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Effectiveness of half masks for respiratory health protection in coal mining

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Abstract:

An improved procedure is presented for testing the level of respiratory health protection and comfort of half masks currently used in coal mining and similar industries. This will allow companies to make the best choice of such equipment for their workers. Half masks used by one Slovenian (PV) and two Polish (JSW and PPG) coal mining companies were tested in terms of filtering efficiency, especially for $PM_{2.5}$, perceived effectiveness, comfort and ease of use.

Filtering efficiency was determined by analysing filters from masks used in underground operations for the levels and sizes of trapped coal dust particles and by carrying out experiments employing a specially developed laboratory test stand. The latter incorporated a replica human head and a climatic chamber to simulate the humidity of exhaled air during mining activities. To determine the comfort and utility of the half masks, selected miners were asked to fill in questionnaires. The main results of these studies were that, in the interest of miners' health, and for those working in other high dust environments, the quality of the half-mask should be assessed on the basis of workplace and stand tests. These are complementary and both should be included to ensure the correct assessment of the half masks. For the masks supplied by the mentioned mining companies, their filtering efficiency for $PM_{2.5}$, as determined using the test stand, was excellent at over 99%.

Keywords: RPE equipment, $PM_{2.5}$, half masks, testing stand

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1. Introduction

The testing of half masks used to protect workers from potentially toxic coal dusts was one of the main objectives of the 3-year (2017-20) EU Research Fund for Coal and Steel project "Reducing risks from Occupational exposure to Coal Dust" (ROCD). This chiefly focussed on particulate matter in the size fraction $PM_{2.5}$ which has an aerodynamic diameter less than or equal to 2.5 μm and can therefore penetrate into the deepest, alveolar regions of the lung [1]. In urban air pollution studies, increased atmospheric concentrations of $PM_{2.5}$ have been linked to higher rates of cardiovascular and respiratory mortality [2,3]: "There is no evidence of a safe level of exposure or a threshold below which no adverse health effects occur". Coal dust $PM_{2.5}$ assessed in the ROCD project was found to contain a range of potentially toxic metals and metalloids [4].

A common problem in mining and other sectors, e.g. the petrochemical industry [5], is the reluctance of workers to use respiratory protective equipment (RPE), even where dust concentrations are above maximum recommended values. Participants in the ROCD project included JSW and PGG from Poland, and PV from Slovenia, which are amongst the most important mining companies in the EU. The range of RPE they use is typical for the European mining industry but differs between companies. PV only uses FFP-1 half masks whereas JSW and PGG use either FFP-1, FFP-2 and FFP-3 masks, depending on the nature of the operation. FFP-1 are mainly used on surface, e.g. in coal processing plants.

The aim of the current study was to improve the testing procedures used for RPE which will allow mining and other companies to make the best choices of equipment for their workers. To begin with, their filtering efficiency was determined by analysing filters from masks used in underground operations for the levels and sizes of trapped coal dust particles. Next, KOMAG developed a laboratory test stand to assess the effectiveness of half masks to filter out dusts, particularly $PM_{2.5}$. To be as realistic as possible, this incorporated a replica human head and a climatic chamber, the latter to ensure the correct humidity of exhaled air during the tests. To determine the comfort and utility of the half masks, some miners were asked to fill in questionnaires.

In addition to providing test data for half masks, the study also gave recommendations for the appropriate selection of RPE for different types of operation and dust, the correct fit-to-face and best practice for its use. For example, facial hair can decrease the efficacy of the seal between the mask and face, and a tighter fit can reduce leaks. These aspects were pointed in the literature [6,7,8]. Breathing resistance is also important; if this is too high, requiring a lot of effort to breath, the user may suffer hypoxia [9]. It has a very significant influence on the rating of the mask.

This article addresses the above-mentioned issues and discusses the following:

- The design of the test stand,
- Results of half-mask tests in the aspect of breathing resistance and air filtering efficiency,
- Work place testing in the underground mines.

2. Methods of half mask testing

RPE in the EU is tested in accordance with standard EN 149 + A1: 2010 [10], which includes the following three types of test:

- Total internal leakage,
- CO_2 content in the inhaled air,
- Filter clogging by dolomite dust.

In addition, to be certified, tests are carried out on RPE to determine its level of protection. The issue with this is that most do not fully simulate workplace conditions [11]. Studies are therefore ongoing to develop more realistic and quantitative test methodologies. For example, a miniature, in-mask, sampling device has been designed to gain a better understanding of worker respiratory exposure to hazardous substances [12]. A new method has been proposed for evaluating the relative efficiency of commonly used respirators and surgical masks for airborne "vegetative cells", e.g. bacteria and viruses [13]. In addition, the COVID 19 pandemic has prompted research into the effectiveness of masks for virus protection [14]. With regards to the ROCD project, the aim was to test the performance of half masks for dusts sampled in working coal mines.

The research process at KOMAG began with the microscopic analysis of filters from half masks to better understand how they work. FFP-3 masks usually consist of 3 layers: 1) the outer layer that consists of synthetic fibres, each with a thickness of 10-20 µm, which acts as a primary barrier to the largest particles; 2) the middle layer, the most important, that is made of densely pressed fibres each with a thickness of 2-3 µm; and 3) the inner layer which is usually similar to the outer layer but provides protection for the middle layer. Fig. 1 shows a fragment of used FFP-3 half mask with its 3 layers, and Fig. 2 a photomicrograph of each layer. The filters were from half masks used by miners during their shift. The main problem with this type of test for quantifying the effectiveness of masks is that different people's behaviour varies greatly, e.g. their working practices, rate of respiration etc., and levels and types of dust vary between mines and mining operations. It was therefore necessary to build a special test stand so that the filtering efficiency of masks could be determined under standard and controlled conditions. To complement this, questionnaires were given to selected miners of the PV, PGG and JSW companies to determine factors such as comfort and ease of use of different masks.

