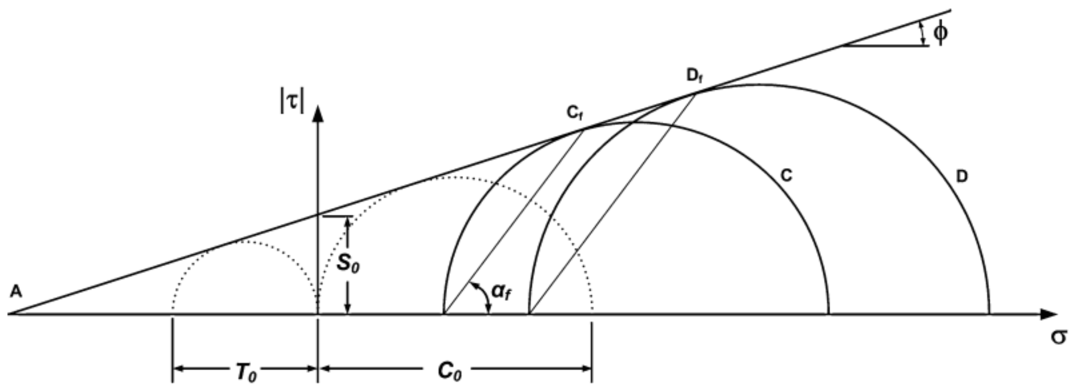

Fig. 4. Coulomb-Mohr envelope in the convention of normal stresses σ and tangential stresses τ [14]

Graphical interpretation of the rock sample failure surface after the test of three-axial compression for $\sigma_1 \neq \sigma_3$ and $\sigma_1 > \sigma_3$ and $\sigma_2 = \sigma_3$ for Coulomb – Mohr criterion is presented in Fig.5.

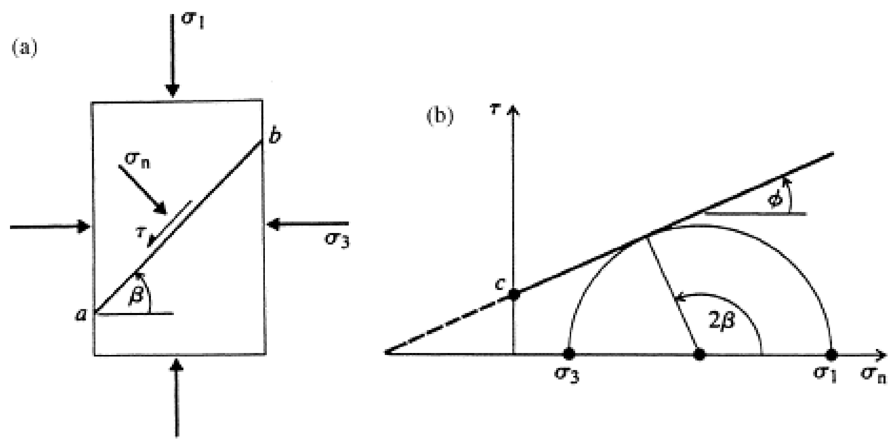

Fig. 5. Graphical interpretation of the rock sample failure surface after the test of three-axial compression for $\sigma_1 \neq \sigma_3$ and $\sigma_1 > \sigma_3$ and $\sigma_2 = \sigma_3$ for Coulomb – Mohr criterion [16]

Knowing about the imperfections of the Coulomb-Mohr criterion in the part concerning the tensile stresses, it seems appropriate to use it to describe the phenomenon of rock failure (or destruction) by the rocks pulling out method, after taking into account and supplementing it with Paul or Labuz's solutions, and own solution.

3. Selected technologies of destruction of rock cohesion with the use of tensile strength

Compressive strength of rocks is much higher than their tensile or shear strength [16, 17]. This property of rocks is often used to develop, design and realize the mining processes with the lowest possible energy consumption. Selected technologies using low tensile strength of rock materials in the process of splitting the rock solids by the expanding method, e.g. mechanical wedging, expanding materials or the electrohydraulic method (*EDH)* are presented and described. The method of mechanical loosening with the use of a string embedded in the solid rock is presented as an alternative to these technologies.

Splitting rock mass by the expanding method

– **Expanding using the *drilling saw* method**

Expanding method is the most widely used method for loosening stone blocks from the deposit and when separating the already mined blocks by drilling holes in the planned partition plane and then applying the *R* forces perpendicular to this plane. The nature and magnitude of these forces depend on the type of rock and the conditions under which the rock is separated. The diagram of the conditions of rock separation by drilling and splitting as well as the adopted terms are presented in Fig. 6.

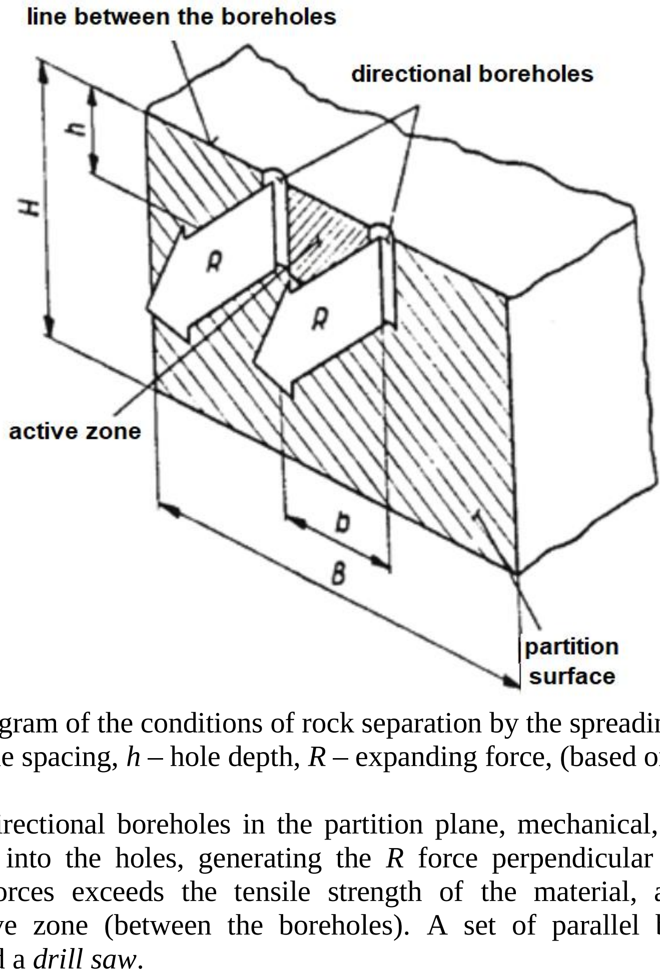

Fig. 6. Diagram of the conditions of rock separation by the spreading method;
b – hole spacing, *h* – hole depth, *R* – expanding force, (based on [18])

After drilling the directional boreholes in the partition plane, mechanical, chemical or hydraulic "wedges" are inserted into the holes, generating the *R* force perpendicular to this surface. If the magnitude of these forces exceeds the tensile strength of the material, a macrocrack appears, beginning in the active zone (between the boreholes). A set of parallel boreholes marking the separation area is called a *drill saw*.

Tests showed that the *splitting* process is the least energy-consuming method of stone partition, and is many times less energy-consuming than cutting with diamond discs and ropes. This technology is irreplaceable in mining the blocks from deposits with a divisible structure with a clear divisibility and/or stratification, and in splitting the already detached blocks into smaller pieces [18].

– **Mechanical wedging**

Rock mass can be split by mechanical wedging, i.e. joint, dynamic expanding of several elements inserted into previously drilled holes in the solid rock. Wedging can be done by manual hammering, or mechanically - with the use of portable pneumatic hammers powered by compressed air, or smaller electrically powered impact hammers. Wedges are placed in the directional holes and hammered successively deeper and deeper, leading to the separation of rock along the plane marked by these boreholes. The separated rock block is further processed to obtain stone parts with specific shapes and textures. An example of a rock block fragment separated by manual hammering the wedges into the previously drilled holes is shown in Fig. 7.

a)  b) 

Fig. 7. An example of manual mechanical wedging: a) process in progress [19], b) the fracture plane of the rock block after using this method [20]

For many years, mechanical wedging has been the basic technology of rock solids mining and stone block mining. With the development of this technology, newer and newer solutions were created to improve the process of wedging and splitting the rock blocks. The splitter shown in Fig. 8 is an example of one of the state-of the-art solutions.

Fig. 8. Hydraulic splitter employed for the non-explosive fracturing of rock in engineering application [21]

– **Rock expanding by use of the expanding materials**

Another way of introducing failure stress into the rock block is to use intumescent materials that are inserted into previously drilled holes. Intumescent materials such as dynacem or cevamite are a dry powder mixture which, when mixed with water, increases its volume and exerts a pressure of 30-40 MPa on the walls of the hole. Materials of this type are successfully used in demolition of buildings and wherever it is impossible to use explosives [22].

After filling the boreholes, in a short time, the material swells and exerts an expansion pressure. After overcoming the tear (tensile) strength of the material, under optimal conditions of use, cracks appear after just 30 minutes, progressing until the chemical reaction ceases; the material continues to work. The successive phases of the technological process of splitting rock solids with the use of expanding materials is shown in Fig. 9 [22].

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Fig. 9. Phases of the technological process of splitting rock solids with the use of expanding materials [22]

The increase in the volume of the expanding material inside the boreholes causes expansion (tensile) forces acting on the borehole side surfaces in the direction perpendicular to the hole axis. When splitting boulders, one central hole causes 3 or 4 cracks. The more holes, the more cracks and loosened materials. For cracks development, the element must have at least one free surface that can move without external resistance due to the material expansion. The number of holes depends on the expected size of the loosened material. The distance from the hole to the hole- or from the hole to the edge of the boulder should not exceed 12 times the diameter of the hole and the required size of the material fragments. Local options for loading, transport or use of the loosened material on-site are essential.

The holes parallel to the free surfaces provide the highest effectiveness. In this case, the entire expansion force moves the detached material towards the free surface. Properly drilled and filled holes, enable to lead the *cutting line* also *along arc*, or to split simultaneously the whole solid rock into many smaller rock blocks, as shown in Fig. 10.

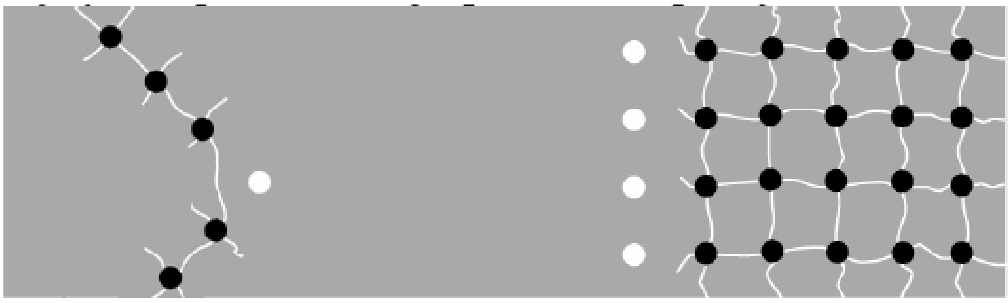

Fig. 10. Directions of cracks propagation in the rock block depending on the place of using the expanding materials [22]

This technology is increasingly used in the construction and demolition industry, as well as for the needs of individual customers. The technology is used for dividing the beams and foundations into parts suitable for transportation, for crushing the structures and boulders, making holes in slabs, drilling tunnels and channels, cutting stone and rock lumps, breaking off concrete from reinforcement, cutting piles, loosening the not cracked rock blocks [22].

– **Loosening the rock blocks using the EHD electrohydraulic method**

Large blocks are obtained during the mining of solid rock masses and demolition using explosives, the blocks size do not allow them to be crushed. The oversized blocks can be broken with the use of hydraulic hammers installed on the excavator's boom. However, more and more often oversized blocks are broken using the electrohydraulic effect (EHD method). A hole is drilled in the block, and after filling it with water, an electrode is placed in it. The electric arc generates pressure shock wave by transferring water into vapour, which gives the effect as in a classical blasting [23, 24]. The idea of loosening the rock material using the EHD method is presented in Fig. 11.

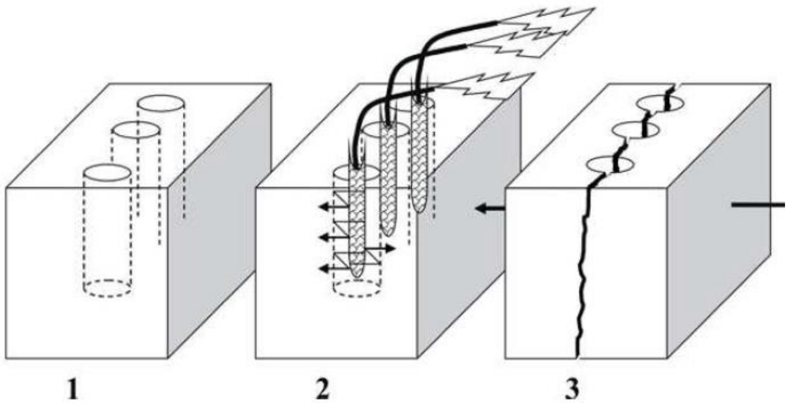

Fig. 11. The idea of loosening the rock material using the EHD method [23]

The first work on designing the device for generation of the electrohydraulic effect was undertaken at the AGH Institute of Mining, Processing and Automation in Krakow in the 1970s under the supervision of Professor Zygmunt Kawecki. As a result of this work, the first devices for crushing rock blocks using the electrohydraulic method were designed. The idea of generating the EHD effect has remained unchanged until today. Schematically, the design of a device generating the electrohydraulic effect is shown in Fig. 12.

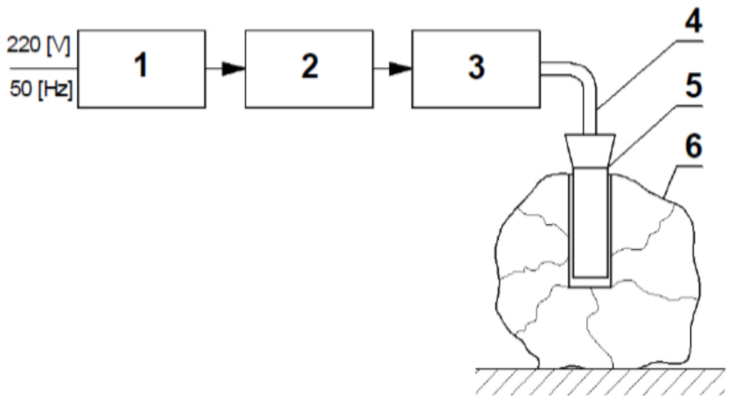

Fig. 12. Schematic diagram of the device for EHD tests [23]

Device for crushing the rock blocks by the electrohydraulic method [23] consists of the following components:

1. Control system
2. System for charging the impulse capacitors
3. Set of capacitors (high voltage power system)
4. Concentric cable
5. Electrohydraulic transducer
6. Object to be loosened

Dimensions of the device depend on the power required to generate an electro-hydraulic wave inside the borehole. Along with the advance in the technology of manufacturing the batteries and electrotechnical equipment, the mobility of using the system is becoming more and more common. The system is mobile and it can be transported in a passenger car. The loosening test together with the test stand components is shown in Fig. 13 [24].

Fig. 13. Loosening the rock blocks by the EHD method [24]

4. Method for mechanical loosening the solid rock using bolts

Under special conditions, the KOMAG's patented technology of destroying the cohesion of rocks using bolts anchored in the solid rock is an alternative method to traditional mining methods, e.g. mechanical or blasting, (Fig. 14). This technology does not damage rocks outside the strictly defined zone and does not affect the close surroundings in any way; there is no emission of gases or generated vibrations [25, 26]. The method can be used for both compact and easy-to-be-break rocks. The drilling direction can be vertical, horizontal or oblique. It does not guarantee rapid progress, but it enables workings development in all mining and geological conditions and is safe.

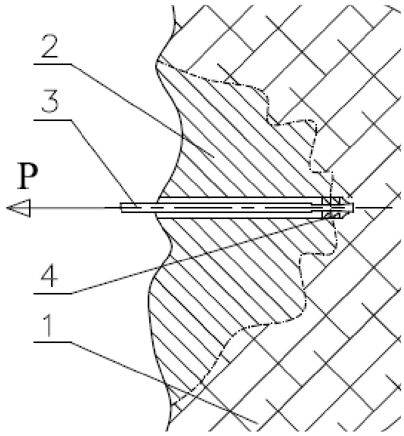

Fig. 14. Idea of mining the solid rock by destroying its cohesion:
1-rock mass, 2- loosened rock, 3-tearing out string, 4-expanding component [2, 3]

Work on the technology of drilling the rescue tunnels with the method of destroying the cohesion of rocks has been carried out at KOMAG for several years. The first concept of the mechanical rock loosening method was developed and the method was assessed within the INREQ project [25, 26, 1]. KOMAG experience gained so far clearly shows that application of under-cutting bolts for this method, due to the nature of the load application, is the most reasonable (Fig. 15). To calculate load-bearing capacity of the bolt, the simplified models of rock loosening, i.e. rock loosening in the form of a cone or a pyramid, were adopted [27, 28, 29, 30]. In the context of the range of loosening, practice shows that this is an oversimplification. The angles at the cone base, in practice, are often more than 2 times smaller than 35º or 45º. As a result, the estimated ranges of loosening, i.e. volume of the loosened solid is much smaller.

Fig. 15. Under-cutting bolt: method of the bolt fixation and range of loosening fracture propagation [20]

Additional limitations in the precise definition of the shape of rock loosening result from the heterogeneous structure of rocks. The impact of lamination planes can determine the angle of the torn out cone, as well as the maximum force required to pull it out. The theoretical impact of the rock structure on the shape of the loosened material is shown in Fig. 16 [31].

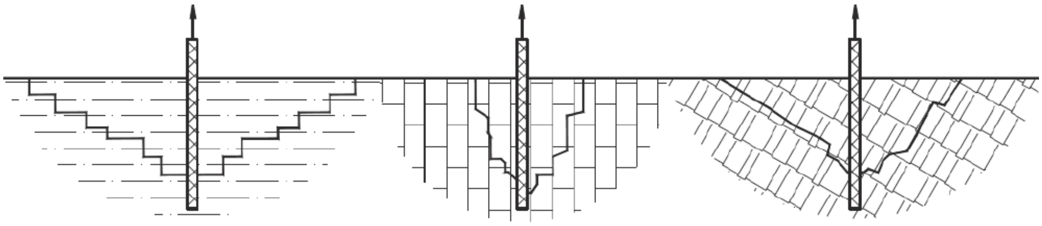

Fig. 16. Impact of the rock structure on a shape of thorn out cones [31]

To analyse the applicability of the rock loosening method using the undercutting bolts, it is necessary to determine of the loosening force, depending on the so-called *effective loosening depth* (undercutting depth in the borehole) and strength properties of rocks.

To understand the loosening mechanism and the state of stress in the tearing out rock material, work under the RODEST project entitled: "Testing and modelling the mechanism of destruction of rock materials in the spatial state of shear and tensile stresses", was undertaken. This project was realized by the scientific consortium: KOMAG Institute of Mining Technology together with the Lublin University of Technology and was financed by the National Science Centre within the OPUS 10 competition [32]. Due to the necessity of testing the rocks of different strength properties, the rock loosening tests were carried out in four different mines, for four different types of rocks. The testing device (Fig. 17a), consisted of a support of a diameter 1 m, a hydraulic cylinder for tearing out the bolts and a manual pump with the possibility of recording the pressure changes in the hydraulic cylinder, and indirectly the tearing out force from the pressure changes time curve (after conversion into force) - Fig. 17b.

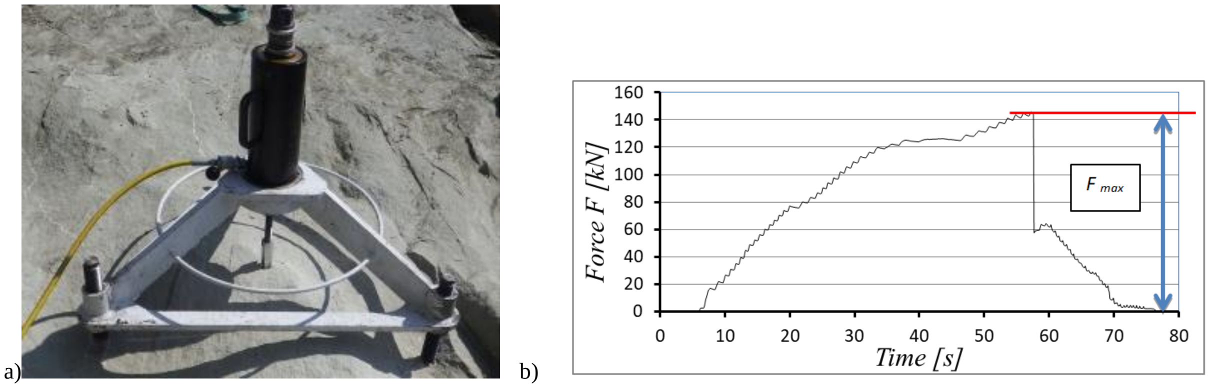

Fig. 17. Own tests on mechanical loosening of rocks within the RODEST project: a) test stand equipment, b) determination of maximum force (F_{max}), recorded during the loosening test [33]

Geometry of the loosening surface, the maximum and minimum range of the destruction surface was mapped using a handheld 3D scanner. On the basis of the points cloud from the scanner, in the specialized Leyos 2 software, the selected cross-sections of the loosened rock fragments, having a shape similar to a cone, were generated. On the basis of the generated cross-sections, it was possible to determine the basic parameters of the loosening process, such as the effective anchoring depth, range and the loosening angle. Fig. 18 shows how they were determined.

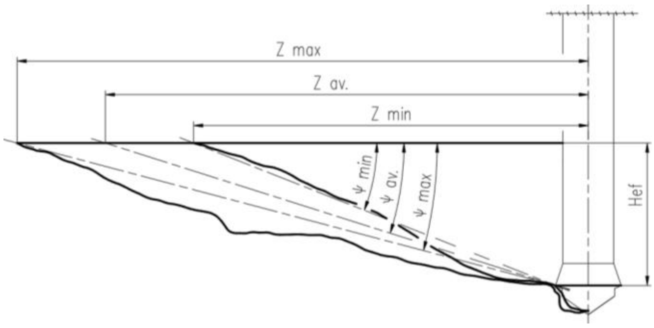

Fig. 18. Cross-section through the loosened solid and the method for determination of the effective anchoring depth H_{ef}, maximum, minimum and average range $Z_{max, min, av}$ as well as loosening angle $\psi_{max, min, av}$ [34]

Graph of impact of the effective anchoring depth H_{ef} on the loosening force F_{max}. and the average loosening range Z_{av} for different rock types is shown in Fig. 19 [33]. The analysis of the test results allows for an approximate determination of the conditions of the loosening tests with the use of a fixed bolt at known rock strength and at given effective anchoring depth.

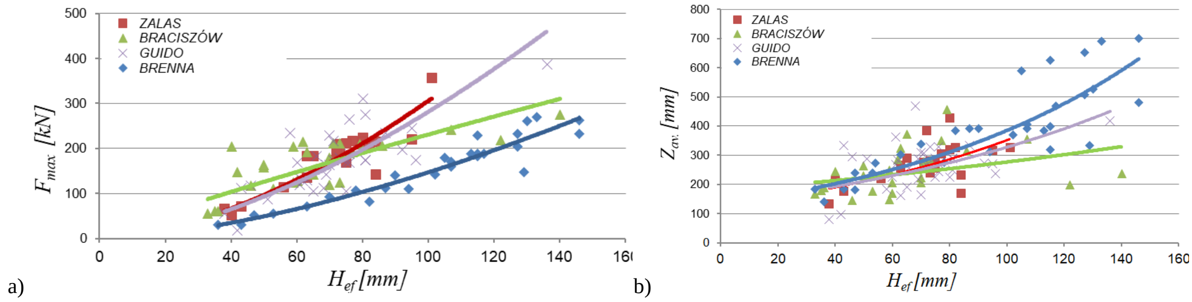

Fig. 19. Functions of the effective anchoring depth: a) loosening force F_{max} and b) average destruction ranges $Z_{av.}$, depending on effective anchoring depth H_{ef} for different rock types [33]

A detailed discussion on the test results is presented in publications [4, 33, 34, 35, 36, 37, 38, 39, 40]. The results provided completely new knowledge about the destruction of rock structures under the load resulting from action of the undercutting bolt. The new knowledge obtained was translated into development of a completely new method of rock loosening, described in the patent applications. The knowledge gained so far in the field of unconventional loosening technology is on the first level of TRL (Technology Readiness Level). The results are important for the potential arrangement of boreholes in the rock loosening technology. Knowing the necessary force needed for loosening the rock, F_{max} and the expected loosening range, rocks loosening is possible obtaining, for example, specified dimensions of the tunnel. It is also possible to precisely tear out only the selected rock fragments, e.g. during rescue operations.

5. Conclusions

Rocks show different strength (and deformation) properties depending on the type of introduced stress acting on them. The mechanism of destroying their cohesion is also different. It is important that the mining process (destroying the cohesion of rocks) is adapted to the mining and geological conditions and the technical possibilities. It is also important that the selected technology corresponds to the conditions in which it is used and is properly optimized in terms of energy consumption and costs of the process.

The methods of splitting rock solids (or blocks) are the methods developed since ancient times, however, the methods of introducing the splitting (tearing, stretching) force are constantly being improved.

The innovative method of loosening the rock fragments with the use of an undercutting bolt or similar methods for introduction of tearing off forces is a new method of loosening technology. The spatial distribution of stresses generated by the undercutting bolt fixed in the rock mass translates into the tear out (loosening) force, as well as to the range and shape of the destruction surface. It was found that the existing models describing the stress distribution in the top area of the crack propagating in concrete, due to the large differences in the internal structure of rocks and concrete, have limited application in describing the cracking phenomena and the development of cracks in rock. For this reason, on the basis of industrial and laboratory tests carried out within the RODEST project, empirical models describing the distribution of stresses in the front zone of the destruction surface were developed and verified, what allowed to predict the tensile force and the loosening range.

The test results provided completely new knowledge about the phenomenon of destruction of rock structures under the action of load resulting from the impact of the undercutting bolt on the solid rock. Studies on development of this technology results from the need to develop tunnels in the vicinity of buildings, which, due to the generated gases and shocks, makes it difficult or even impossible to use conventional methods, e.g. blasting or mechanical drilling.

Clearing the collapsed workings, e.g. during rescue operations, or the liquidation of pillars in board-an-pillar working is another area of application of the suggested technology in the underground mining industry. In such situations, it is not expected that the cutting (loosening) processes will be carried out with efficiency comparable to other methods, but it is expected that the loosening operations are safe or in the case of difficult condition even possible.

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Longwall shearer's haulage systems - a historical review. Part 1 – cable haulage systems

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Keywords: longwall mining, longwall system, coal cutter-loader, coal shearer, shearer haulage system

Słowa kluczowe: system ścianowy, kombajn węglowy, kombajn ścianowy, system posuwu kombajnu

Abstract:

The longwall shearer haulage systems are an indispensable component of these machines. The technical solutions of the haulage systems have changed along with the evolving mining technique and the development of mechanization of the entire longwall system. The longwall technology development has also resulted in increasing length of the longwalls and also influenced the technical solutions of the longwall shearer haulage systems. Next reason for shearer's haulage systems changes and improvement were expanding of acceptable conditions for LW use as inclination or geological disturbances. Implementation of mechanized roof supports and bidirectional cutting were next reasons for haulage systems development. This article is the first part of the historical review of solutions of the longwall shearers' chain haulage systems from the creation of the first shearers to the present day.

Streszczenie:

Systemy posuwu ścianowych kombajnów węglowych są niezbędnym zespołem tych maszyn. Rozwiązania techniczne systemów posuwu zmieniały się wraz z ze zmianą techniki urabiania i rozwojem mechanizacji całego systemu ściany. Rozwój technologii ścianowej spowodował także wzrost długości ścian i także wpłynął na techniczne rozwiązania systemów posuwu kombajnów ścianowych. Rosnące długości ścian i wzrastające wymagania wobec produktywności ścian węglowych powodowało zmiany i rozwój systemów posuwu kombajnów ścianowych. Dodatkowym czynnikiem wymuszającym zmiany tych systemów stanowiło rozszerzanie zakresu stosowania systemów ścianowych, w tym zakresu nachyleń. Wprowadzenie zmechanizowanych obudów ścianowych oraz dwukierunkowego urabiania kombajnami także było czynnikiem powodującym zmiany technicznych rozwiązań systemu posuwu kombajnów ścianowych. Artykuł stanowi pierwszą część historycznego przeglądu rozwiązań cięgnowych systemów posuwu kombajnów ścianowych od chwili powstania pierwszych kombajnów do czasów współczesnych.

1. Foreword

The hard coal mining longwall system has been known since the 17th century [1], but practically until the end of the 19th century it was a traditional mining method with manual performance of all the actions and operations in the longwall. The first mechanized action was mining with pneumatic hammers, and the first mechanized operation was probably undercutting of the coal face. At the beginning of the 20th century, the first conveyors (vibratory conveyors and then belt conveyors) were applied in the coal longwalls which resulted in "the conveyor system" term to be used instead of "the longwall system" in the British mines. However, the longwall production rate still depended on the number of miners working there and their individual efficiency in the following operations: mining, coal loading and erecting the roof support [2].

At the end of the 1930s, the first attempts were made to create mining machines that would mechanize longwall operations of coal mining and loading onto the conveyor, based on the renowned coal cutters. Thus, the first coal cutter-loaders appeared in Great Britain and Germany, performing both functions by means of several different actuators (components) driven by a single engine (initially a pneumatic motor, then an electric engine) [3]. The condition for the good operation of these machines was to enable them to move along the face and to ensure constant pressure on the coal body being mined. This function was provided by the longwall shearer haulage systems. These shearers were created as a development of the former coal cutters and they repeated many of their mechanical solutions, including the haulage systems. The first longwall shearers lay on the floor and moved along the face conveyor (originally a belt conveyor, then an armoured face conveyor), then the shearer mainframe stood on the floor on legs above the conveyor, to finally move along the armoured face conveyor. The requirements for the longwall performance (production rate) enhanced, aimed at increasing the number of working cycles per day, increasing the speed of longwall shearers. The shearers meeting these expectations appeared in the 1950s, including but not limited to the trepanner shearers and the milling drum shearers [4]. The increasing power and weight of these machines forced the development of longwall shearer haulage systems in order to increase the cutting speed. The scope of application of the longwall systems also expanded, including inclined and steep coal seams, which required different solutions of the haulage systems [5, 6]. The first longwall shearers were developed and intended for an exploitation of faces at the height of 1.0 m approximately, where manual operation was difficult and inefficient. When the capabilities of cutting higher faces with shearers increased (nowadays even up to 8.5m [7]), the exploitation of thin faces started to be avoided. However, the extraction of thin coal seams with mechanized shearer longwall systems was not completely abandoned. Due to spatial constraints, these shearers used the solutions of the haulage systems taking into account the aforementioned constraints were applied.

2. Typologies of coal shearer haulage systems

The typologies of longwall shearer haulage systems according to various classification criteria [8, 9, 10, 11], including:

- Haulage drive location,
- Method of the drive relocation.

Fig. 1 shows the typology of longwall shearer haulage systems based on the haulage drive location.

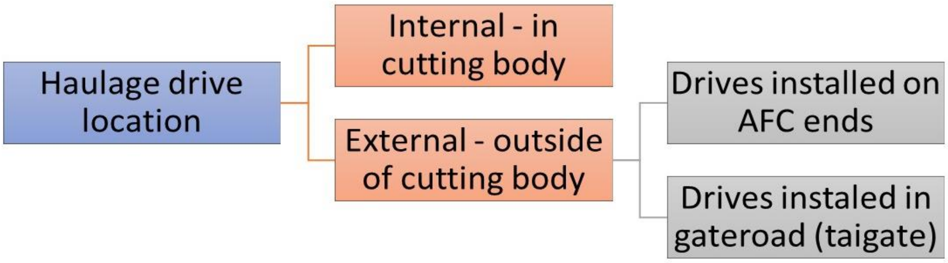

Fig. 1. Coal shearers haulage systems typology based on drive location [author’s]

Some sources [2] indicate that the first coal cutter-loaders were relocated by means of winches installed in gateroads, but this information probably relates to the coal cutters moving on rails along the longwall.

The second criterion for a classification of the longwall shearer haulage systems is the method of carrying out the haulage operation with breakdown into the systems with cable and cordless systems (Fig. 2). This typology creates a certain difficulty due to the fact that there are solutions with a flexible cord – chain, but rigid due to being guided.

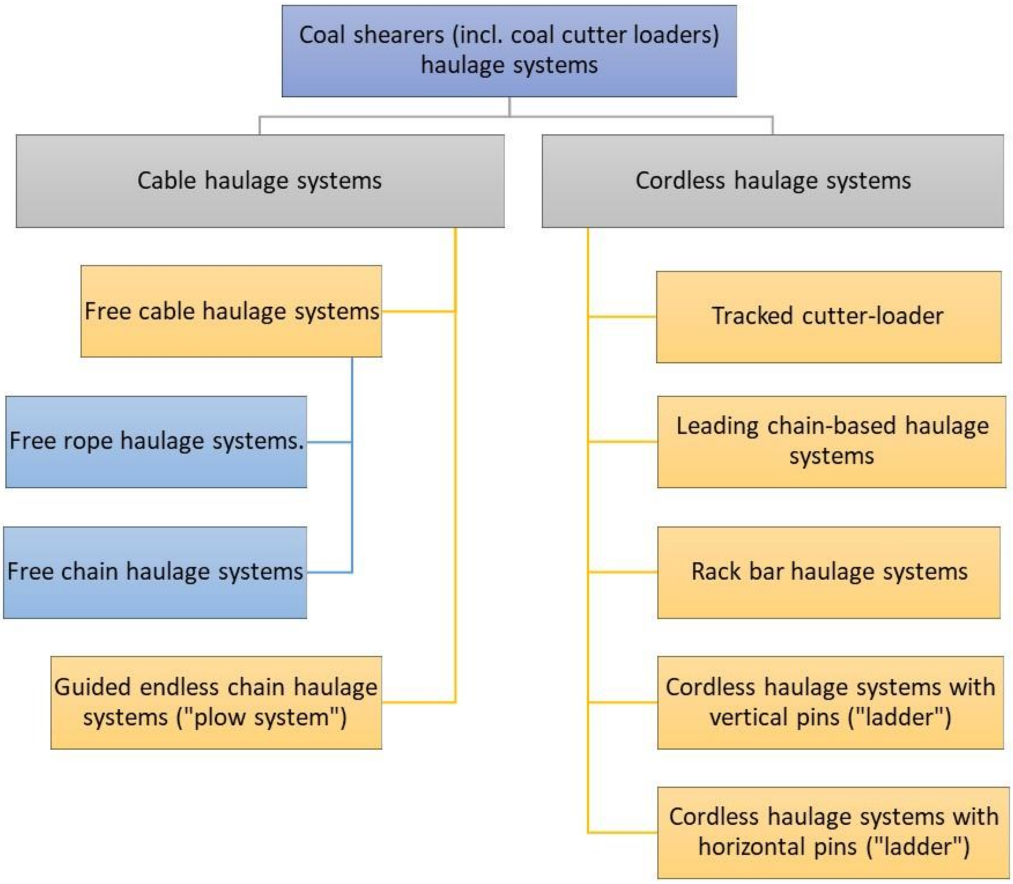

Fig. 2. Coal shearers haulage systems typology based on cable or cordless systems [author's]

In the past, systems with a cable were used to move the longwall shearers, originally in a form of a steel rope and then a chain. Starting from the 1960s, cordless haulage systems were implemented.

3. Cable haulage systems

The longwall shearers' cable haulage systems are used when the haulage drives are located in the frame of the cutting machine or with external haulage drives.

3.1. Free rope haulage systems with internal drive

The first coal cutter-loaders were created due to a development of the former coal cutters. Their haulage system was derived directly from the latter. The machines moved on the floor next to the face conveyor (Fig. 3).

The shearer was hauled by means of a winch (installed in the shearer mainframe) winding the steel rope, the end of which was attached to a pull up prop positioned in the longwall. Such a solution enabled correcting the direction of the shearer movement by a transverse displacement of the pull up prop. The limited capacity of the winch drum and the resulting reduced rope length and low traction force did not cause the phenomenon of transverse rope vibrations.

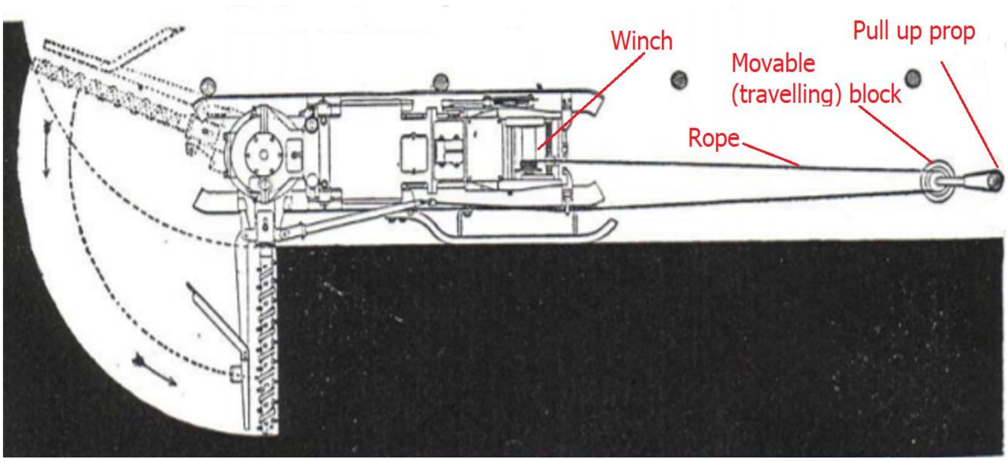

Fig. 3. First free rope haulage system with winch [12]

The first coal cutter-loaders cut the face in one direction only, and the idle return movement required only a different positioning of the pull up prop to start the next cycle. The winch was mechanically driven from the cutting system's drive motor and it ensured a low, constant haulage speed (up to 0.6 m/min). Ratchet or pulse drive and finally hydraulic drives were applied. The operation of displacing the pull up prop, after the entire rope had been wound up on the drum, caused frequent downtimes related to unwinding the rope and displacing the prop. At that time, solutions of longwall shearers with the mainframe above the face conveyor also appeared, and the first shearers, moving over the armoured face conveyor route were applied. Instead of a rope pulling winch, a parabolic drive wheel was used (Fig. 4). This solution enabled an extension of the working rope and a reduction of the number of operations related to the displacement of the pull up props.