Fig. 1. Sample of filter from a half mask used during coal mining operations; the three layers have been partially separated, the outer layer in the foreground, then middle layer and finally inner layer

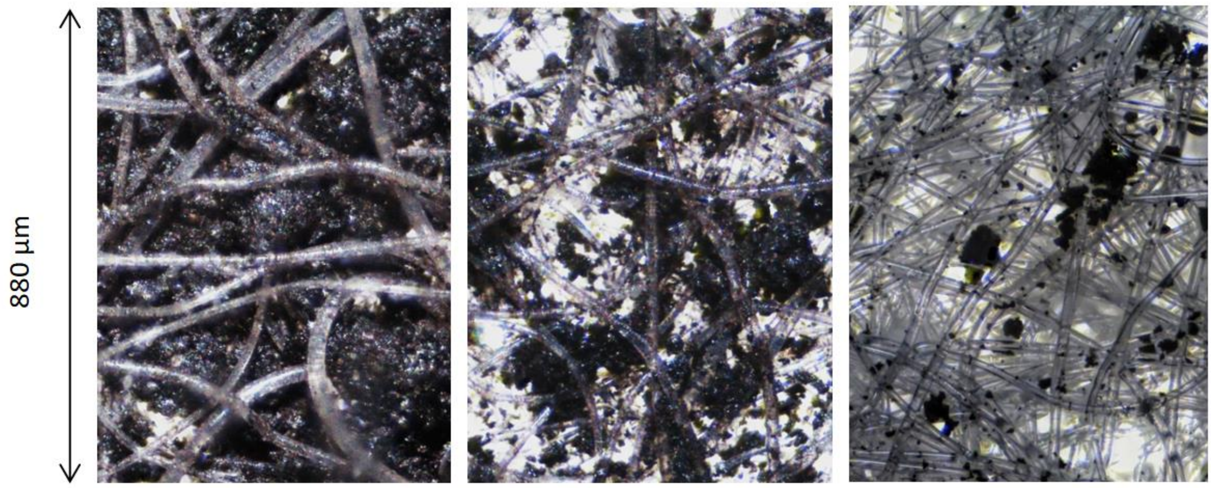

Fig. 2. Three layers of the FFP-3 mask visible at 50x magnification, from left to right: outer layer, middle layer, and inner layer; the black materials on and between the fibres are the particles of coal dust

2.1. Test stand, procedure of testing, half masks and filter materials testing

The new test stand designed under the ROCD project enabled the comprehensive assessment of different disposable and reusable half-masks, including breathing resistance which has a very significant influence on the rating of the mask [6,15], is shown in Fig.3. The schematic diagram of the test stand is shown in Fig. 4. The half-mask to be tested is strapped to the artificial head which is then placed in a dust chamber. The use of the artificial head does not eliminate leaks between the head and the mask, which is the same as for when a mask is fitted to a real human head. So that the masks could be tested without the effects of leakage, a comparative tests were also carried out, with the edges of the tested masks tightly glued to the artificial head.

The artificial head is joined to an artificial lung by two cylinders. The left (exhalation) cylinder is connected to the climatic chamber. Its task is to take air (with the required humidity) from the climatic chamber and to transmit this through the mask being tested and into the dust chamber. The right cylinder draws air through the half mask from the dust chamber and transfers it to the compensation tank. The measuring device measures the dust concentration in the air alternately, first in air from the dust chamber and then in air from the compensation tank. The artificial lung works in two operating modes: inhalation mode and exhalation mode.

Inhalation mode – when the piston rises, the dust-laden air from the dust chamber is sucked in (the right cylinder and red marked direction) through the half mask attached to the artificial head, using the inhalation cylinder. At the same time, the humid air from the climatic chamber is sucked in by the second cylinder (the left cylinder in Fig. 4 and red marked direction), which is called the exhalation cylinder.

Exhalation mode – when the piston descends, the air from the inhalation cylinder is directed into the compensation tank and (at the same time) the air from the exhalation cylinder is directed towards the dust chamber.

The dust concentration in the compensation tank (i.e. dust which passed through the mask) and in the dust chamber are measured alternately by the same dust monitoring unit.

Fig. 3. Test stand for RPE equipment with a view of its artificial lungs on the right