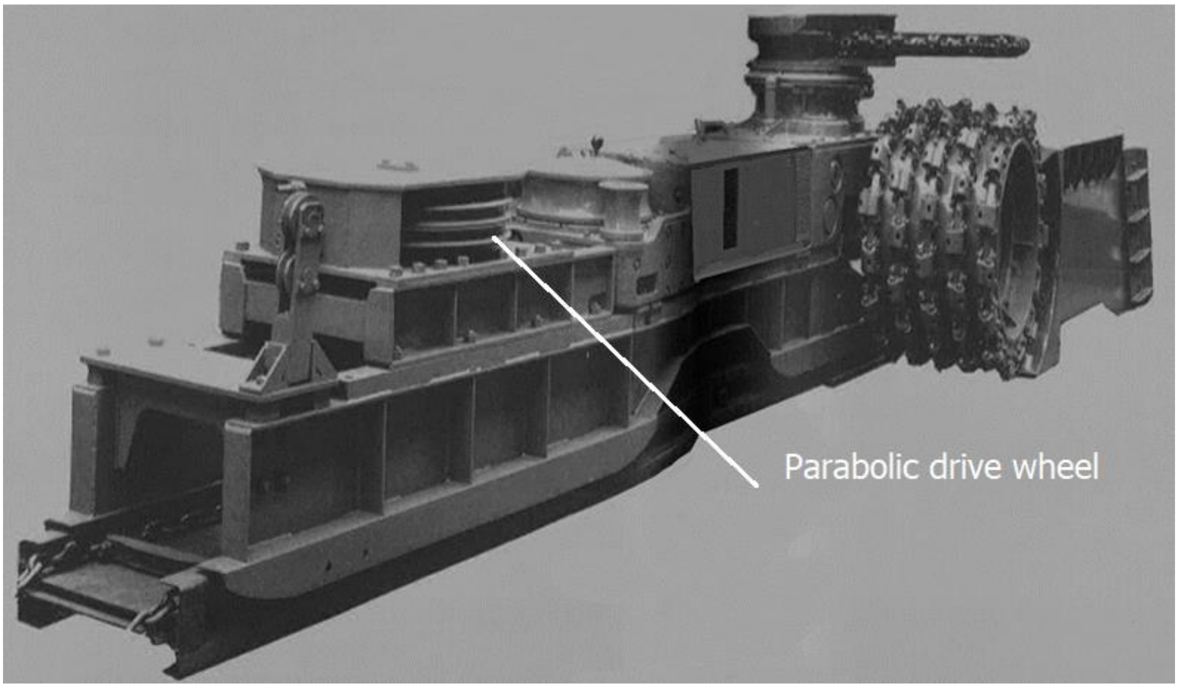

Fig. 4. Free rope haulage system equipped with parabolic drive wheel with vertical axis in the first Eickhoff's W-SE III drum cutter-loader (shearer) [13]

The use of parabolic drive wheels in shearers moving over the armoured face conveyor enabled attaching the rope ends the conveyor drives located at the longwall ends. This made it necessary to protect these drives against the force transmitted from the drive wheel through the rope. In the first mining machines with a parabolic drive wheel, the haulage power was taken from the cutting unit motors by means of a mechanical gearbox (force ratio). The inability to adjust the haulage with the simultaneously expected increase in the machine haulage speed resulted in a hydraulic haulage drive with a smooth haulage speed control to be applied for the cutting machine.

The first Polish mass-produced drum coal shearers (KWB-2) had a rope haulage system (Fig. 4). The shearer adapted for one-direction mining was equipped with a plow type loader. The shearer movement over the face conveyor was not forced yet.

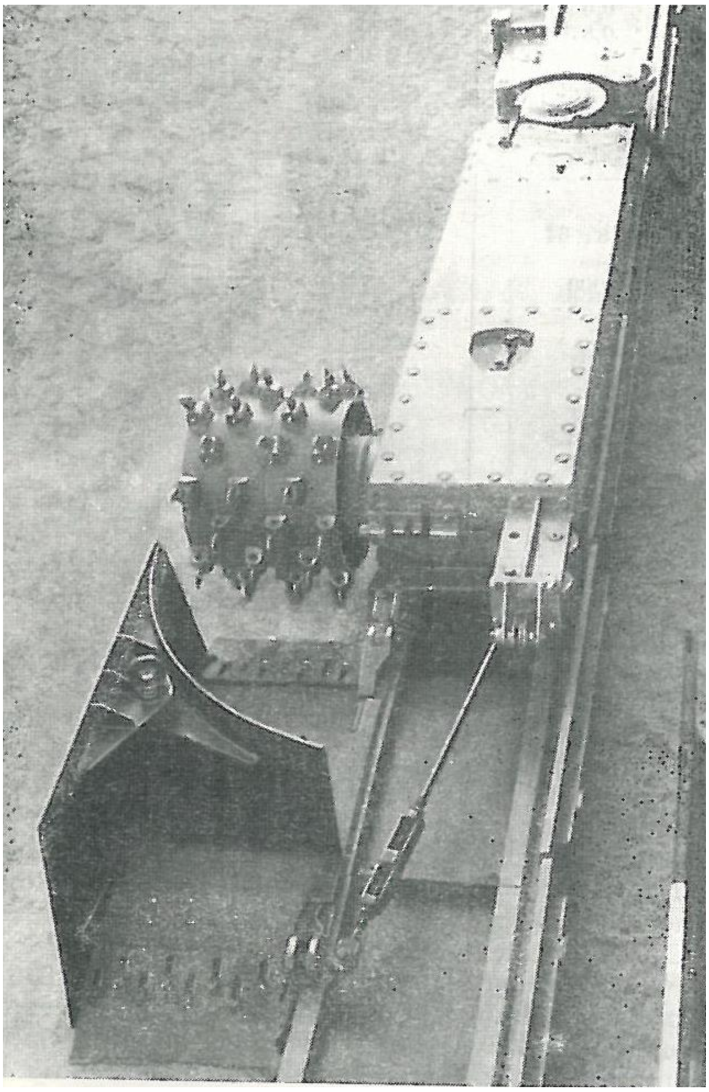

Fig. 5. First Polish single drum shearer with rope haulage system with parabolic drive wheel. [14]

An increasing productivity was expected from the longwall shearers, which was associated with an increase in the cutting speed of the shearer. For this reason, it became necessary to increase the haulage speed, and at the same time, the trepanner shearers and drum machines were implemented more widely [15]. The steel ropes used in the shearer haulage systems were of insufficient strength in relation to the expected increase in the pulling force, and due to multiple winding on the parabolic wheel, they were also subject to fast wear. Therefore, a new type of cord in a form of steel chains was applied.

3.2. Free rope haulage systems with external drive

As the intended use of the longwall system expanded, this system was implemented into the seams with increasing inclination gradients (steep slopes). Since the end of the 1950s the longwall shearers have been also implemented in the longwalls with slopes of up to 90°. On slopes up to approx. 35°, classic solutions of the shearers moving over the AFC with a hydraulic cable haulage system were used [15]. As the cable could be broken when the inclination gradient was exceeding 12°, it was necessary to secure the shearer with a special safety hoist installed in the tailgate [16, 17].

For greater inclinations, where the mined coal rolled itself down, a longwall system without a conveyor with a shearer moving longwall floor was applied. The shearer's movement along the longwall was carried out by means of a system of two hoists installed in the tailgate and a system of two ropes (work rope and back-up rope) (Fig. 6).

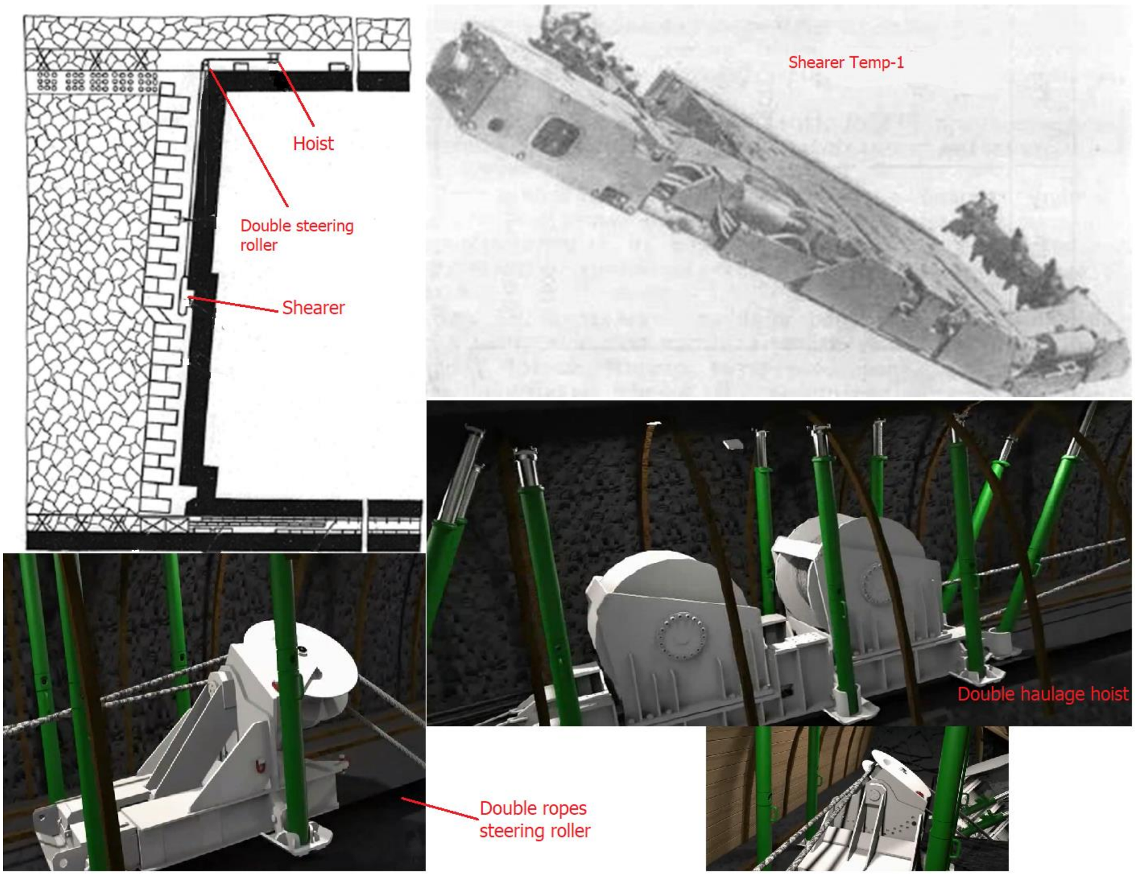

Fig. 6. Solution for steep seams – coal shearer with free ropes haulage system with external drives [author's]

The shearer in this system cut the coal mechanically, but the loading and transport of the excavated material were carried out under gravity.

The shearers with free rope haulage system with external drive were developed in the former Soviet Union and were also used in the coal mining industries of Poland, former Czechoslovakia, Spain, Iran and Turkey. As early as in the 21st century, a mechanized longwall system (shearer + powered longwall support) was delivered (Ostroj) [18] to the Turkish ATi Amasra mine. The shearer systems of this type were also produced in Ukraine, Spain and the Czech Republic.

3.3. Free chain haulage systems with internal drive

The implementation of link chains as a cord in the coal shearer haulage systems allowed to increase the pulling force of the shearer and increase the cutting force. The KWB-2 shearer with a hydraulic haulage system with a steel rope had a haulage speed of up to 2.5 m/min, and the KWB-3 shearer (also with a hydraulic haulage system, but with a chain) achieved the cutting speed of up to 5.0 m/min. - it ensured a twofold increase in cutting efficiency (mining production). There was also a problem of increasing traction forces transmitted to the shearer chain and the phenomenon of transverse chain vibration (chain whipping), which was a great threat to the miners working in the longwall. Initially, this threat in unidirectional cutting, mainly concerned the part of the chain in the cutting direction of the machine (Fig. 7). The shearers were constructed in such a way that the working part of the shearer chain was guided along the coal face side, which only partially solved the problem because the amplitude of the transverse vibrations of the chain could exceed 1.5m [19], even when the chain was partially gripped.

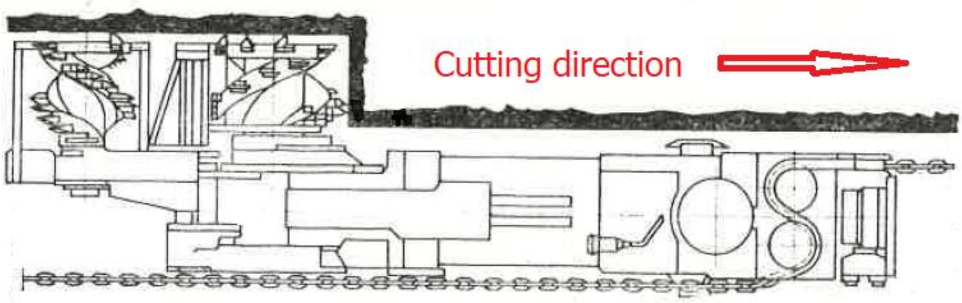

Fig. 7. Soviet 2K-52 shearer with working chain guided close to the wall – drive wheel with vertical axis [6]

The appearance of shearers enabling two-directional face cutting, especially shearers with ranging arms and having cutting heads at both ends of the machine, meant that the threat of chain transverse vibrations occurred along the entire length of the longwall - the chain had to be located along the working compartment. Therefore, attempts were made to reduce the threat by multi-point gripping of the chain with special grips attached to the structure of the armoured face conveyor (Fig. 8).

Fig. 8. Simply, hand operated anti-whip grips in longwall face [author's]

Such a solution required modifications in the AFC design and only partially eliminated the problem [19]. Solutions at various levels of technical complexity were applied - from fully manual ones, through hydraulic, to automatic devices to prevent transverse vibrations of the chain – anti-whip systems (Fig. 9).

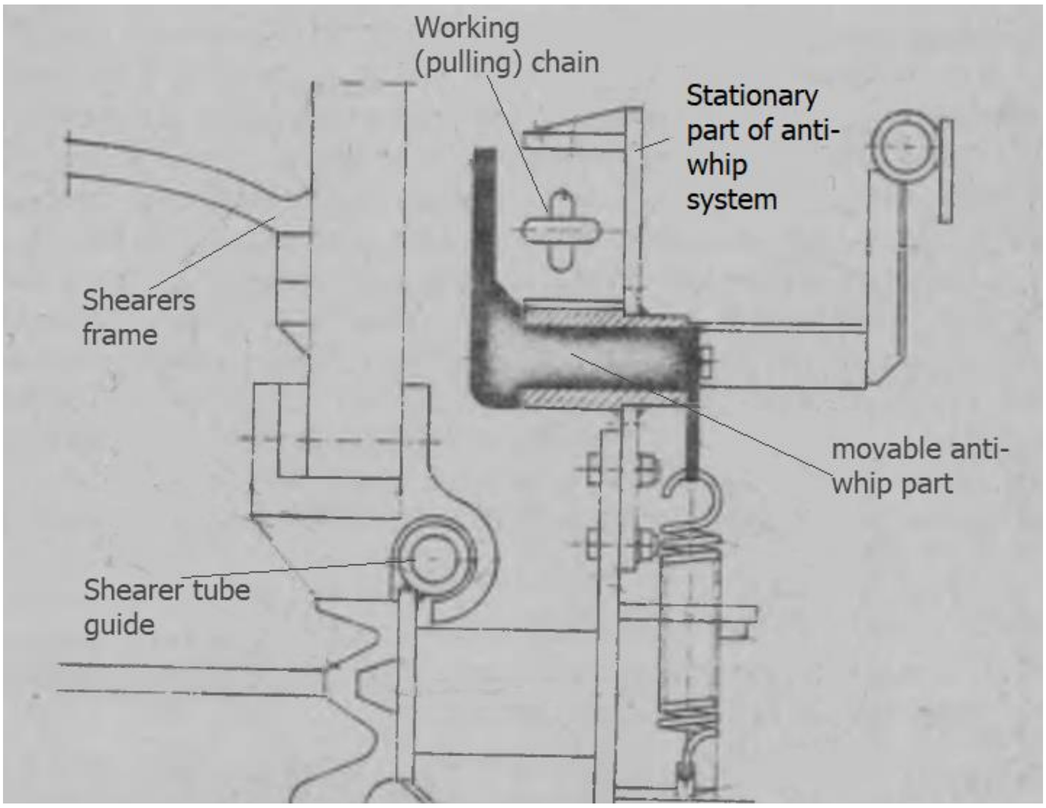

Fig. 9. Example of working chain anti-whip grip system [19]

The increasing requirements concerning the performance (production rate) of the longwall shearers, and therefore the cutting speed and the shearer traction force related to it, made the chain haulage systems extremely dangerous. Due to the increasing lengths of longwalls, the shearer chain made the excavated material ejected out of the armoured face conveyor route, and it was subject to premature wear by contact with the face conveyor chains. All these unfavorable phenomena were identified very quickly and since the 1960s, attempts have been made to eliminate the free shearer chains, but in the 1990s the cable haulage systems were used in the coal mining industry worldwide. A hydraulic haulage drive was mainly applied with a drive wheel having a vertical or, less frequently, a horizontal axis of rotation. The chain required special systems fixing/aligning its position at the entrance to the drive wheel and eliminating its twisting.

3.4. Guided endless chain haulage system with external drives ("plow type")

First coal shearers were intended for mining low longwalls of the heights slightly exceeding 1 meter. This was due to the need of replacing human labor in walls, where it was difficult to obtain high human labor efficiency, and the effectiveness of mining with coal body undercutting was constrained. An implementation of coal drum shearers for low longwalls caused another systemic conflict to arise between the expected capability to transport raw coal on the armoured face conveyor under the shearer (coal clearance) and the need to contain the shearer's haulage system (originally hydraulic, then electric one) in the shearer mainframe. A solution renowned from plow systems was applied, i.e. haulage of the longwall shearer by means of a chain driven by driving wheels installed on the AFC drives. The drive chain was guided inside specially profiled guideways in the AFC adapters, thus eliminating the possibility of its transverse vibrations (whipping). A smooth adjustment (control) of the haulage speed was achieved by changing the frequency of the current powering the haulage drives by an inverter installed into one of the gateroads. In the Polish coal mining industry plow type hauled KGS-150 shearer was implemented as first. As an improvement next the KGS-200 shearer with this haulage system operated in several longwalls (Fig. 10).

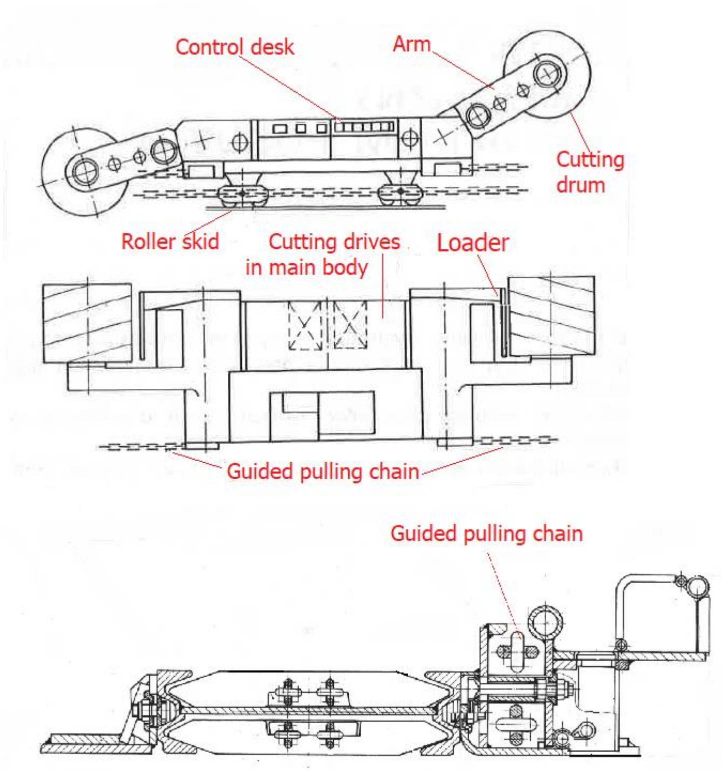

Fig. 10. Guided chain haulage system with external drives – Polish KGS-200 shearer on Rybnik-175/642/TP Armoured Face Conveyor [author's]

The shearer was adapted [18] for cutting coal seams in longwalls of the 0.9-1.5 m height and 200 m lenght with the haulage speed of up to 4.0 m/min [20].
Since 2010, the Mikrus GUŁ-500 shearer with guided chain haulage system with external drives has been developed in Poland as a part of the longwall system for thin seams (Fig. 11). The first version was tested in one of the Polish mines, where further modifications were introduced based on the experience gained.

Fig. 11. Polish GUŁ-500 shearer with guided chain haulage system with external drives [20]

Having gathered relevant experience, a development version of the machine was elaborated, which was used in the Chinese Shygetai mine in the Ordos Basin.

For several years, a Chinese shearer for thin seams has been presented at exhibitions and mining fairs in China, also with guided chain haulage system with external drives (Fig. 12).

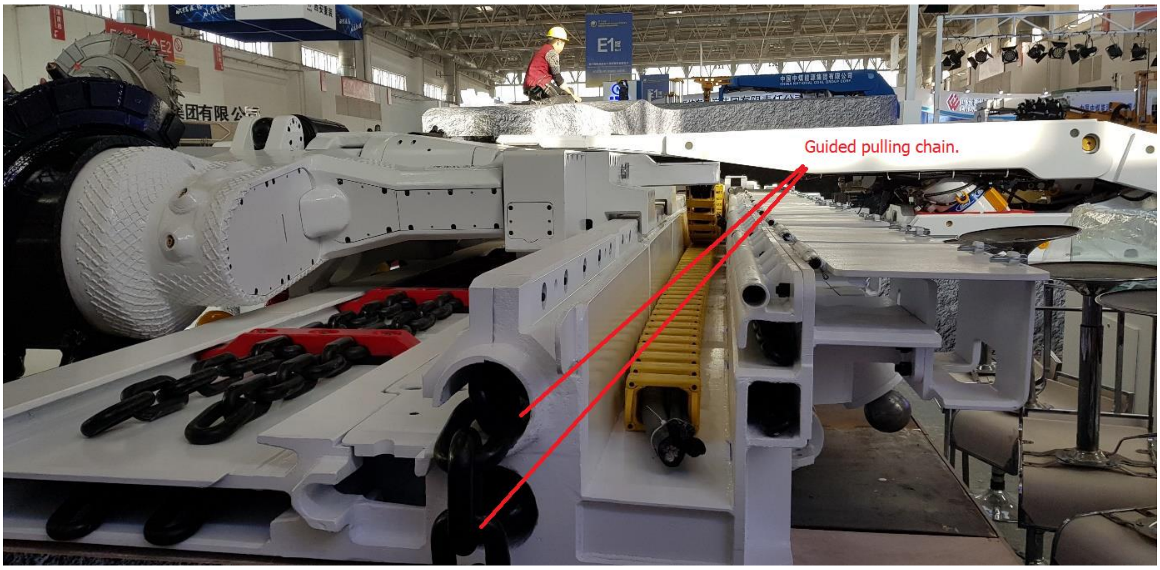

Fig. 12. Chinese shearer with endless guided chain haulage system with external drives [author's]

Two modern solutions (Polish and Chinese ones) have very similar guided chain haulage systems with external drives. There are differences in the design solutions of the cutting and loading systems.

4. Cable haulage systems – summary

From one cycle per day in semi-mechanized longwall systems to multicycles solutions with mechanized roof supports and next fully mechanized longwall systems with shearers was crossed long way and part of this road was with cable (rope or chain) haulage systems.

Cable (rope or chain) cutter-loader and shearers haulage system were developed from longwall cutters. Longwall technological progress and capacity expectations forced shearers haulage systems improvement but showed disadvantages and constraints of them also. Cable haulage systems with hydraulic drives allowed to get both: higher cutting speed and smooth speed control than with mechanical drives.

Increasing longwall length, expected capacity as a result forced haulage power increasing new disadvantages and threats for longwall crew as chain whipping. It was reason of many accidents.

In time of chain haulage systems with hydraulic drives improvement in connection with growing production showed another constrains as hydraulic oil cooling and possible oil volume - it was main reason for searching for new drive solution.

After a long period of development, the cable haulage systems of longwall shearers began to decline and disappear as a result of their identified defects and technical limitations. In most cases, they were replaced by chainless haulage systems, which have been developing since the 1960s. Currently, the haulage systems with external drives and a chain intended for low longwalls are still being developed but today main group of shearers haulage system are chainless with electric drives with frequency converter in shearer body.

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Intelligent module for monitoring proportional directional valves in hydraulic drive systems

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Keywords: intelligent module, proportional directional valve, sensors, fault diagnosis

Słowa kluczowe: inteligentny moduł, proporcjonalny rozdzielacz, czujniki, diagnostyka usterek

Abstract:

Increased performance of hydraulic drive components, as well as easier maintenance and diagnostics, can be achieved through the use of intelligent devices. Introducing sensors, electronic blocks and control algorithms into the equipment will enable easier repairs in the case of failure, or can increase the efficiency of the installation by providing selected operating parameters to the machine controller. In the case of a malfunction, the smart device can provide error codes. Smart devices can receive and send via various communication protocols (RS232, CAN, Fieldbus, Modbus) commands and feedback signals of monitored parameters. This paper presents the construction of such a monitoring and diagnostics module, the test application and the obtained charts.

Streszczenie:

Zwiększenie wydajności podzespołów hydraulicznych instalacji napędowych, jak również łatwiejsza konserwacja i diagnostyka mogą zostać osiągnięte poprzez zastosowanie inteligentnych urządzeń. Wprowadzenie czujników, bloków elektronicznych i algorytmów sterowania do urządzeń, umożliwi łatwiejsze naprawy w przypadku awarii lub może przyczynić się do zwiększenia wydajności instalacji dzięki dostarczeniu do sterownika maszyny wybranych parametrów roboczych. W przypadku nieprawidłowego działania, urządzenie inteligentne może dostarczyć kody błędów. Inteligentne urządzenia mogą odbierać i wysyłać przez różne protokoły komunikacyjne (RS232, CAN, Fieldbus, Modbus) polecenia i sygnały zwrotne monitorowanych parametrów. W artykule przedstawiono budowę takiego modułu monitoringu i diagnostyki, aplikację testową oraz uzyskane wykresy.

1. Introduction

Intelligent hydraulic components such as Hydraulic Valves with pressure sensors and built-in electronics with fast communication protocols lead to greater accuracy of machine control. These smart devices have diagnostic capabilities and compatibility with the Internet of Things (IoT) and can have built-in close control loops (pressure limitation, force control) without the need for a centralized processing structure (e.g. PLC), as in the case of centralized control systems [1]. The control responsibilities of the different subsystems of a machine can be taken individually by intelligent equipment, by distributed control [2]. The PLC can only ensure the overall management of the machine operation and the human – machine interface. The advantages of introducing intelligent hydraulic equipment on machines are the following: fewer cables, faster commissioning, remote diagnostics and alerting the maintenance team through IoT capabilities, customizable operation, cost reduction. The article presents an intelligent module with built-in sensors, which can be used for proportional directional valve monitoring and control. Such modules together with the related electronics can be embedded from the factory in new models of hydraulic equipment. With the information provided by the internal sensors, functional tests can be performed on specialized stands, without the need for external measuring equipment. The purpose of the paper is to present the structure of such an intelligent module that can be used to monitor the operating condition of the proportional directional valves by transmitting data remotely via the company's intranet (LAN) or for machinery automation. Also in the paper is presented a testing methodology for the intelligent module and results obtained after testing.

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2. The structure of the intelligent module for proportional directional valves

The scheme of a module attachable to a proportional directional valve can be found in Fig. 1. Thus, in a hydraulic manifold in derivation with the routes to the ports P, T, A, B, miniature pressure sensors are installed and a temperature sensor on the return route T. Through the metal body, ducts are made for the route of the electrical wires towards the electronic board.

The microcontroller from the electronic board may contain algorithms for monitoring the pressure drop at the hydraulic motor, determining the pressure drop on the valve, limiting the pressure, controlling the force at the hydraulic motor and monitoring the hydraulic fluid temperature. For the connection to the process (PLC) the electronic scheme can have analog control input ± 10 V or ± 5 V, and for the transmission of all parameters it will have a RS232 serial port or a Modbus, CAN or fieldbus ports [3].

Direct driven proportional directional valves can use spool position feedback and embedded electronic module or not.

The valves without feedback act with the force of a proportional solenoid against a spring placed at the other end of the spool with role of restoring the spool to the null position. Two forces act on the spool, the flow force and the stiction forces [4].

Flow forces are a phenomenon found in all directional valves resulting from the momentum that occurs as a result of the strangulation effect of the flow section. This happens when the potential energy (pressure) is converted to kinetic energy (speed) in the strangulation region of the flow section. On spool valves, the flow force always acts to close the spool, regardless of the direction of flow. The consequence is that when using the valve, say at a low pressure drop, the spool is in a position where the force of the electromagnet is balanced by the return spring. As the valve pressure decreases, either due to a reduction in the motor load or an increase in the supply pressure, the flow force increases so as to close the valve spool.

Stiction forces also act on the spool and the solenoid armature, so that the spool position does not change slightly as the control current changes continuously and smoothly. Instead, the flow has a chain effect and the trail of the curve as the control current increases are not the same as the trail of the curve as the control current decreases, producing hysteresis induced by stiction phenomenon.

These inconveniences can be countered by generating an electronic dither signal to reduce stiction forces and by incorporating a closed loop for the spool position with LVDT position transducer, to minimize hysteresis.

By incorporating additional pressure and temperature sensors as well as an electronic board with microcontroller to allow remote parameter monitoring, diagnosis and internal control loops proportional valves become intelligent [5, 6, 7].

Other research on the integration of sensor modules in the structure of electro-hydraulic and electromechanical equipment has been performed by various authors [8, 9, 10]. Specific applications use different communication interfaces and data processing methods. In this paper, a module with pressure and temperature sensors with Modbus over TCP / IP transmission was studied. The module can perform and transmit the results of certain calculations performed, based on the measured parameters (pressure values of P, T, A, B ports) (e.g. pressure drop). Data analysis and processing can be done online with a monitoring application software.

A proposed constructive form of the intelligent module, looks like in Fig. 2, being in the form of a hydraulic manifold that has built-in pressure and temperature microsensors and has an electronic board box attached. The sensors are located in hollows that communicate with P, T, A, B lines and are connected through threaded holes.

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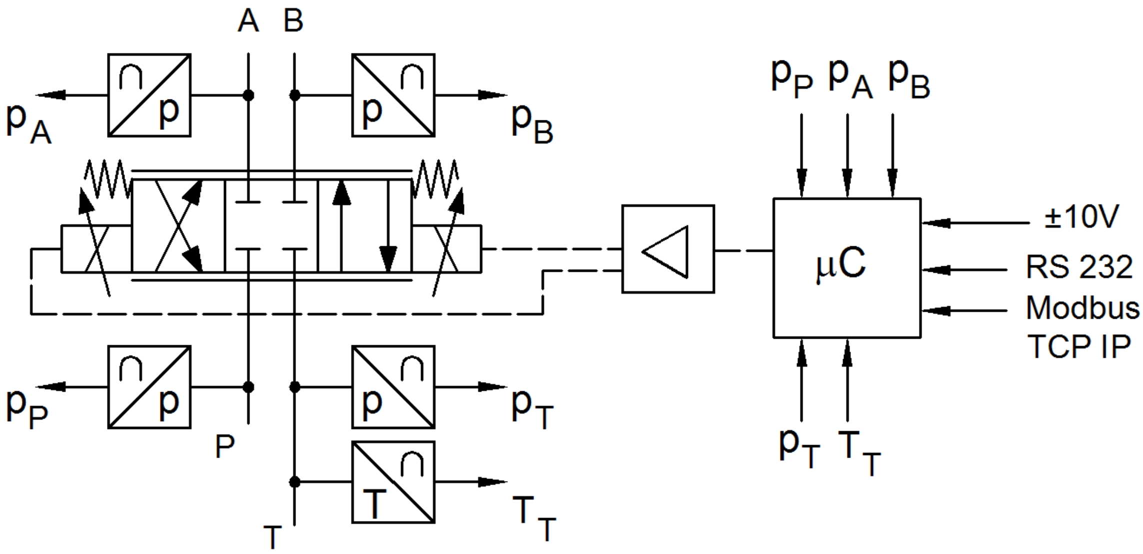

Fig. 1. Simplified scheme of proportional directional valve with intelligent module

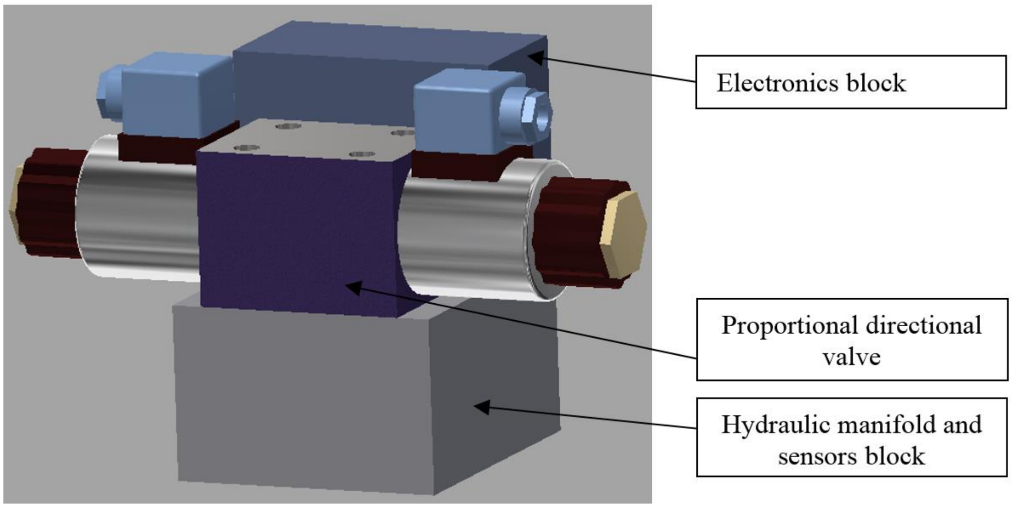

Fig. 2. Proposed constructive form of the intelligent module for proportional directional valve

The sensors can be like the ones in Fig. 3 with their own housing, but they can also be without the housing, placed directly in the metal block, well sealed and secured with threaded parts. In order to connect the sensors with the lines in the hydraulic manifold that communicate with the directional valve ports and for a compact arrangement, it is necessary to make technological holes that are subsequently plugged on the outside after processing.

Fig. 3. Micro pressure sensors type JC91 and NTC 10K temp sensor

The software architecture used for data communication is the client/server configuration. The microcontroller from electronic board, equipped with Ethernet controller, is configured as a server and communicate using the *MODBUS over TCP / IP* protocol. Client applications such as: monitoring and testing or for parameterization and control can be used. Other software applications may be some useful for experimental identification or simulations [11, 12] or application for data management, respectively the connection with a database via the LAN.

The testing of the intelligent module can be done by seeing that the data from the sensors are transmitted through the Modbus protocol and received correctly to a client application that monitors the values transmitted. If the module has implemented an algorithm for calculating the valve pressure drop, it can be used to obtain the graph of the static characteristic at Δp = ct [13].

3. Testing methodology

The intelligent module can be tested on a stand specialized in proportional equipment (Fig. 4). Fig. 5 shows the block diagram with the data acquisition system for testing the intelligent module and for plotting the static characteristic for a proportional directional valve. For testing, the P port of the module is connected by means of a hydraulic fitting and a hose to the flow source of the stand, another hose is connected between ports A and B, and the T port is connected to the tank by means of a flow meter. The flow meter is used to obtain the static characteristic of the proportional directional valve. If the proportional directional valve has a closed loop for the position of the spool, then the signal "actual value" provided at its connector can be used. To draw the diagram, a Virtual Instrument made in the LabView environment is used. The application generates a ramp signal that increases and decreases in the range $0 \rightarrow +10 \rightarrow 0 \rightarrow -10 \rightarrow 0$ volts by equal steps. At each step, the flow passing through the valve is measured and a point is recorded on the diagram. After completion, the diagram is saved.

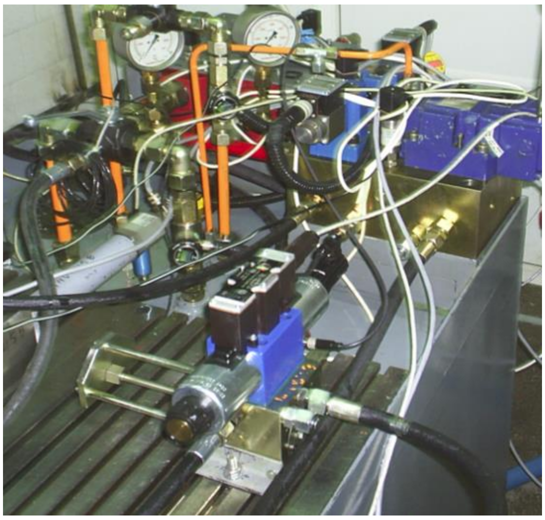

Fig. 4. Test bench and the proportional directional valve mounted on the manifold with sensors

Obtaining the static characteristic of the proportional directional valve requires that the value of the nominal pressure drop to remain constant during a test cycle between the minimum and maximum command signal [14, 15, 16]. This can be done by monitoring the directional valve pressure drop and correcting its value before each step of recording the points of the static characteristic. Correction of the pressure drop through the tested device, before acquiring the points for the diagram, can be done manually or through an algorithm in the virtual test instrument.

With the help of the sensors in the intelligent module it is possible to obtain the pressure drop on the device using the relation (1).

$$\Delta p = p_P - |p_A - p_B| - p_T \tag{1}$$

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where:
Δp – pressure drop on directional valve
P_P - pressure at valve port P
p_A – pressure at valve port A
p_B– pressure at valve port B
p_T – pressure at valve port T.

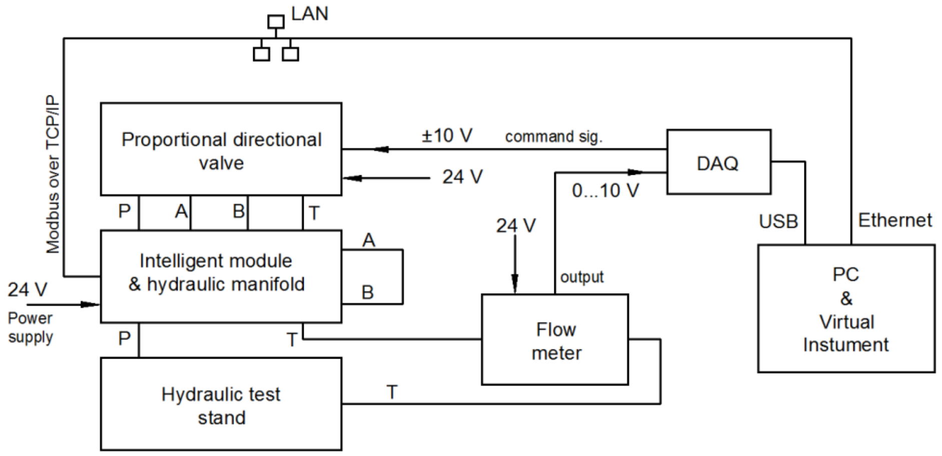

Fig. 5. Block diagram with data acquisition system

4. Intelligent module test results

The signals transmitted by the electronic board of intelligent module via LAN was acquired and also displayed with a virtual instrument made in LabView (Fig. 6). The block diagram of the VI for modbus data acquiring can be seen in Fig. 7.