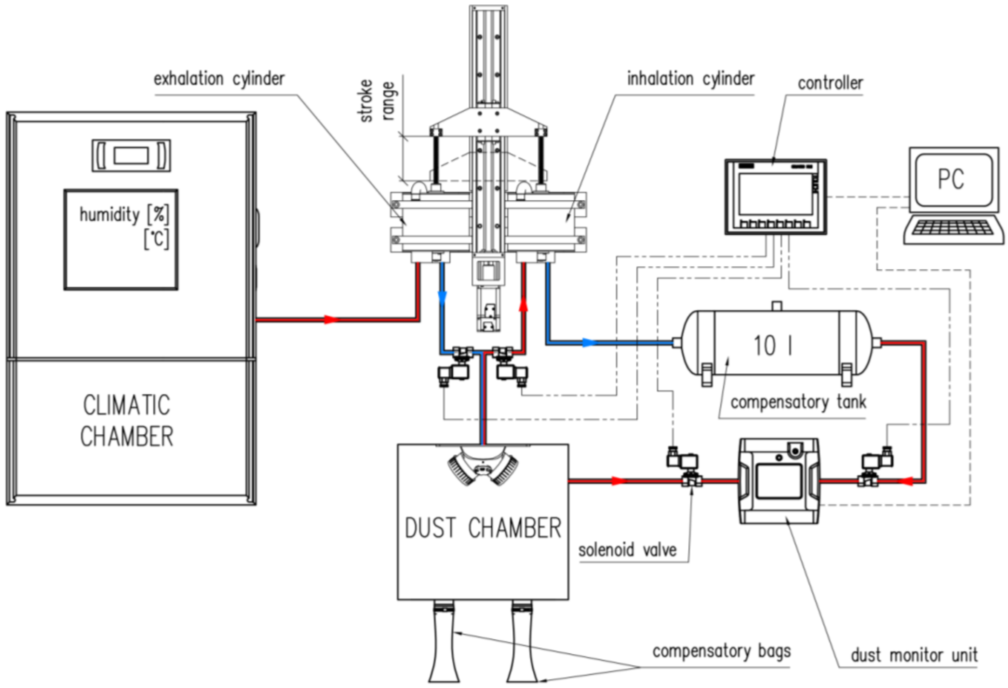

Fig. 4. Schematic diagram of the test stand used for assessing half masks

The auxiliary test stand for testing the filtration efficiency of filter materials and its breathing resistance is based on the main test stand. The auxiliary test stand enables comparative tests of mask filters through the elimination of the exhalation valve and mask-to-face leaks. To achieve this, an additional port was installed on the dust chamber which terminates in a threaded tip for attaching the filtration medium to the chamber. Only one cylinder, which sucks air from the dust chamber through the tested section of the filter material is used.

Schematic diagram of the auxiliary test stand is presented in Fig. 5.

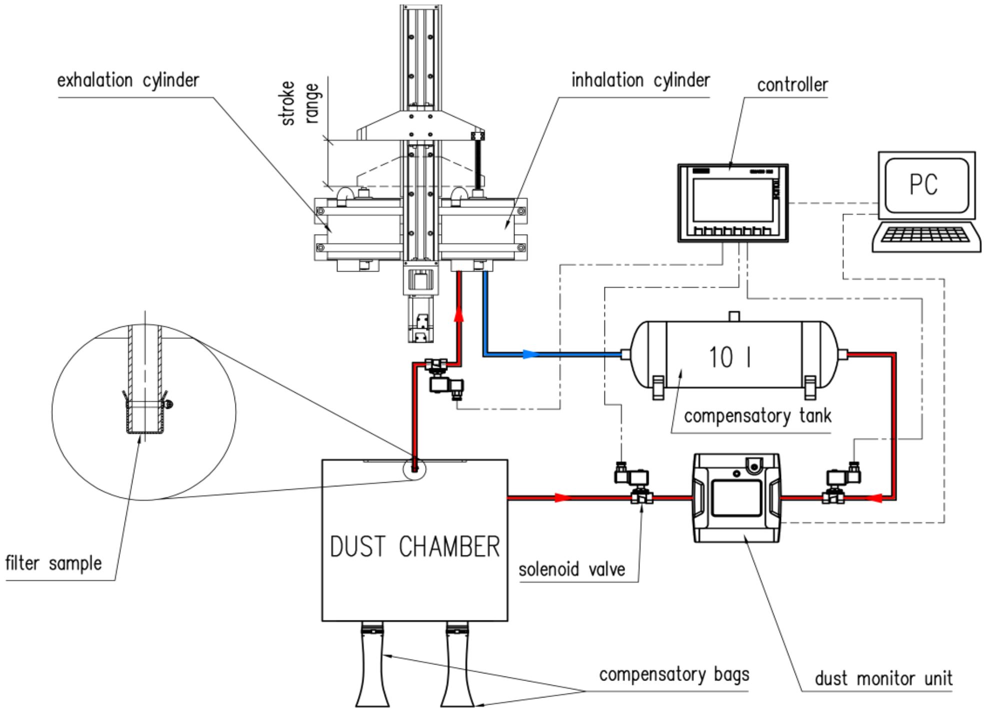

Fig. 5. Schematic diagram of the auxiliary version of the test stand

The test stand developed by KOMAG to determine the filtering efficiency of different types of half mask has three test modes:

- Testing of half masks fitted and strapped to the artificial head;
- Testing of half masks fitted and glued to the artificial head;
- Testing sections of filter material glued to the cover of the hermetic box (Fig.7) using the auxiliary test stand.

The test stand allows for determination of breathing resistance for a number of combinations of two breathing parameters - breathing volume and rate. The following three main combinations were used:

- 700 ml /12 breaths/min – simulating easy breathing (rest);
- 1000 ml / 25 breaths/min – simulating moderate effort (light work);
- 1500 ml / 60 breaths/min – simulating high effort (hard work).

Breathing resistance was measured four times, first at the beginning, when the mask is new and clean, and the three more times, when the following number of breathing cycles under light work rate were completed:

- after the first 1100 cycles;
- after the next 1100 cycles i.e. jointly after 2200 cycles;
- after the next 1100 cycles i.e. jointly after 3300 cycles.

For testing samples of mask filter, the following breathing volume and rate were used:

- 300 ml breaths with 12 breaths / min;
- 400 ml breaths with 12 breaths / min;
- 500 ml breaths with 12 breaths / min.

The dust for testing was prepared by the Główny Instytut Górnictwa from the dust samples taken from an underground mine. The dust was dosed into the air using a special pneumatic system, developed by KOMAG. During the tests of half-masks, dust was periodically replenished, while during the tests of the filter sections, one dust dose for a 20-minute test time was used. Due to a gravitational reduction in dust concentration in the chamber over 20 minutes (Fig. 6), dust concentrations in the chamber and in the passing air (air not drawn through the mask) were compared to calculate the effectiveness of the half mask or filter material.