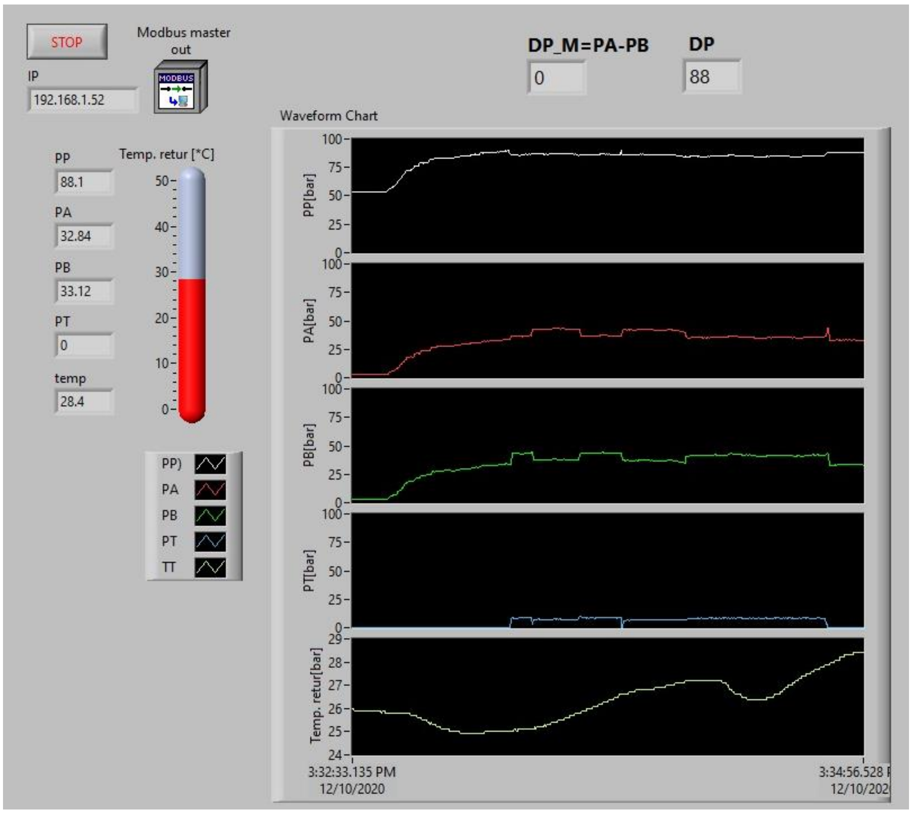

Fig. 6. LabView virtual instrument for monitoring the parameters transmitted by the intelligent module

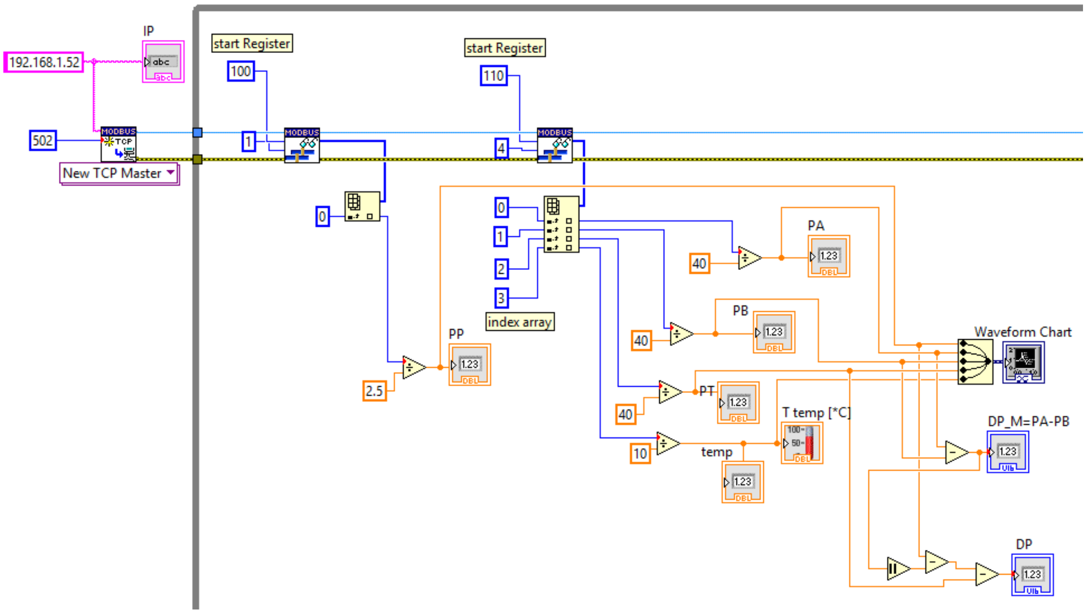

Fig. 7. The block diagram of the VI for modbus data acquiring

The static characteristic of the proportional directional valve obtained with an instrument made in the LabView environment is found in Fig. 8. The intelligent module was used to keep constant the pressure drop through the valve when drawing the diagram.

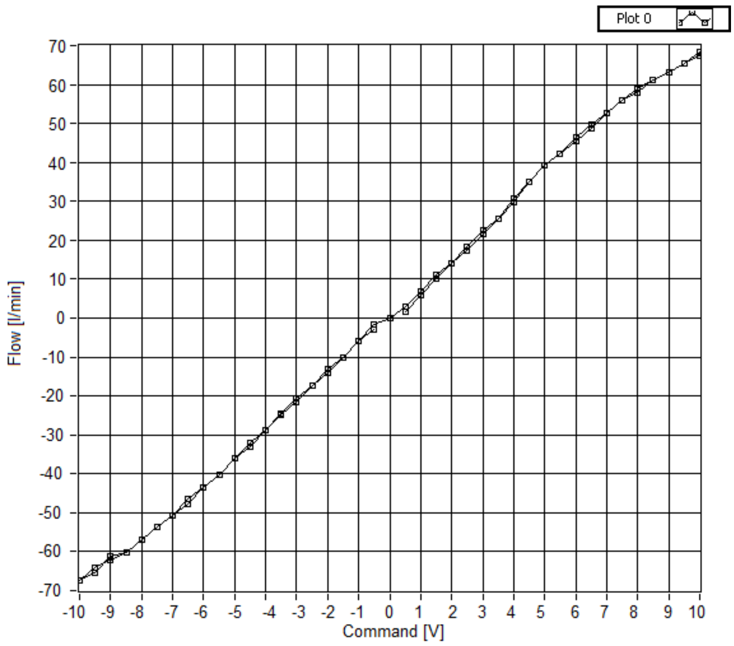

Fig. 8. Static characteristic for a proportional directional valve

The data transmitted by the electronic board of the module via TCP / IP modbus, in the LAN network, can be processed with the virtual instrument made in LabView. By means of a Modbus TCP master block, data and temperature registers can be read [17]. The data is processed to obtain the pressure drop and displayed on the screen for monitoring, thus being able to observe a malfunction of the equipment [18, 19, 20, 21].

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5. Summary

Miniature sensors and electronics can be incorporated into modern hydraulic equipment and together with communication modules and software algorithms lead to the realization of intelligent products.

Proportional directional valves with attached iintelligent module or with built-in sensors and electronics can be easily monitored and controlled.

Smart products connected in the network allow the provision of intelligent services. Thus, recording a history in a database or monitoring on mobile equipment leads to an increase in efficiency during servicing and maintenance.

Hydraulically driven machines that incorporate intelligent equipment can be diagnosed more easily, for repair, with the help of information or error codes transmitted to the operating console.

Automation subsystems of a hydraulically driven machine can be individually controlled by intelligent equipment.

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Predictive maintenance techniques for wear reducing and elimination of equipment failures in hydrostatic drive systems

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Keywords: predictive maintenance, hydraulic drive systems, infrared thermography, vibration analysis, oil analysis, wear reducing

Słowa kluczowe: konserwacja predykcyjna, hydrauliczne układy napędowe, termografia w podczerwieni, analiza drgań, analiza oleju, zmniejszenie zużycia

Abstract:

Maintenance is a very important activity, which is necessary for the good operation of any technical system, even for the hydraulic drive systems. The predictive maintenance evaluates the state of technical performances of a system, by identifying the wear and thus avoiding the failures of the equipment. Using three methods of the predictive maintenance, namely infrared thermography, vibration analysis and oil analysis, the authors present their results of an experimental research on hydraulic pumps. The authors obtained thermograms, vibration spectra and diagrams of the oil contaminants which helped them indicate the proper or the malfunction of the studied pumps. Although they were only made on pumps, their investigations highlight the need of widely implementation of these modern and efficient methods in the industrial activities for the quick monitoring of the hydraulic machinery and equipment wear, before their failure occurs. Obviously, the goal is to have strong maintenance instruments in hydraulic drive systems diagnosis.

Streszczenie:

Konserwacja to bardzo ważna czynność, niezbędna do prawidłowego działania każdego systemu technicznego, nawet hydraulicznych układów napędowych. Konserwacja predykcyjna ocenia stan wydajności technicznej systemu poprzez identyfikację zużycia i unikanie w ten sposób awarii urządzeń. Wykorzystując trzy nowoczesne metody konserwacji predykcyjnej, tj. termografię w podczerwieni, analizę drgań i analizę oleju, autorzy przedstawiają wyniki badań eksperymentalnych hydraulicznych pomp. Autorzy uzyskali termogramy, widma drgań i diagramy zanieczyszczeń olejowych, które pomogły wskazać prawidłową lub nieprawidłową pracę badanych pomp. Chociaż zostały wykonane tylko na pompach, ich badania podkreślają potrzebę szerokiego wdrażania tych nowoczesnych i efektywnych metod w działalności przemysłowej do szybkiego monitorowania zużycia maszyn i urządzeń hydraulicznych, zanim dojdzie do ich awarii. Oczywiście celem jest posiadanie mocnych narzędzi konserwacyjnych w diagnostyce hydraulicznych układów napędowych.

1. Introduction

When we talk about the quality of products and services, it is mandatory to refer to maintenance, seen as an integrated model input-output system, which is characterized by planning, organizing, monitoring and checking operations [1]. The input process output model (IPO model) of the maintenance process is shown in Fig. 1. Regarding the maintenance and its management, in the technical literature the following notions are made known:

- corrective (or breakdown) maintenance;
- time-based (or use-based) preventive maintenance;
- condition -based preventive maintenance.

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Other maintenance strategies are:
- opportunity maintenance;
- fault finding;
- design modification;
- overhaul;
- replacement;
- reliability-centred maintenance;
- total productive maintenance (TPM), in Japan, mainly.

Choosing a specific strategy or policy depends on the links between the maintenance system and the objectives of the organization [1].

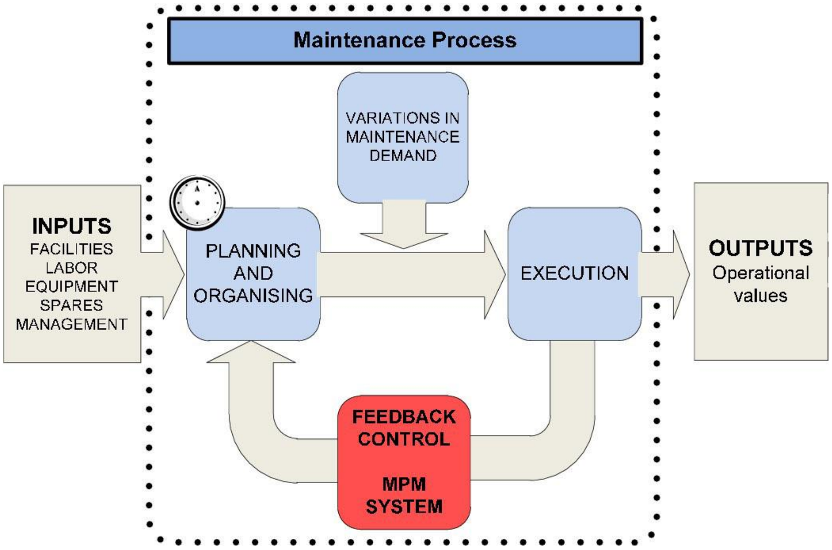

Fig. 1. Input process output model (IPO model) of the maintenance process [2]

- ✓ Corrective maintenance (**CM**) has its main purpose the performance of repairs immediately after the failure of the component or system.
- ✓ Time-based preventive maintenance (or simply, preventive maintenance, **PM**) is a planned maintenance made to prevent and fix problems before defect occurs.
- ✓ Condition-based preventive maintenance (**CBM**) is based on monitoring and gathering of information regarding the condition of the equipment aiming to prevent unexpected defects and to indicate optimal maintenance plans. [3] Condition-based maintenance is a form of predictive maintenance strategy and is more than a simple preventive maintenance (**PM**); in this case the reliability indicators of the system are improved and the maintenance costs are low. In **CBM** the time between two pauses is shorter than in **PM**. Condition-based maintenance is applied to a machine system, and also to a sub-assembly, or a component. In time, all data obtained from the monitoring parameters, according to the predictive maintenance program (**CBM**) are studied and compared with the existing data. The periodicity of the future maintenance program and its optimization is possible by statistical analysis.

In hydraulic drive systems, the most common predictive maintenance methods (Fig. 2) are the follows:
- Vibration analysis;
- Oil analysis;
- Infrared thermography;
- Ultrasound control.

For monitoring the parameters of a hydraulic system and its components, the specialists recommend mainly the first three methods [3].

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Fig. 2. The most common predictive maintenance methods [4]

2. Vibration analysis

Vibration remains among the first status indicators of a machine. Vibration allows any problems to be identified before other symptoms occur, including overheating, possible noise, power consumption, and lubricant impurities. [5].

Hydraulic pumps vibration analysis

Internationally, there are notable concerns regarding the monitoring of vibrations in hydraulic pumps and especially where they work in high-risk working environments, such as mining facilities. Thus, in Indonesia, the Underground Mining Education and Training Unit (ETUUM) which has hydraulic groups used to support the mine galleries has conducted researches on the vibration behavior of a hydraulic pump, a basic component in their operation. Hydraulic groups are hydraulic units used to help installing of supports in underground mines [6, 7]. The installation of underground mining supports that require a hydraulic unit means the installation of active supports, such as the hydraulic support and the ceiling support, operated by means of a fluid under pressure. This pressure is obtained by means of a piston pump driven by an electric motor (Fig. 3) [6].

Fig. 3. Hydraulic piston pump and electric motor[6]

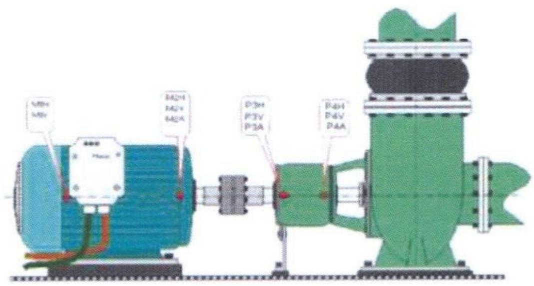

Fig. 4. Measurement points vibration data [6]

Vibrations occur when the capacity, rotation, cavitation, imperfection of the pump drive system lead to instability [8]. Vibration analysis can be used not only to measure the vibration phenomenon caused by mechanical forces, but also for electrical or hydraulic phenomena [9]. With the advancement of technology and predictive maintenance management of mechanical equipment, it is necessary to test mechanical vibrations as an indicator of attention [10]. Knowing the general state of the feasibility of machines requires the analysis of the vibration spectrum [11].

Vibration monitoring was done at various points on the pump and motor. The measuring points on the motor and pump (horizontal and vertical) for the vibration data are represented in Fig. 4. The Indonesian research estabilshed the general state of feasibility of the analyzed hydraulic group based on the analysis of vibration spectra from the pump and motor, using the ISO 10816-3 vibration standard.

Vibration analysis of five hydraulic pumps in a pumping station

In the Hydraulics Laboratory of the Hydraulics and Pneumatics Research Institute INOE 2000-IHP Bucharest, several experiments at the pumping station of the testing stand for hydrostatic equipment have been conducted in order to evaluate its operation, through research method based on vibration analysis. Following the tests, vibration diagrams were obtained for a number of five pumps of different types. The pumping station of the testing stand is equipped with a tank of 800 l capacity, for H46 mineral oil (Fig. 5). The hydraulic oil in the tank is moved to the stand by 5 pumps (Fig. 6-10 and Table 1).

Fig. 5. Pumping station

Fig. 6. Pump P1

Fig. 7. Pump P2

Fig. 8. Pump P3

Fig. 9. Pump P4

Fig. 10. Pump P5

Table 1. Technical characteristics of the pumps

P1	hydraulic vane pump, very compact model, fixed displacement, with catalog code PVV4-1X/122RA15UMC, Manufacturer: Rexroth/ Spain
P2	hydraulic simple vane pump, fixed displacement, with catalog code PVV2-1X/060PA150MB, Manufacturer:Rexroth/ Spain
P3	hydraulic bent axis axial piston pump, variable displacement, model D-89275, type A7VO55EP/63R-NZB01, Manufacturer:Rexroth/Germany
P4	hydraulic bent axis axial piston pump, variable displacement, model D-89275, type A7VO55EP/63R-NZB01, Manufacturer: Rexroth/Germany
P5	hydraulic external gear pump, model 7930, catalog code 510425009, Manufacturer: Rexroth/Germany

In order to perform the tests, an accelerometer – model SN 126981 (Piezotronics PCB - USA) was attached to the pump bodies. The accelerometer was connected to the data acquisition board via a signal conditioner, model 480 B10 (Piezotronics PCB - USA) to an analog input of the board. The signal conditioner was powered by a 24 V DC voltage.

The signal from the analog input was scaled in the LabView application to be displayed as acceleration value, according to the accelerometer measurement range, i.e. the 5 V signal will be displayed on the diagram as 50 g (g = 9.81 m/s^2). The test for each pump was performed by attaching the accelerometer with a magnetic support on the discharge line in the pump. Each pump was started and the vibration level (acceleration) was recorded in two operating modes (idle and load). The working pressure used during the tests was 130 bar. For example, the vibration diagrams thus obtained for the pumps P1 and P2 are presented below (see Fig. 11-14).

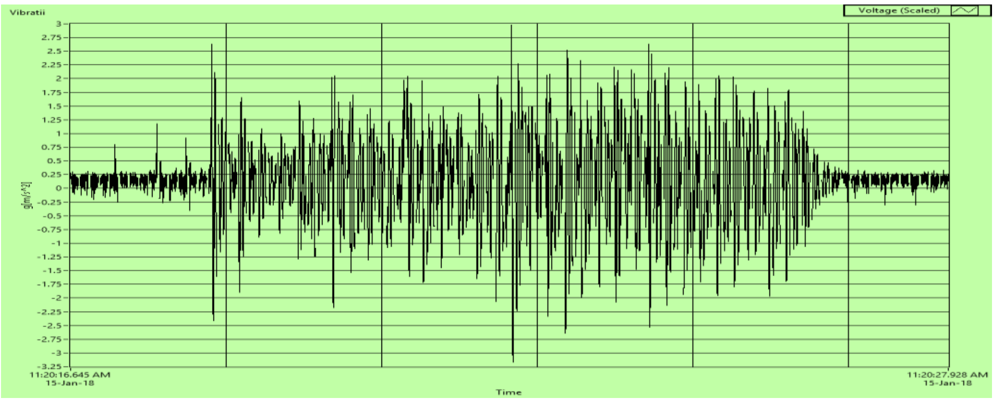

Fig. 11. P1 (idle working) vibration diagram

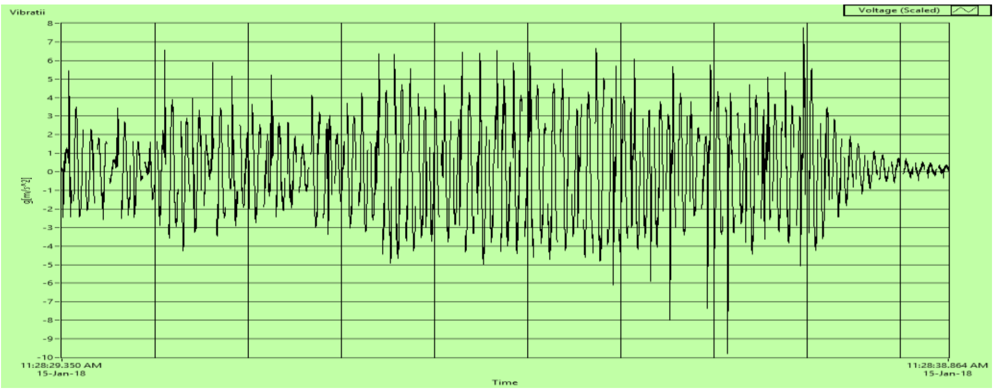

Fig. 12. P1 (load working) vibration diagram

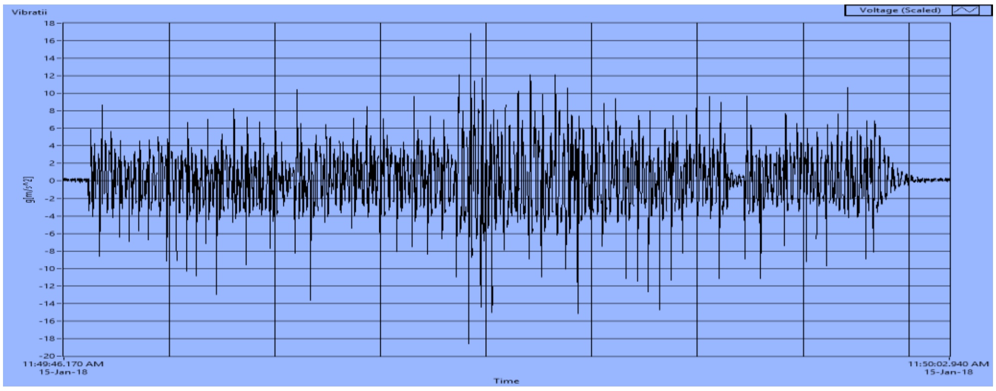

Fig. 13. P2 (idle working) vibration diagram [12]

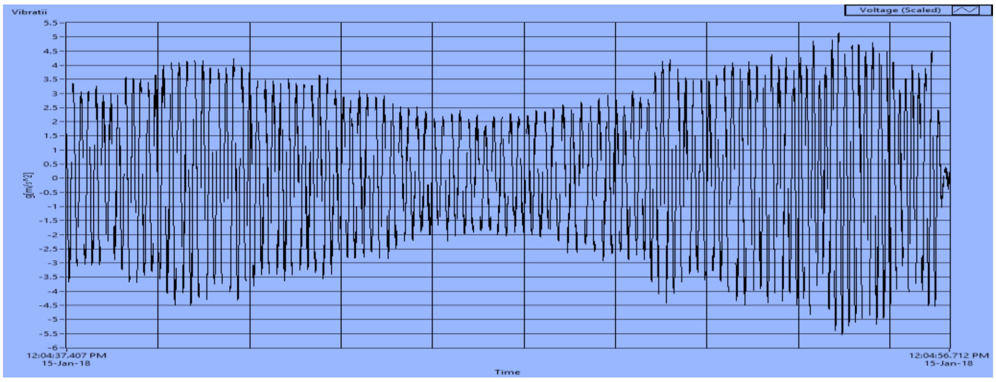

Fig. 14. P2 (load working) vibration diagram [12]

Comparing the two sets of resulting diagrams, it can be seen that the amplitude of the vibrations of the pump **P1**, load working, is greater than the amplitude of vibrations corresponding to the idle pump mode, while the amplitude of the vibrations of the load working pump **P2**, is smaller. than the amplitude of the vibrations corresponding to the idle pump mode. If we consider these vibration diagrams as a reference, for the load working or idle working behaviour of the pumps, at a pressure P = 130 bar, then all the vibration diagrams resulting from the load or idle operation at the same pressure , will be able to be compared with them, in order to be able to draw some relevant conclusions regarding the state of wear / functionality of the analyzed hydraulic equipment. Obviously, this reason is also valid for the other three component pumps of the pumping block: **P3, P4, P5**.

Further in-depth research was carried out separately, on an experimental stand (Fig. 26) in which the behaviour of a hydraulic gear pump, identical to the **P5** pump, subjected to the cavitation phenomenon, was studied. Specifically, the pump cavity was induced by mounting an adjustable throttle on the suction line. At a working pressure in the system Pm = 100 bar, corresponding to a depression Pv = -0.20 bar, from the analysis of the obtained vibration spectra, it was possible to demonstrate the direct connection between the defect appeared in the pump as a result of the cavitation phenomenon and the measured vibration frequency. on the pump body using three accelerometers, Bruel & Kjaer brand, type 4507 B (Denmark)

The processing of the accelerometers signals was done using a data acquisition plate National Instruments brand, type NI 9233 (USA) connected to a laptop.

The obtained results analysis

We can see on the overlays spectra that in the high frequencies range (9000-16000) Hz, the levels of the accelerations is bigger at big cavitations (-0.7 bar; -0.6 bar) and lower at small values of pressure (-0.2 bar and -0.5 bar).

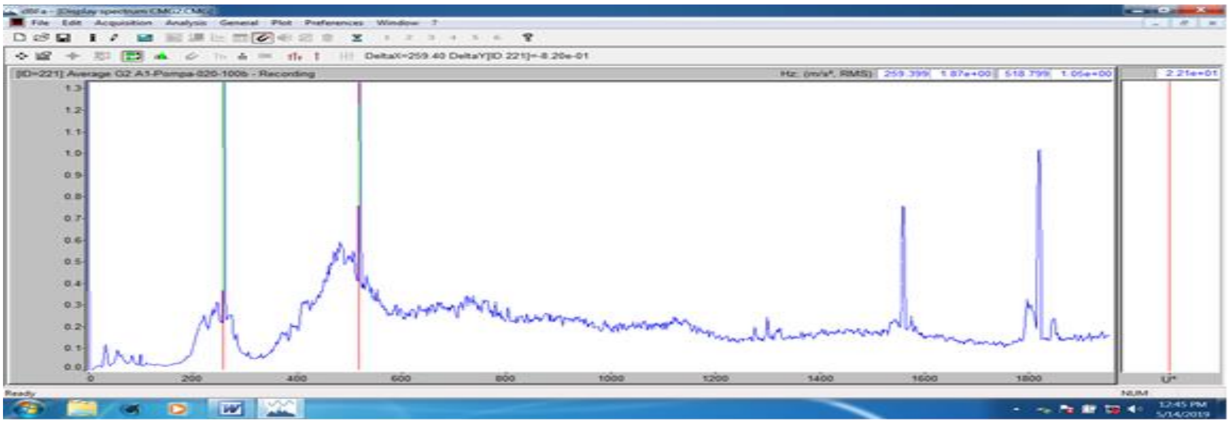

Fig. 15. Spectrum analysis for Pv= -0.20 bar; Pm = 100 bar [13]

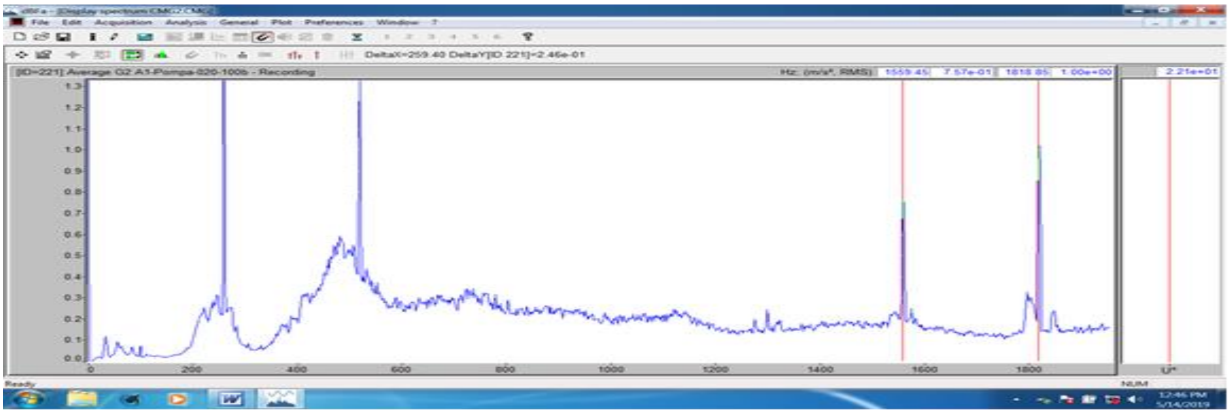

Fig. 16. Spectrum analysis for Pv= -0.20 bar ; Pm = 100 bar [13]

- At the Fig. 15 spectrum, we see it appears a frequency of about 259.4 Hz, with a harmonic of 518.8 Hz [13].
- At the Fig. 16 spectrum, we see this frequency then it's repeating with superior harmonics 1559 Hz (6x 258.4 Hz), then 1818 Hz, etc., that indicate a pump defect [13].

3. Oil analysis of three hydraulic gear pumps

Solid particles, soot, heat, air, glycol, fuel detergents and process fluids are all contaminants that are frequently found in hydraulics oils [14]. Generally, a particle counter is probably the most versatile tool for implementing the concept of proactive maintenance[14]. However, remarkable results can be obtained in this direction with the help of oil analyzers.

At INOE 2000 –IHP, the first attempts to use the oil analysis method started from the mid-2019 by predicting the behavior of three hydraulic gear pumps (HGP1, HGP2, HGP3), mounted on three stands prepared for testing specific endurance to a partner company. The experiments traced the evolution over time of the number of particles of oil contaminants, appeared as a result of the running-in of the pumps, having diameters d > (4 µm; 6 µm; 14 µm; 21 µm; 38 µm; 70µm), and its particular contributions to the wear of the pumps. The authors highlight the important role that monitoring of the clarity level of hydraulic oil has. If big levels of impurities particles are noticed in the working fluid, the malfunction can be removed in short time, avoiding damages to the pumps and reducing the costs of repairing them. In order to conduct the experiments, the oil samples taken from the partner company, were carefully monitored at INOE 2000-IHP Bucharest, using a laser analyzer within the Fluid Mechanics Laboratory.

The Laser CM 20 portable laser analyzer (Fig. 17) used for experiments is a product of Parker company (USA) that incorporates the most modern technology in the field for the analysis of solid particle contamination. The appliance is particularly complex and reliable and is designed to be easy to handle [15]. The average time to perform a test is about 2 minutes. In addition to the analyzer printer that is mounted in its body, the appliance consists of a keyboard with a display to show the obtained data (Fig. 18) and a sampling module (Fig. 19) equipped with two oil containers that can work separately, except for a pressure tap. 100 ml of hydraulic oil samples from the monitored endurance stands were placed in the container on the left side of the appliance. At the beginning of any analysis, the Flush command must be activated so that the oil sample is filtered and cleaned of impurities [15]. The amount of oil that has been processed in this way is then transferred to the container in the right of the appliance. Immediately after the operation of calibrating the analyzer printer, the Print command was given, which allowed the printing of a receipt indicating the number of solid particles of corresponding impurities in the ascending order of their diameters > 4 µm,> 6 µm,> 14 µm, > 21 µm,> 38 µm > 70 µm. Examples are shown in Fig. 20-22, for the last oil sample analysis of the pumps HGP1, HGP 2, and HGP3.

Fig. 17. Laser CM Analyzer Parker

Fig. 18. Keyboard analyzer

Fig. 19. Sampling module

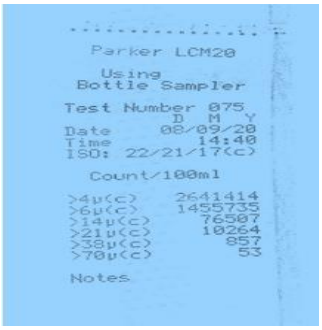

Fig. 20. HPG1 receipt

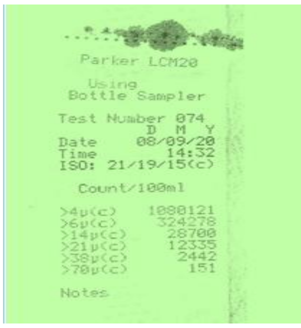

Fig. 21. HPG2 receipt

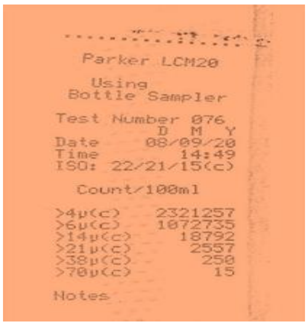

Fig. 22. HPG3 receipt

Immediately after the end of the endurance cycles of the 3 pumps, the trend diagrams of the contaminant particles with diameters d> (4 µm, 6 µm, 14 µm, 21 µm, 38 µm, 70 µm) will be drawn up and the contribution of each of these classes of impurity sizes to the wear of the related pumps will be determined precisely.

4. Infrared thermographic analysis method applied to hydraulic gear pumps

The infrared thermography method comes in support of the "20-20-20" program, which requires a 20% reduction in greenhouse gas emissions (CO2 equivalent) compared to 1990, and also reducing the final energy consumption by 20% compared to 2005, by increasing energy efficiency and increasing the share of renewable sources in the total energy mix to at least 20% by 2020 [16]. Predictive maintenance by infrared thermography is a method that meets the current requirements of reducing the CO_2 footprint and protecting the environment; it is non-polluting and has low energy consumption. The predictive maintenance is a maintenance method in which measurements and signal processing methods are able to accurately diagnose the equipment behavior during operation mode [17]. Vibration analysis and thermography are predictive maintenance techniques that can be used to monitor of an engineering system [18].

In the field of hydraulic drive systems, infrared thermography has been used at INOE 2000-IHP Bucharest since September 2016 and the first thermographic analyzes on hydraulic equipment were conducted.

The experimental research aims to demonstrate the possibility of using infrared thermography to evaluate the state of wear and functionality of hydrostatic pumps used in hydraulic drives. The measurements and analyzes carried out by the authors of this paper on hydraulic gear pumps have led to the conclusion that their abnormal operating conditions, resulting either from increased wear or from the appearance of cavitation or any other defects which result in an increase in their temperature, can be detected in short time by measuring the temperature with infrared thermal imaging cameras. This allows remedial action to be taken before the pumps are completely destroyed. It can be concluded that the use of infrared thermal imaging cameras can be the basic tool for elaboration / developing methods or methodologies for preventive and predictive maintenance on the behavior of hydrostatic pumps, in order to assess their state of wear and functionality. Using infrared cameras, more information is obtained then infrared thermometers. Infrared cameras can give a structural deficiencies image and temperatures on any point of the structure's surface; infrared thermometers measure only the temperature from a distance. Each method is a non contact method to measure the temperature [19, 20, 21]. Fig. 23-24 show two FLIR models of infrared thermal imaging cameras used by the authors of the paper in their work. In order to achieve the research objective, at INOE 2000-IHP Bucharest, a test stand was designed and developed, to demonstrate the usefulness and efficiency of using the infrared thermography method in the behavioral prediction of hydrostatic drive systems (Fig. 25). The stand is used to test hydraulic gear pumps, currently used in hydraulic drive systems. The tests consists in the simulation of the different working regimes, and the operation at different pressure levels, as well in the gradual modification of the suction conditions of the pump, after a suitable procedure. With the help of thermograms one can find out if the pumps work correctly or have defects. For example, Fig. 26 and Fig. 27 show two obtained thermograms for the same pump, but in different state of working: normal and abnormal, respectively. The difference between the two pumps is given by the normal temperature (39.9°C) and the very high and abnormal temperature (89.7°C) measured by the FLIR thermographic camera on the pump housing, which indicates the malfunction of the pump, because the temperature in its normal operating mode, as specified in the manufacturer's data sheet, must not exceed 70°C.

Fig. 23. FLIR camera

Fig. 24. Pocket model FLIR camera

Fig. 25. Testing stand for gear pumps

Fig. 26. Proper working pump

Fig. 27. Defective working pump

5. Summary

The paper aims to present part of the research carried out by the specialists at INOE 2000 – IHP in the field of the predictive maintenance activities. Although, so far, the work has focused only on the analysis of several pumps, further in-depth research on other types of hydrostatic equipment will be conducted, such as research on directional valves, or rotary and linear hydraulic actuators. With regard to the three non-invasive methods presented, the following clarifications are required:

– The vibration analysis applied to to the 5 component pumps of the pumping station allowed to draw some vibration diagrams that will serve as a comparative model for other such diagrams that will have to be periodically raised by the personnel involved in the predictive maintenance activities. With these results thus obtained a database can be built which can provide important information about the state of wear or functionality of the pumps.
– The oil analysis applied to the monitoring of the 3 hydraulic gear pumps will allow a complete image of their state of wear/functionality, immediately after the end of the endurance cycles to which they have been subjected by the manufacturer. The authors intend to present in a future paper the complet results of their researches carried out in this direction.
– The method of thermographic analysis applied to hydraulic gear pumps allows one to obtain reference (standard) thermograms corresponding to the normal operating regimes of the analyzed pumps. A database may also be set up in conjunction with thermograms indicating the malfunction of the same types of pumps, operating under the same pressure and temperature conditions, which can provide important information about the state of wear/functionality of the pumps.
– Practically, in many important industrial fields, such as military, aeronautical, metallurgical, power or mining, hydrostatic equipment is widely used, on the proper functioning of which complex machines, systems and equipment depend.
– For this reason, the authors consider that this article will capture the interest of those specialists who carry out maintenance activities in these basic sectors and will make a good contribution to the development of the field through the information provided.

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Application of Progress Eco equipment for modernization of mechanical coal processing plant at PG Silesia

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Keywords: coal preparation, sieving, heavy media cyclone, jig, dewatering

Słowa kluczowe: przeróbka, przesiewanie, cyklon ciężkich mediów, osadzarka, odwadnianie

Abstract:

Application of a new generation of sieving machines made by PROGRESS ECO is shown, based on Coal Processing Plant at PG Silesia. Screens are used as classifier and dewatering units. Brief characteristics of machines are shown. The article presents the results of the selection of screens in the PG Silesia coal processing plant. The modernization of the PG SILESIA coal mechanical processing plant resulted in the optimization of classification and dewatering processes in order to improve the parameters of the final product obtained. The optimal selection of the designed and delivered screens influenced the economic aspects of this project. The screening efficiency was increased by 95% and the water content after the material dewatering process was increased to less than 6%. Obtaining the above-mentioned optimal results was possible thanks to the effective cooperation of PROGRESS ECO designers with the design office and with the future user himself at every stage of the process.

Streszczenie:

Przedstawiono zastosowanie nowej generacji przesiewaczy firmy PROGRESS ECO w oparciu o Zakład Przeróbczy PG Silesia. Sita służą jako jednostki klasyfikujące i odwadniające. Przedstawiono krótkie charakterystyki maszyn. W artykule przedstawiono wyniki doboru przesiewaczy w zakładzie przeróbki mechanicznej węgla PG Silesia. Efektem modernizacji zakładu przeróbki mechanicznej węgla PG SILESIA była optymalizacja procesów klasyfikacji i odwadniania celem poprawienia parametrów otrzymanego produktu końcowego. Optymalny dobór zaprojektowanych i dostarczonych przesiewaczy wpłynął na aspekty ekonomiczne tego przedsięwzięcia. Podwyższono skuteczność przesiewania o 95% oraz zawartość wody po procesie odwadniania materiału poniżej 6%. Uzyskanie powyższych, optymalnych wyników było możliwe dzięki efektywnej współpracy konstruktorów firmy PROGRESS ECO z biurem projektowym oraz z samym przyszłym użytkownikiem na każdym etapie procesu.

1. Introduction

The literature on screening and screens are very wide, for the most important item to be considered [1, 2, 4]. The article presents the effects of the modernization of the classification systems in the coal enrichment plant at PG Silesia. The modernization included, among others, the replacement of all screens and the implementation of modern PROGRES ECO screens. In each node of the technological system, a screening system was used, selected in accordance with the previous research results presented in the previous publications of the Authors [5-13].

The modernization of the PG SILESIA coal mechanical processing plant resulted in the optimization of classification and dewatering processes in order to improve the parameters of the final product obtained. The optimal selection of the designed and delivered screens influenced the economic aspects of this project [15-21].

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2. Brief characteristics of the coal processing technology at PG Silesia

Coal production at Silesia PG consists of two main processes: the enrichment of fines in the class of 6 – 20 mm in wet cyclones and enrichment of medium and coarse grains in the class of 20 – 100 mm in Disa concentrator (Fig. 1). The enrichment in both processes (separation of coal from so-called gangue) proceeds via using differences in density in aqueous medium, which is a mixture of water and magnetite. In both processes so-called "heavy liquid" is maintained in density range of 1.4 g/cm3 and 1.6 g/cm3 and is dependent on the current production needs and densimetric composition of the feed. The products of above processes are density fractions, whose density is lower than that of the heavy liquid. The resulting product (coal), separated from gangue during enrichment processes and having size classes of 6 – 20 mm and 20 – 100 mm, is then dewatered. Coal class 20 – 100 mm, after dewatering on vibrating sifters, goes to the final classification node where it is separated into narrower graining classes so-called assortments, i.e. nut coal – grains ranging 40 – 100 mm; nut coal I – grains ranging 20 – 40 mm; pea coal – grains ranging 6 – 20 mm. Then, assortments are directed to the appropriate tanks from which they are loaded on the wagons by means of conveyor belt. Coal class of 6 – 20 mm is dewatered in vibrating centrifuge and, without final classification, directed to tanks and, in consequence, to wagons. Coal class of 0 – 6 mm, secreted in the preliminary classification node as well as in reseeding node, does not undergo any enrichment process and it is treated as a commercial product, called raw fines of 0 – 6 mm class.