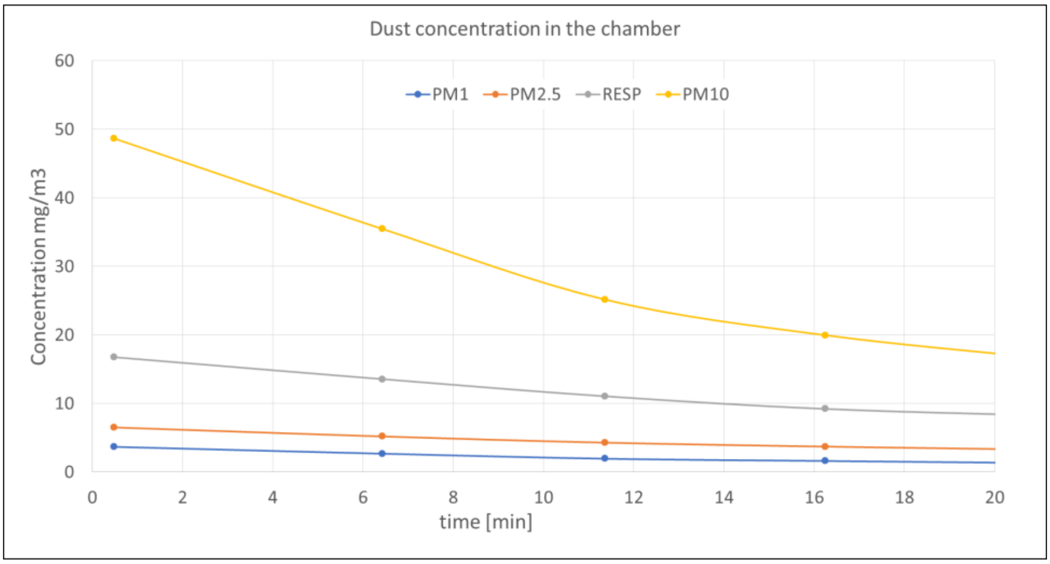

Fig. 6. Dust concentration as measured inside the dust chamber over a period of 20 minutes

The following procedure for half mask testing was developed:

a. a new mask is placed on the artificial head or sealed onto the artificial head (i.e. the mask rim is glued);

b. the breathing resistance is first tested for three levels of physical activity: rest, light work and hard work;
c. the dust chamber is closed, dust and humid air are introduced into the system;
d. when the dust concentration in the chamber reaches 30 mg/m^3, 1100 breathing cycles are started with light breathing rate (i.e. 1000 ml and 25 breaths per minute) and dosing dust and humid air;
e. the operation of artificial lungs is stopped, the chamber door opened and breathing resistance is tested, as in item "b";
f. the chamber is then closed again and the next 1100 (1100-2200) cycles are realized at the light work breathing rate, as in item "d", with dosing dust and humid air
g. the operation of the lungs is stopped, the chamber's door opened and, for the third time, breathing resistance is tested, as in item "b";
h. the chamber is then closed and the next 1100 (2200-3300) cycles at the light work breathing rate, same as in "d", are realized with dosing dust and humid air;
i. the lungs are stopped, the chamber's door opened and, for the last (fourth) time, breathing resistance is tested, as item in "b".

The testing of fragments of mask filters on the auxiliary test stand eliminates the impact of leaks between the mask and face and from the exhalation valve. It allows the most accurate assessment of filter quality, regardless of the shape and size of the mask. Filter materials from masks were tested in the following procedure. A piece of filter material was glued onto the cover (Fig. 7) of a hermetic box. The box with cover is placed on the dust chamber and connected by a pipe to the measuring equipment in the test stand.

Fig. 7. A fragment of mask filter glued to the cover of the hermetic box before its testing

For each filter, 240 breathing cycles of 12 breaths/min for each of the three selected volumes i.e. of 300 ml, 400 ml and 500 ml was carried out. Seven types of half masks were tested during the ROCD project; two from JSW, two from PGG and one from PV. Additionally, 2 masks used by KOMAG's (KOM) workers were also tested to gain more data. The tested half-masks are listed in Table 1 and examples of tested disposable and reusable half masks are shown in Fig. 8 and Fig. 9.

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Table 1. Masks tested with the newly developed test stand.

Item	Mining co.	Designation only for the article purpose	Mask type
1.	JSW	1J FFP2	bowl type disposable, exhal. valve
2.	JSW	1J FFP3	bowl type disposable, exhal. valve
3.	PGG	2P FFP3	foldable disposable, exhal. valve
4.	PGG	3P FFP2	foldable disposable, exhal. valve
5.	PV	1V FFP1	bowl type disposable, exhal. valve
6.	KOM	4K FFP2	foldable disposable, no exhal. valve
7.	KOM	5K FFP2	reusable, exhal. valve

Fig. 8. Examples of disposable masks: bowl type (on the left) and two types of foldable masks (on the right)

Fig. 9. Example of the reusable mask SECURA 2000

Reusable masks have two replaceable filters which makes the active filtering area larger than for a disposable mask, which may affect the test results. Reusable masks were therefore also tested for comparison with disposable masks.

2.2. Workplace testing

Providing workers with RPE is not enough to protect them. RPE should be selected correctly, worn properly and fitted adequately [7,8,9]. The lifetime of masks before their efficiency drops below acceptable levels depends on the breathing rate and the concentration of airborne dust. During intensive work in dusty conditions, the filter material quickly becomes wet, due to the passage of humid exhaled air, and clogged with deposited dusts which increases breathing resistance. Use of an exhalation valve in the mask is advantageous as it reduces exhalation resistance and the wetting of the filter. Only one valve is usually necessary (rather than one per filter) as the second valve will normally remain idle, except for situations of very high physical activity. Moreover, it should be remembered that the second valve unnecessarily reduces the active area of the filter for dust capture as it replaces a portion of the filter area. The effective lifetime of a half-mask or a set of replaceable filters in dusty conditions may be from 30 minutes to several hours. Mine employees have indicated a practical working life of between 2 and 6 hours. It is obvious that a higher density of fibres in the mask filter (giving greater filtration efficiency) will cause an increase in breathing resistance (i.e. greater difficulty breathing) and therefore the choice of mask should be a compromise between these features. The type of mask to be used should be carefully selected according to the dust-related health hazards which is reflected in the literature [16,17]. The workplace method of research using questionnaires is important for verifying RPE utility [18], however it has been noticed that the questionnaires used in some mining companies promote masks with a long lifetime. These tend to have a low breathing resistance and immediate breathing comfort but may not offer the best filtering efficiency. This aspect was also taken into consideration when planning the underground RPE test program in the ROCD project, which involved PGG, JSW and PV. The agreed questions in the questionnaire are presented in Table 2 of section 3.3.

3. Results

The results of the half-mask testing are discussed below in the following order:

- Results from the testing of breathing resistance;
- Results of filtering efficiency tests;
- Results from workplace testing.

3.1. Half mask breathing resistance test results

With regards to points a-i of the testing procedure, the breathing resistance tests for half masks were conducted for all three breathing parameters. An example of the results from these breathing resistance tests are shown on Fig. 10 and 11. It was observed that during the hard work mode (i.e. 1500 ml and 60 breaths/min), the under-pressure was high. As expected, the resistance of reusable masks (dark blue and brown bars in the graphs) was the lowest.

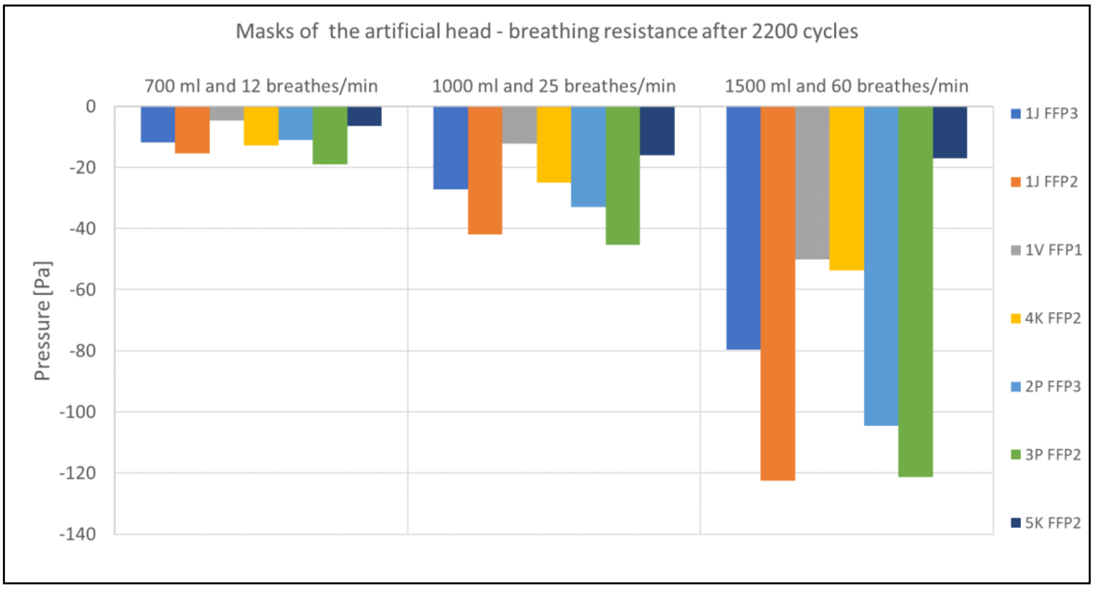

Fig. 10. Graph comparing the breathing resistance of different half masks attached to the artificial head, after 2200 cycles

To assess the possible impact of leakage between the mask and the face of the artificial head, similar tests were carried out on masks glued to the artificial head, see results in Fig. 11.