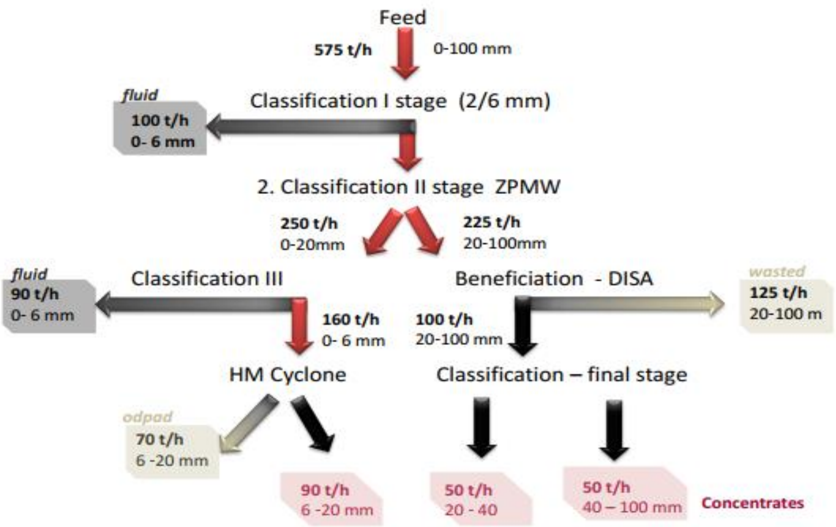


Fig. 1. Coal processing technology at PG Silesia [3]

3. Fines enrichment node

Raw output is directed on the control sifter WK1-2.0x4.0 (Fig. 2) equipped with one heavy sieve of 100 mm mesh diameter and welded sieves of Progress Tytan type having square mesh of 100 mm. Overflow product from the sifter (+100 mm class) is headed, through picking belt where wastes are hand-selected (wood, stone, scrap), to the single drum crusher for grain crushing to the size less than 100 mm, then the product is mixed with sifter's underflow product of 0 – 100 mm class. Raw output of 0 – 100 mm class, prepared in this way, is then directed to preliminary classification on two parallel sifters PWP2-2.2x5.25 (Fig. 3) equipped with two open grid plates. Protective upper grid plate in the form of woven sieves of TL type and mesh size equal 20 mm takes over the feed impact and thereby protects the lower grid plate equipped with steel harp sieve of T type and mesh size equal 6 mm. The underflow product of 0 – 6 mm class is directed to the raw fines tank in station 2.6, then transported with mine cars to the heaps and loaded to wagons.

Product of 0 – 100 mm class, already devoid of 0 – 6 mm class, is directed to initial classification on two tandem lines of PWP1-2.2x5.25 sifters (Fig. 4, 5). These sifters are equipped with woven sieves of TL type and 20 mm meshes.

Overflow product from screens of 20 – 100 mm class is directed to enrichment process in the DISA concentrator. The underflow product in the class of 0 – 20 mm is directed to the PWP1-2.6x5.9 screen (Fig. 6) equipped with longitudinally stretched harp sieve of T type and 6 mm mesh.

The underflow product from the screen is directed to raw fines tank in the class of 0 – 6 mm, then loaded to wagons. The overflow product in the class of 6 – 20 mm is directed to enrichment process in heavy liquid cyclones. Harp sieve used in the screen (Fig. 7), with its distinctive design, through vibration screening and feed undergoes additional discordant vibrations, which prevent from clogging the sieve. Thus, they are characterized by a high degree of self-purification.

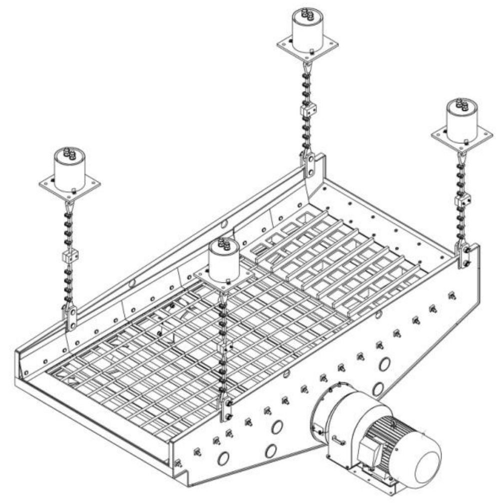
4. Metodology

The efficiency of screens is of particular importance in the selection of the size or number of screens in a system, as well as in the optimization of technological parameters. A calculation of the technical efficiency of machines in the coal processing system is crucial for the proper assessment of production efficiency. The complete processing plant is a set of basic and auxiliary machines. The basic ones include crushers, screens and belt conveyors. Other machines and devices, such as feeders, tanks, cranes, scales, monitoring or automation devices, fulfil auxiliary functions. The article presents the issue of the selection of basic machines in the design of aggregate production technology. This is the reference to the author's previous articles [5-15] as the third phase of the process of designing and analyzing production systems. Machines are selected in terms of the quality of the products, operations and performance.

The quality in the case of crushing is the so-called grain cubic capacity, and in the case of screening, it is the ability to effectively separate grains smaller than the mesh size into the under-screen product, i.e. to remove fine grains from the over-screen product. In general, the quality of the products of processing operations depends simultaneously on the design solutions of the machines and their geometric and dynamic parameters, as well as on the physical and morphological properties of coal, as well as on the moisture content, grain composition of the feed and the size of the load.

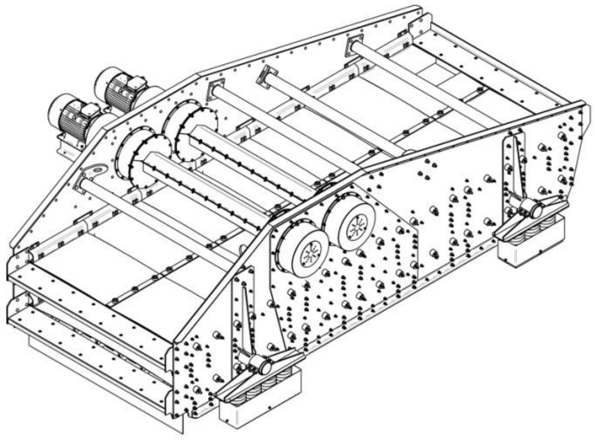
The issue of the efficiency of basic machines is of particular importance in the selection of the size or number of screens in the system, as well as in the optimization of technological parameters of these machines. The selection of machines in terms of efficiency is not easy, because it requires specialist knowledge and the ability to predict the performance of these machines in changing conditions of their work.

5. Selection of screens for subsequent stages of enrichment



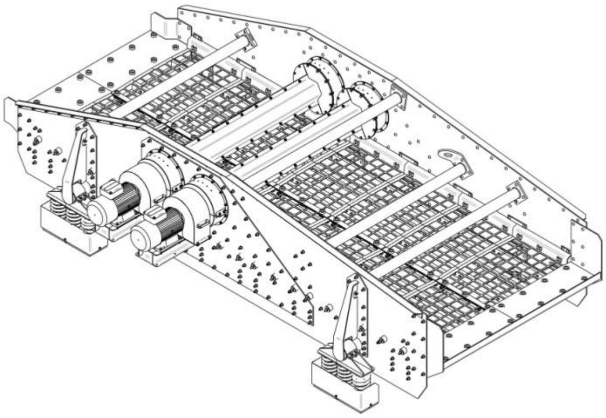
Characteristics	
Purpose	Classification
Quantity	600 Mg/h
Feed diameter max	400 mm
Sieve surface	8.0 m^2
Sieve type PROGRESS TYTAN	100 mm
Frequency	12.2 Hz
Leap	11 mm
Angle	12^o
Motor power	18.5 kW
Weight	4.4 Mg

Fig. 2. WK1-2.0x4.0 vibrating screen



Characteristics	
Purpose	Classification
Feed diameter max	100 mm
Surface	2x11.5 m^2
Upper deck diameter	20 mm
Lower deck diameter	6 mm
Frequency	16 Hz
Leap	9 mm
Angle	10^o
Motor power	2x15 kW
Weight	8.6 Mg

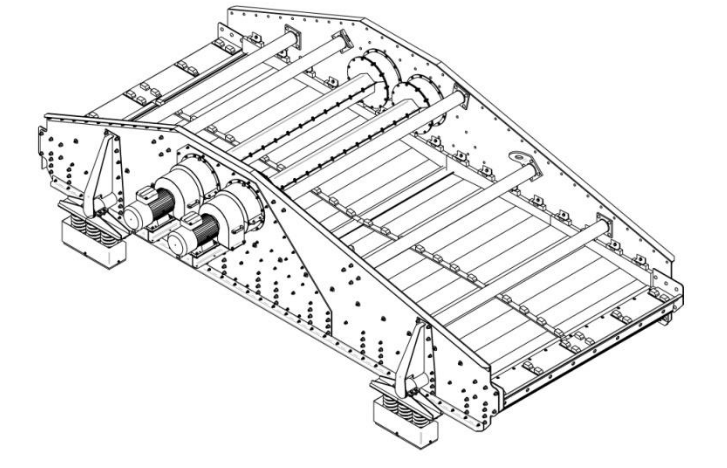
Fig. 3. PWP2-2.2x5.25 vibrating



Characteristics	
Purpose	Classification
Feed diameter max	100 mm
Surface	11.5 m^2
Frequency	16 Hz
Leap	8 mm
Angle	2^o
Motor power	2x11 kW
Weight	5.8 Mg

Fig. 4. PWP1-2.2x5.25 vibrating screen

Fig. 5. Two tandem vibrating screens PWP1-2.2x5.25



Characteristics	
Purpose	Classification
Quantity	250 Mg/h
Surface	15.3 m^2
Diameter	6 mm
Frequency	16 Hz
Leap	8 mm
Angle	8^o
Motor power	2x11 kW
Weight	8.0 Mg

Fig. 6. PWP1-2.6x5.9 vibrating screen

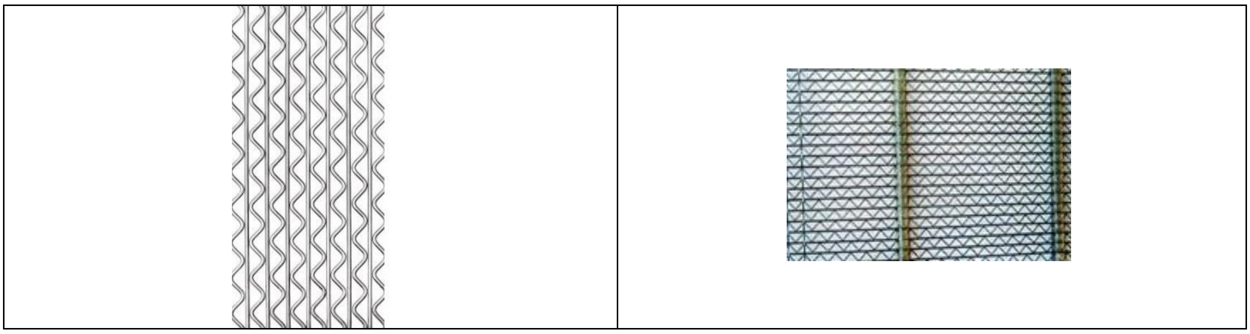
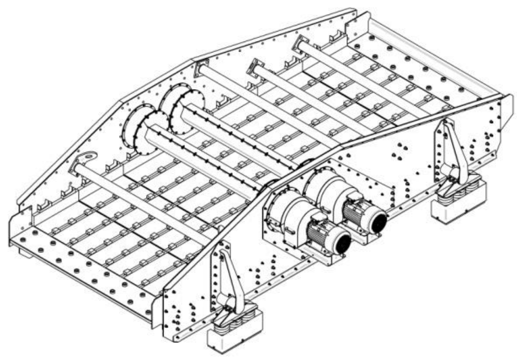


Fig. 7. The structure of harp screen type (part of PWP1-2.6x5.9 vibrating screen)

6. Enrichment in DISA concentrator

The feed material for the enrichment process is raw output in the class of 20 – 100 mm. Enrichment is carried out based on density difference related to aqueous medium (heavy liquid – water and iron ore mixture). Grains weighing more (waste – stone) than medium fall down to the bottom of the concentrator and are transported by means of wheel to the chute, and then to the dewatering process and tank. Grains weighing less than medium (coal product) float on the surface and go to the dewatering screen PWP1-2.4-5.25 (Fig. 8, 9) equipped with welded sieves mounted in the PRO-CLIN system.

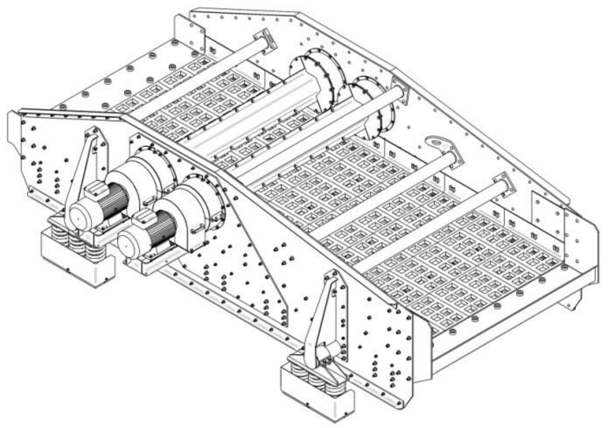
The material from dewatering screen is directed to the PWP1-2.1x4.5 control screen (Fig. 10) equipped with rubber modular sieves of 100 mm mesh. Grains larger than +100 (screening overflow product) get to the double-roll crusher, where they are degraded to the size smaller than 100 mm, then they are mixed with the grains of underflow product and together directed to the final classification screen equipped with sieves of 20 and 40 mm. After the classification on the screen, the commercial products of proper graining are obtained i.e. nut coal (40 – 80 mm); nut coal I (20 – 40 mm); pea coal (6 – 20 mm). Commercial products are directed to the appropriate tanks, from where they are loaded to wagons or transported to the heap. The stone separated in the DISA concentrator (Fig. 11) goes to the PWP2-1.8x5.25 dewatering screen (Fig. 12) equipped with upper polyurethane grid plate mounted in the PRO-CLIN system of 20 mm mesh. The lower grid plate comprises slotted welded sieve with a gap of s = 2 mm, mounted in the same system. After dewatering, the stone in directed to the stone tank, where it is loaded for transport.



Characteristics	
Purpose	Dewatering
Surface	12.6 m^2
Sieves of slot	2 mm
Frequency	16 Hz
Leap	8 mm
Angle	2^o
Motor power	2x11 kW
Weight	7.6 Mg

Fig. 8 PWP1-2.4x5.25 vibrating screen

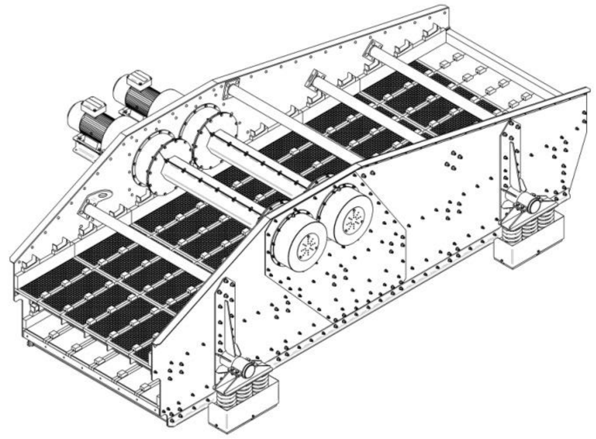
Fig. 9. Installation of deck in the PWP1-2.4x5.25 screen



Characteristics	
Purpose	Classification
Sieve surface	9.4 m^2
Clearance	100 mm
Vibration frequency	16 Hz
Riddle	8 mm
Inclination angle	2^o
Motor power	2x11 kW
Weight	5.6 Mg

Fig. 10. PWP1-2.1x4.5 vibrating screen

Fig. 11. DISA concentrator coal output, feed to dewatering and sorting sieve



Characteristics	
Purpose	Classification, dewatering
Surface	2x9.45 m^2
Upper deck	20 mm
Lower deck	2 mm
Frequency	16 Hz
Leap	8 mm
Angle	2^o
Motor power	2x11 kW
Weight	7.3 Mg

Fig. 12. PWP2-1.8x5.25 vibrating screen

7. Enrichment in cyclones

Feed material for the enrichment process is raw output of 6 – 20 mm class. Enrichment, similarly as in the DISA concentrator (Fig. 11), takes place based on the density difference related to aqueous medium (heavy liquid – water and iron ore mixture), except that the feed is premixed in the tank with heavy liquid, then it is directed under pressure to two cyclones. In the cyclones the grains are subject to additional centrifugal force, which forms counter-current. Feed, separated to wastes and coal product, is directed by pipes to the PWP1-2.4x5.25 vibrating dewatering screens (Fig. 9) to the equipped with slotted welded sieve with the gap of 1 mm, mounted in the PRO-CLIN system (Fig.13, 14). In addition, coal product is directed for dewatering purposes to the vibrating centrifuge, from where as dry material it is directed to the tank and then to loading. In the PRO-CLIN system, the sieve forms a module, which is mounted to the support structure using hooks and wedges. Offered system is characterized by an absence of screwed joints, which greatly accelerates a replacement of an individual sieve as well as of the whole grid plate. The advantage of using mounting hooks for screen construction purposes is scattering of the material on the grip plate and thus limiting the impact of so-called skip zone. The transverse bumps, which increase the effectiveness of screening and dewatering processes, can be used instead of the clamping wedges. An important advantage of the system is

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a lower grid plate weight, which greatly reduces the impact on the structure of the screen. The PRO-CLIN system is ideal for screens characterized by low grid plates.

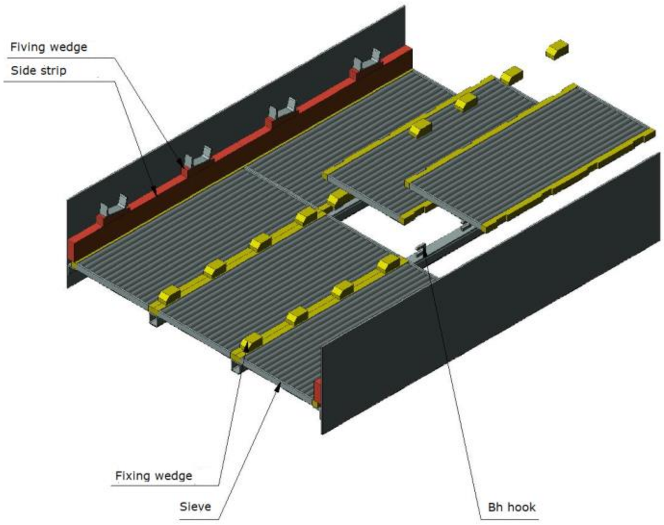

Fig. 13. Schematic PRO-CLIN screen fixing system

Fig. 14. Sieve deck, slotted, welded, built-in PRO-CLIN system

By analyzing the world solutions presented in the literature [14-20], it can be concluded that national solutions reach the world level. Specific considerations on the further development are presented in the article [21]

8. Conclusions

After an implementation of the screens industrial tests were performed at the PG Silesia. The obtained results were: efficiency of screening 95%, moisture content after products dewatering in the screen less than 6%.

The modernization of the PG SILESIA coal processing plant resulted in the optimization of classification and dewatering processes in order to improve the parameters of the obtained final product. The optimal selection of designed and delivered devices also affects the economic aspects of this project. After the implementation and commissioning of the modernized PG Silesia Processing Plant, material samples were analyzed. Obtaining the above-mentioned optimal results was possible due to the effective cooperation of the PROGRESS ECO designers with the design office and with the future user at every stage of the process.

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Flexible scopes of accreditation at the Conformity Assessment Body and Testing Laboratories

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Keywords: accreditation, testing laboratories, certifying body of products, fixed scope of accreditation, flexible scope of accreditation

Słowa kluczowe**:** akredytacja, laboratoria badawcze, jednostka certyfikująca wyroby, stały zakres akredytacji, elastyczny zakres akredytacji

Abstract:

An accreditation of testing laboratory as well as of the certifying body of products is always based on the fixed scope of accreditation which precisely and explicitly establishes the activity area of these units. As the time was passing, it was noticed that the fixed scope of accreditation is so restrictive that it limits an application of new methods, which could be added to the laboratory scope of accreditation and in the case if the certifying activity makes a product assessment, based on the latest editions of standards and legal regulations, impossible. In 2008, the above mentioned organizations, obtained a possibility to react to customers` needs through modifying or including additional activities to their scope of accreditation without a necessity of informing the supervisory body each time. This possibility resulted from the fact that competences of these organizations had been assessed by the supervisory bodies before. In both cases a possibility of applying the flexible scope of accreditation caused an increased responsibility of the organization due to a necessity of the system maintenance, which could control the changes. At present the flexible scope of accreditation is more and more commonly applied because it gives measurable benefits to all the accredited bodies – it enables a quick reaction to customers` expectations and it creates possibility of applying new methods. The article presents possibilities of applying flexibility in the accreditation of the laboratories and certifying bodies of products, based on the example of the KOMAG Institute.