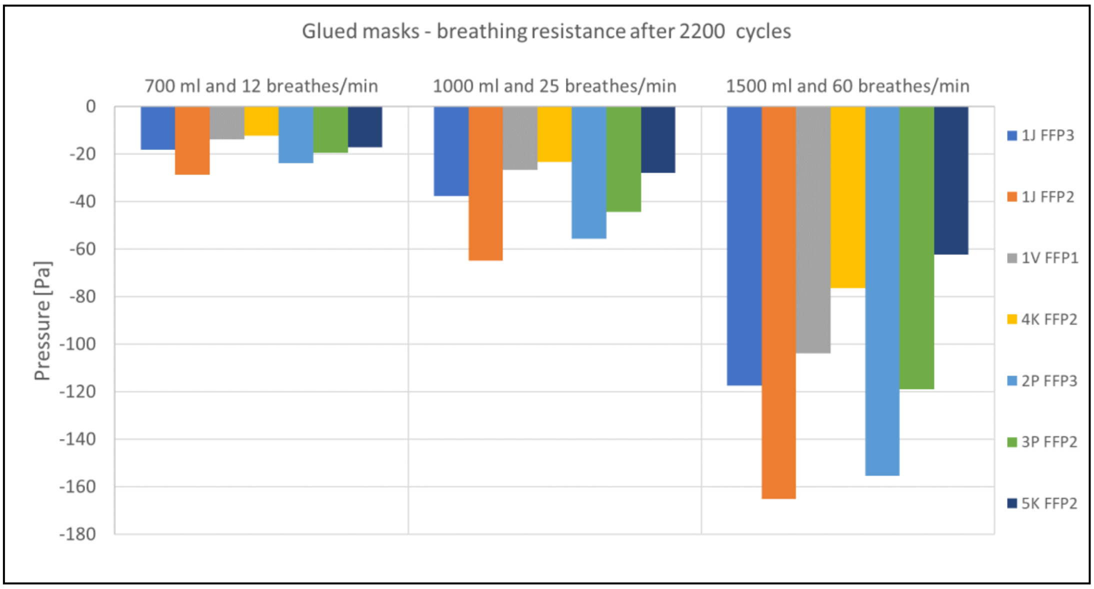

Fig. 11. Graph comparing breathing resistance of different glued masks after 2200 cycles

When comparing the graphs in Fig. 10 and 11, it is clear that there is a significant impact of leaks on breathing resistance. Reusable masks (dark blue) had the lowest resistance and the disposable masks (brown) the highest. The mask type represented by the yellow data bar (3M Vflex 9152R FFP-2) gave good results even without an exhalation valve. This result is similar to that of the reusable masks shown in dark blue, with a centrally located exhalation valve.
After analysing the resistance data for the masks, it was interesting to compare them with the results from the testing of filter sections, see Fig. 12.

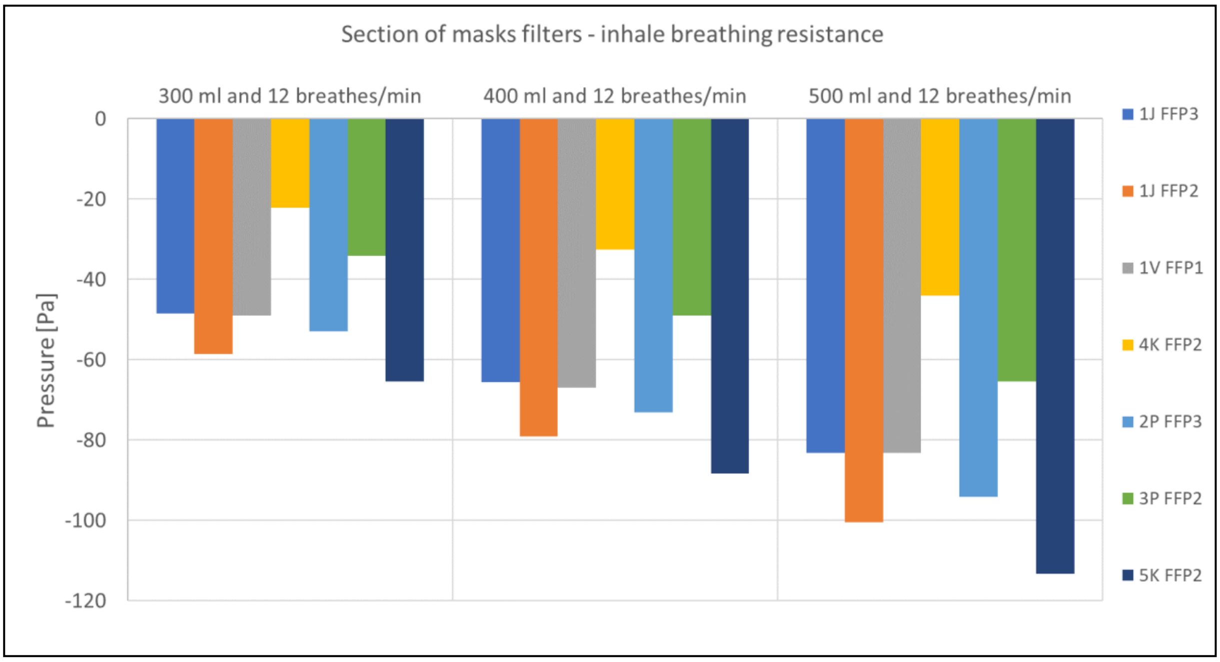

Fig. 12. Graph comparing the inhalation resistance of filter sections from different masks

Reusable masks, which have two filters and therefore a combined active filter surface of 300 cm^2, have a lower resistance than disposable masks with an area of up to 240 cm^2. However, when testing a defined area of the filtering material (the same as that for the disposable masks), their inhalation resistance is higher (Fig. 12). This emphasises the importance, better comparability, of testing filter sections rather than whole filters when assessing the filtration efficiency of mask filters. The same is true for the results of testing the exhalation resistance of filter sections (Fig. 13).