Streszczenie:

Akredytacja laboratorium badawczego, jak również jednostki certyfikującej wyroby, zawsze oparta jest na stałym zakresie akredytacji, który precyzyjnie i jednoznaczne ustala obszar działania tych jednostek. Z upływem czasu zauważono, że stały zakres akredytacji jest na tyle restrykcyjny, że ogranicza nowe metody, które mogłyby zostać dodane do zakresu akredytacji laboratorium, a w przypadku działalności certyfikacyjnej uniemożliwia ocenę wyrobu w oparciu o najnowsze wydania norm lub przepisów prawa.

W 2008 roku umożliwiono wspomnianym jednostkom, reagowanie na potrzeby klientów poprzez modyfikowanie lub włączanie dodatkowych działań do swojego zakresu akredytacji bez konieczności każdorazowego informowania jednostki nadzorującej. Możliwość ta wynikała z faktu, że kompetencje tych jednostek zostały już wcześniej ocenione przez jednostki nadzorujące.

W obu przypadkach możliwość zastosowania elastycznego zakresu spowodowała większą odpowiedzialność jednostek z uwagi na konieczność utrzymania systemu, który mógł kontrolować zmiany. Obecnie elastyczny zakres akredytacji jest coraz powszechniej stosowany, gdyż przynosi wymierne korzyści wszystkim podmiotom akredytowanym - umożliwia szybką reakcję na oczekiwania klientów i stwarza możliwość zastosowania nowych metod. Artykuł przedstawia możliwości, zastosowania elastyczności w akredytacji laboratoriów oraz jednostek certyfikujących wyroby na przykładzie Instytutu KOMAG.

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1. Introduction

An accreditation is a formal recognition of technical competences of organizations, being active in the conformity assessment scope, by the authorized domestic body and thus it is an impartial proof that they act according to the best practice.

According to the ISO/IEC 17000 Standard *"the accreditation it is third-party attestation related to a conformity assessment body conveying formal demonstration of its competence to carry out specific conformity assessment tasks"* [1].

The accreditation is connected with a possibility of mutual recognition and comparison of the results of conducted tests and of conformity assessment on the international level through an implementation and application of international standards as well as guidelines.

In the European Union the Regulation (EC) No 765/2008 of the European Parliament and of the Council of 9 July 2008 setting out the requirements for accreditation and market surveillance relating to the marketing of products and repealing Regulation (EEC) No 339/93 [2], which aims at a regulation of legal frames for an accreditation process, was edited to guarantee an activity of all the organizations at the same level. The main objective of the Regulation is: to ensure the legal basis in relation to the accreditation and to ensure a uniform system of the market surveillance, i.e. a control of products introduced to the market, and in consequence – a uniform level of consumers` protection.

The mentioned Regulation strengthens the EU policy in the scope of accreditation through the following principles:

- each Member State shall appoint a single national accreditation body,
- national accreditation body has the appropriate financial and personnel resources for the proper performance of its tasks.

In Poland the accreditation process is voluntary and available to all the organizations and the body, authorized for conducting accreditation processes, is the Polish Centre for Accreditation (Polskie Centrum Akredytacji (PCA) [3].

The condition of granting an accreditation is a statement that the testing laboratory or conformity assessment body, applying for an accreditation, meets all the accreditation requirements, however the accreditation process itself consists in an assessment of a given organization both in terms of its competences in the technical scope as well as in the scope of the functioning management system.

The assessment effect includes an edition of the certificate together with the scope of accreditation by the authorized accreditation body**.** This certificate is an authorization within specific conformity assessment activities for which accreditation is sought or has been granted.

Each accreditation system is based on the fixed scope of accreditation, which enables an exact description of accredited activities and thus it introduces a certain restrictiveness in its management. This restrictiveness consists in a lack of possibility of an independent modification or addition of new areas of activity in which the organization wants to quote the granted accreditation [4].

Summing up, the scope of accreditation is a general description of technical competences, presented in a form of a specification of scopes of activity in connection with objects/ groups of objects.

In the case of conformity assessment body, the scope of activity included:

- name of product / product group,
- name of product certification schemes and/or acronym together with the edition identification,
- normative documents and/or legal requirements in relation to which the products are certified,
- the ICS identification for a product or a group of products.

In the case testing laboratories the scopes of accreditation consist of uniform thematic blocks (domains of tests-objects- technologies- methods) in which the following information is given [5]:

- testing area,
- product of materials - objects of tests / groups of objects / tested materials or products,
- test method (method, international standard, validated laboratory-developed methods),
- range of measurement,
- documented laboratory-developed methods and procedures and standard methods use.

The documents called in the scope of accreditation can be domestic, regional and international standards, Polish and European Union legal regulations, codes of conduct, generally available publications and author`s testing procedures or certification programmes.

At the moment of applying for an accreditation both the certifying body of products, as well as testing laboratories decide themselves about their scopes of accreditation, mainly taking into account such factors as:

- a customer`s interest in an assessment of products,
- personnel's competences,
- a knowledge of testing methods,
- technical possibilities.

In the case of the fixed scope it is not possible to extend it quickly, introducing new or modified methods, even if the laboratory competences in a realization and validation of similar methods have already been assessed by the accreditation body. Indeed, the application for an extension of the scope of accreditation can be submitted any time, however the time – consumption of the whole process may in reality make a quick reaction to the customer`s expectations impossible.

Therefore at the moment of establishing and approving the scope of accreditation, organizations take into consideration real possibilities and in general they do not apply for accreditation "for the future".

Such a situation caused an elaboration of the flexible scope of accreditation.

The scope of accreditation for testing laboratories can inhibit, in certain cases, their quick response to customers` needs, if the scope is too rigid with regard to the modification of test methods and the introduction of new ones using the same measurement principles. Document EA-2-05 published by the European Cooperation for Accreditation describes possibilities to allow flexibility in accredited laboratories [6].

Since then initially only in the environment of testing laboratories two terms have been used:

- **fixed scope of accreditation** - which means that the laboratory cannot modify the methods included in its scope. An introduction of modified methods to the scope of accreditation can take place no sooner than after an independent assessment conducted by the authorized accreditation body
- **flexible scope of accreditation** - which allows testing laboratory to make changes in methodology and other parameters which fall within the competence of the laboratory as confirmed by the accreditation body. The condition, enabling to change the scope for flexible one, is a positive assessment of laboratory competences, not only in the scope of conducting tests but also managing the activities within the framework of the flexible scope.

2. Management system features for laboratories seeking flexible scope on the example of the KOMAG`s Testing Laboratories

The most essential element, enabling an activity of accredited testing laboratory in the flexible scope, is an adaptation of the laboratory management system to the new requirements.

The management system based on the EN ISO/IEC 17025 standard should in particular regulate such issues as [7]:

- principles of cooperation with a customer, a review form of enquiries, offers and contracts, (contract review process confirms and informs the customer/enquirer that a request is within the limits of its flexible scope),
- the responsibilities for the management of the flexible scope and for each set of activities,
- a description of technical activities in the field of:
    - personel,
    - testing methods and their validation,
    - measuring instrumentation,
    - management.

The element, distinguishing the laboratories having the flexible scope of accreditation, includes an obligation of elaborating and continuous up-dating of the *List of accredited activities conducted under* *their flexible scope*. This List should contain information as a minimum to that detailed in section 7.8.3 a-h of the ISO/IEC 17011:2017 [4].

The laboratory itself manages the List. The purpose of the List is to provide up-to-date transparency of the application of the flexible scope and shall be made publicly available.

Up–dating of the „List" results exactly from the management of activities within the framework of the flexible scope and may occur only and exclusively after an appropriate execution of all the planned stages of technical activities.

The testing laboratory which has the flexible scope in its accredited technical domain or area has a possibility [8, 9]:

- to use up-dated, standards methods,
- to adopt successive revisions of standard methods, provided that they are based on previously demonstrated technical competence,
- to apply modified methods of its own,
- to implement new methods of its own and standard methods.

A determination of flexible scope in tests can occur in relation to:

- samples, objects of tests, materials or products tested,
- tested features, properly measured along with range of measurement,
- a realization of testing procedures, standard specification: identifying the procedure used in tests, measurement techniques used,
- associated testing and measurement uncertainties.

However, it should be highlighted clearly that the testing laboratory, having such a big authorized capacity to act, can introduce new measuring or testing techniques in the framework of flexible scope of accreditation only after an assessment of competence and technical possibilities conducted by the accreditation body.

Three accredited testing laboratories, functioning in the structure of the KOMAG Institute, act on the basis of flexible scopes [10]. The experience, gained from the ten-year period of the applying such scopes, is a proof that such a system is efficient and useful.

These laboratories can decide themselves about an implementation of an additional testing method or about its modification within the limits determined by the scope and after having fulfilled all the requirements described in the management system.

In the KOMAG`s testing laboratories their own methodologies and procedures, which guarantee a proper management of flexible scope, were elaborated and implemented. These methodologies have, among others the following objectives:

- a use of the agreement survey procedure, taking into consideration an aspect of applying the accredited flexible scope,
- regular contacts with a customer and conveying information connected with the flexible scope,
- an assessment of technical and competence abilities of the laboratory for a realization of testing service,
- a continuous up-date of the "List" after a proper execution of appropriate technical activities and an introduction of the documents describing the modified or new testing methods,
- conducting analyses and undertaking corrective measures in the cases when in the result of a validation process it will be stated that the laboratory is not capable of issuing competent reports.

Each new need in the scope of realizing a testing service is analyzed from the point of view of technical and formal possibilities.

The laboratory assesses if it has possibilities of realizing a determined testing service in the framework of the fixed or flexible scope.

In the case of tests from the flexible scope there is a necessity of a verification of the suggested method and the laboratory conducts a risk analysis connected with an application of a new or modified testing method.

The hazards which may occur during an introduction of new methods are analyzed. They can include:

- the case, when the laboratory states that is not capable (due to any reasons) of realizing tests correctly and rejects a new method as impossible for a correct realization,

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– the situation when the laboratory is not capable of realizing tests within the period required by the customer due to different factors e.g. a long – lasting validation process of the method, a necessity of purchasing new measuring instrumentation, a necessity of conducting additional consultations and trainings etc.

After having conducted a risk analysis, the laboratory undertakes activities connected directly with an elaboration of a new methodology or a modification of the existing one and then it approves of it and implements a new testing procedure. The laboratory also conducts a validation of the method or its verification, if it is a standard method.

After having up-dated and approved of the List extended by the new testing method, the laboratory can quote the accreditation in reports on the tests conducted according the new or modified method, a general procedure is shown in Fig.1.

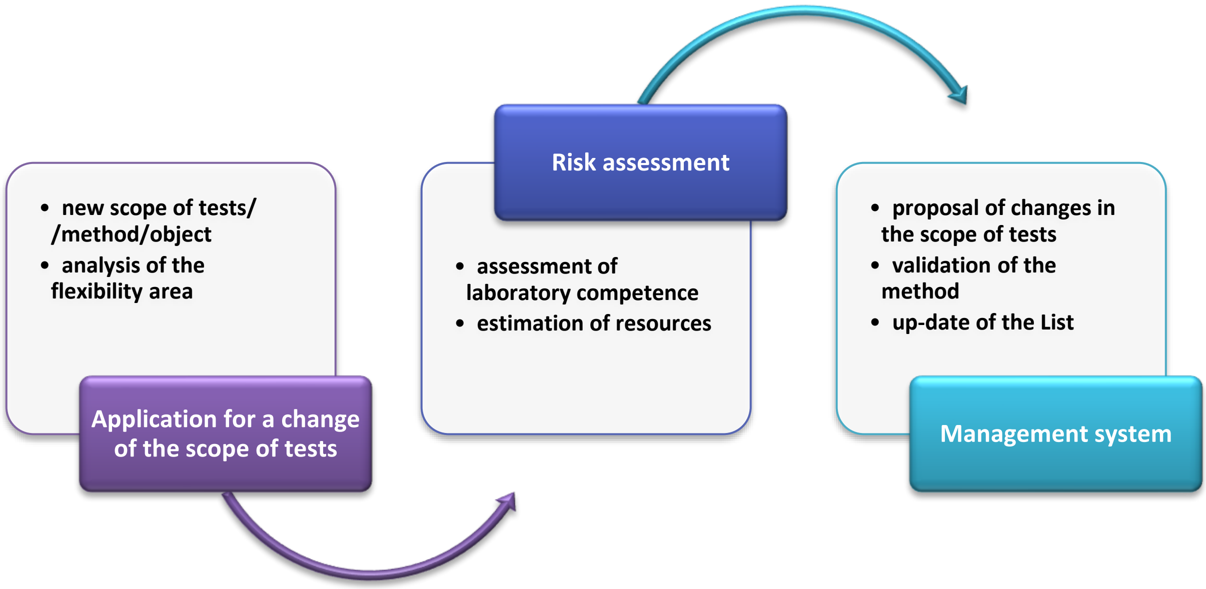

Fig 1. General scheme of a procedure for an introduction of a new method to the List

The implemented author`s methodology of conduct at the KOMAG testing laboratories guarantees a repeatability of procedures and ensures the proper management of the flexible scope.

In the decision for an accredited body there is a description of the scope of accreditation, i.e. what the body is competent to perform within its accreditation.

The design and details in the description of the scope are adapted to the respective conformity assessment area. A scope that includes flexible accreditation may be described in the accreditation decision with fewer details.

Experience of three KOMAG laboratories indicates that the expression flexible scope varies greatly from sector to sector. The following examples are proof of this [10].

The laboratory may have fixed five types of flexibility for certain test areas and may have fixed accreditation or two types of flexibility for certain test areas. Footnotes or other signs indicate the degree of flexibility for each part of the scope.

Example 1 - Laboratory of Material Engineering and Environment (AB 910)

Flexible scope		
Consumer products, products for contact with food, toys and articles for children, materials which may have contact with children, polymer and rubber products and raw materials for their production [1)]	Tests for safety Contents of bisphenol A –BPA [3)] Method of gas chromatography with tandem spectrometry of masses (GC-MS/MS)	Testing procedures [5)] Legal regulation [5)]
Limits of flexibility 1) An addition of the object to be tested in the framework of the group of objects 3) A change of measuring scope of the testing method 5) An application of up-dated and an implementation of a new method described in; standards/ procedures elaborated by the laboratory /legal regulations		

Example 2 – Laboratory of Tests (AB 039)

Flexible scope		
Products and construction components Components of machines and equipment	Linear and angular geometric dimensions Direct measurements [2)3)] Static strength Direct and indirect measurements [2)3)] Load - bearing capacity Direct measurements [2)3)]	PN-G-15050 [5)] PN-G-15533 [5)] DIN-5685-1 [5)] DIN 20637 [5)]
Limits of flexibility 2) An addition of the feature under testing within the framework of the object/group of objects to be tested and methods (testing technology) 3) A change of measurement scope of the testing method 5) An application of up-dated methods described in: standards/ procedures elaborated by the laboratory /legal regulations		

Example 3 - Laboratory of Applied Tests (AB 665)

Flexible scope		
Electric equipment (including devices designed for operation in space where gas explosion hazard occurs, of strengthened construction "p", *"pD"*, "e", "n", "m" and electric outfit [1)]	Electric, physical, mechanical strength, climatic properties and functional tests - direct and indirect measurements [2)3)]	PN-EN 60079-0 [5)] PN-EN 60079-2 [5)] PN-EN 60079-7 [5)] PN-EN 60079-15 [5)] PN-EN 60079-18 [5)] PN-EN 60204-1 [5)] PN-EN 61241-4 [5)]
Limits of flexibility 1) An addition of the object to be tested in the framework of the group of objects 2) An addition of the feature to be tested in the framework of the object/group of objects subject to tests and method (testing technology) 3) A change of measurement scope of the testing method 5) An application of up-dated methods described in: standards/ procedures elaborated by the laboratory /legal regulations		

In all the cases, the laboratory has to keep an updated list of accredited test methods including newly modified, introduced or developed methods available for the accreditation body. In all the cases, the scope of accreditation, i.e. the list of test methods, the range of products and measured parameters allow the laboratory and accreditation body to identify the limits of flexibility [11,12].

3. Management system for Conformity Assessment Body and Conformity Assessment Bodies using flexible scopes

In 2019 the up-dated document EA Requirements for the Accreditation of Flexible Scopes was published. It extended a possibility of using flexible scope also in relations to the activity of products' conformity assessment bodies [13].

The flexible scope in the products' conformity assessment body may concern:

- provisions of normative documents related to products,
- certification programmes of products.

A conformity assessment body of products, accredited in the flexible scope in the determined limits, has a possibility of:

- applying up-dated normative requirements and provisions concerning products,
- applying up-dated certification programmes including their following versions, if their use is not regulated by a different owner of the programme.

In the case of the conformity assessment body, having the accreditation for the notification purposes in the flexible scope, it has a possibility of using, in the determined scope of accreditation, the following documents:

- current editions of normative documents indicated in the scope of accreditation, in relation to which assessment processes are carried out,
- relevant normative documents (not indicated in the scope of accreditation) and their current edition appropriate for demonstrating conformity with the requirements of the legal regulations to be applied.

The implemented author`s proceeding methodology at the KOMAG`s Conformity Assessment Body is based on the management system acc. to the EN ISO/IEC 17065 Standard, due to which a repeatability of procedures is guaranteed and an appropriate management of the flexible scope is ensured [14,15,16].

According to the implemented methodology within the framework of the management system, an introduction of changes on the List is preceded by:

- checking of changes introduced in the normative document or in a new edition included in the scope of accreditation and a verification of testing possibilities in reference to these changes,
- a verification of possibilities to conduct a product assessment in reference to normative documents (not indicated in the scope of accreditation) relevant for demonstrating conformity with the requirements of the legal regulation to be applied and a verification of testing possibilities.

The following examples are proofs of flexible scope in two areas [15].

Example 1 - Accredited Body Certifying Products (AC 023)

Product/Product Group	Certification Scheme	Standard/normative document	ICS
Safety of machinery	PC-DBA/01 PC-DBA/02 PC-DBA/04	PN-EN ISO 13849-1 PN-EN 60204-1 PN-EN IEC 60204-11 PN-EN 62061 PN-G-50000	13.110
Limits of flexibility - an application of up-dated normative requirements and provisions concerning products			

Example 2 - Notified Body No 1456

Directive No. 2006/42/WE			
Product(s)	Conformity assessment procedure/module	Reference to national law	Reference to European law
12. Machinery for underground working of the following types: 12.1. locomotives and brake-vans; 12.2. hydraulic-powered roof supports.	EC type-examination	Annex 6, p. 2 1)	Annex. IX 2)
Limits of flexibility - an application of relevant normative documents, appropriate for a demonstration of conformity with the requirements of legal regulations to be applied 1) Rozporządzenie Ministra Gospodarki z dnia 21 października 2008 r. w sprawie zasadniczych wymagań dla maszyn Dz.U. 2008 nr 199 poz. 1228 (order of Minister of Economy from 21st October 2008 on basic requirements for machines, Official Gazette 2008, No 199, Item1228) 2) Directive 2006/42/EC OF the European Parliament and of the council of 17 May 2006 on machinery			

4. Conclusions

Modern market gives testing laboratories and accredited bodies certifying products new challenges. A necessity of a fast reaction to customers` needs, resulting, inter alia, from changing legal regulations as well as from the technical progress, are the basic reasons of introducing innovative solutions by these entities.

Flexible scope of accreditation yields benefits to all the accreditation stakeholders, but on the other hand, introduces more requiring interpretations of relevant standard clauses and includes the bounds of the scope which are defined in a more distinct way [17, 18].

At present all the national accreditation bodies create a possibility of accrediting flexible scopes.

There is no doubt about the fact that the flexible scope is a reflection of laboratory competence for a realization of accredited tests not only in technical areas but also a laboratory ability for managing the process connected with having the flexible scope and its engagement in offering accredited tests within the framework of this scope.

At the market there are laboratories in operation, which conduct standard tests often within the framework of multi-year contracts and the form of the fixed scope of accreditation is completely sufficient for them.

In other cases a flexible form of the scope is a necessity, enabling testing laboratories to fulfil the requirements which change continuously.

In turn, in the case of the Conformity Assessment Body a possibility of applying the flexible scope facilitates an activity of following - up continuously changing normative requirements, being the basis of conducted assessments by such a body.

However, there is still a need of gathering experience, resulting from use of flexible scope of accreditation, because it is a new tool which requires an assessment of its efficiency.

It is clear that an accreditation should be based on the flexible scope if an entity wants to follow - up a modern development and serve customers` needs in determined areas.

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