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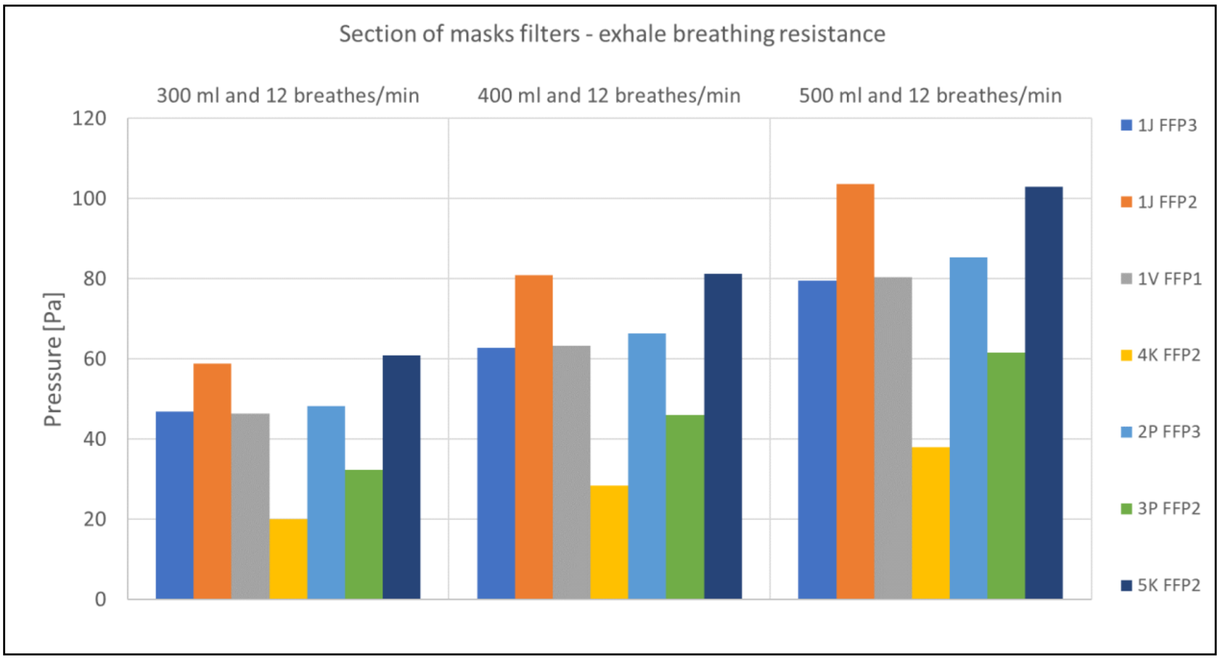

Fig. 13. Graph comparing the exhalation breathing resistance of filter sections from different masks

3.2. Results of filter efficiency tests

The tests undertaken to determine the filtering efficiency for $PM_{2.5}$ of different masks were carried out using the test stand with the artificial head, see results in Fig. 14. It can be observed that filtration efficiency did not decrease noticeably when the number of breathing cycles increased up to 3300, however, there were differences between each mask. The reusable masks (FFP-2 filters) showed a relatively low efficiency comparable with FFP-1 masks (provided by PV), which was a bit surprising. In Fig. 15, similar results are presented for $PM_{2.5}$, for masks glued to the artificial head, i.e. where there is no possibility of leakage. The glued masks showed a much higher filtering efficiency (>99%) than for the masks fitted to the artificial head (>87%).

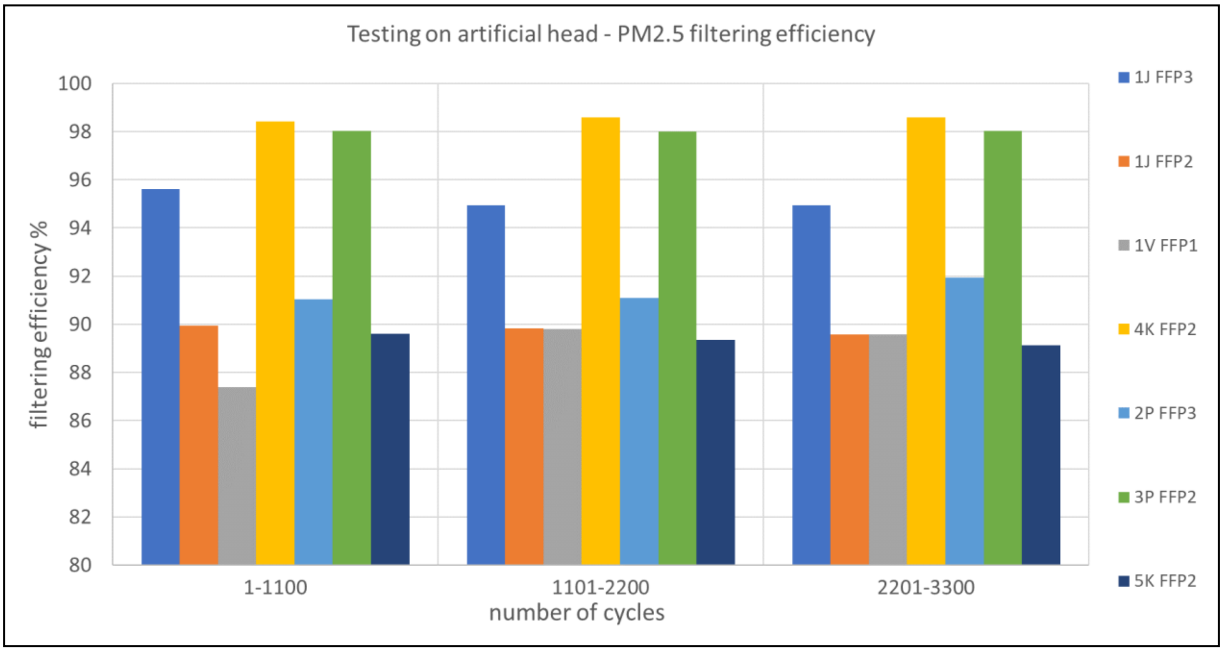

Fig. 14. Filtering efficiency for $PM_{2.5}$ of masks fitted to the artificial head

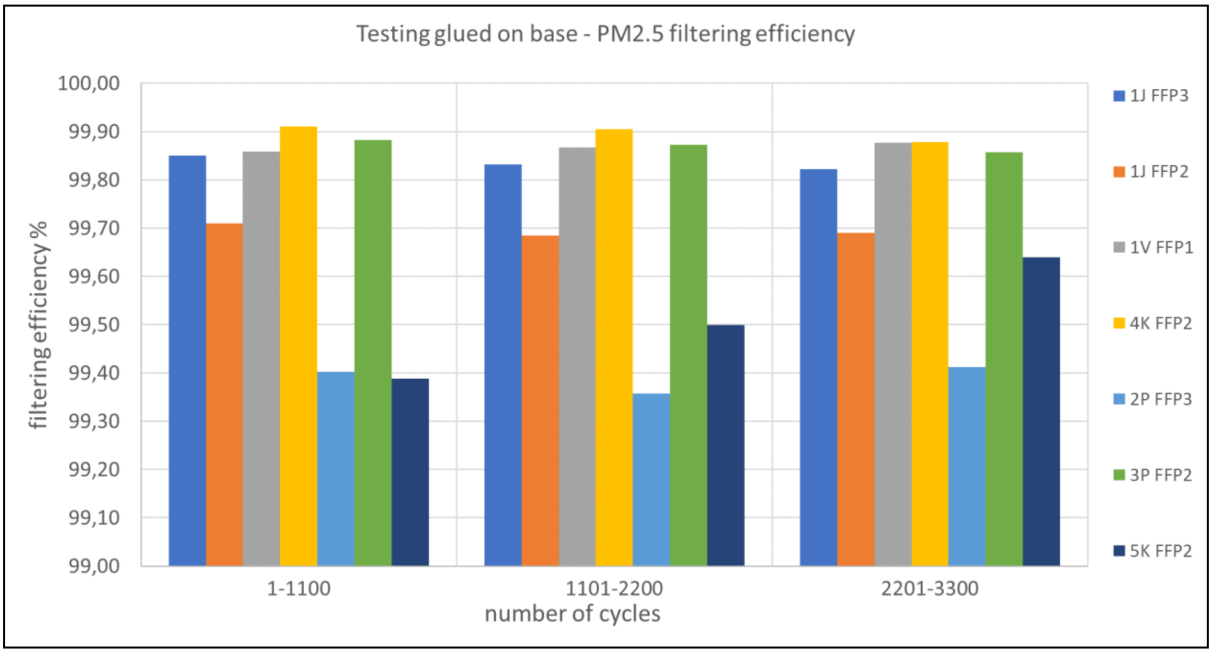

Fig. 15. Filtering efficiency for $PM_{2.5}$ of masks glued to the base of the auxiliary test stand

Fig. 16 shows the filtering efficiency of the masks tested on the artificial head for the full range of dust sizes, i.e. PM_1, $PM_{2.5}$, PM_{10}, and respirable dust. For comparison, the same tests were carried out for masks glued to the base (Fig. 17). By comparing these graphs, the impact of leakage can be seen, i.e. where dust filtration efficiency is always above 85% in Fig. 16 and above 99.2% in Fig. 17. The filtering efficiency of some fitted and glued masks was extremely impressive reaching >99.8% for PM_1.

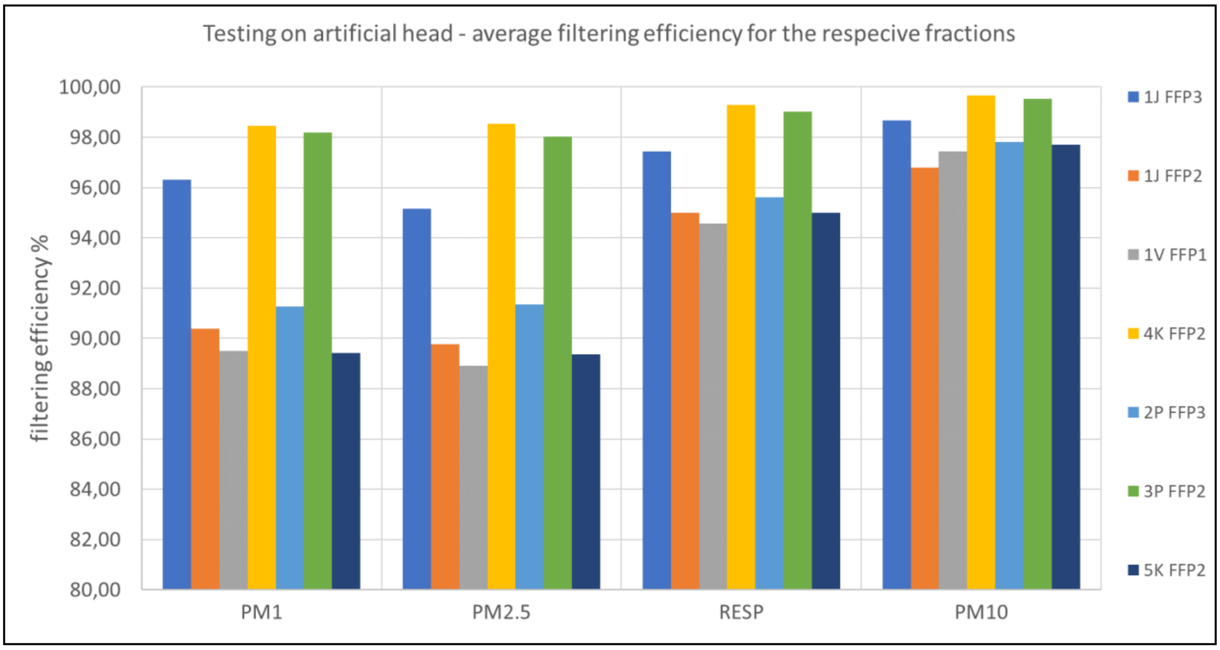

Fig. 16. Average filtering efficiency, for different dust particle size fractions, of masks fitted to the artificial head

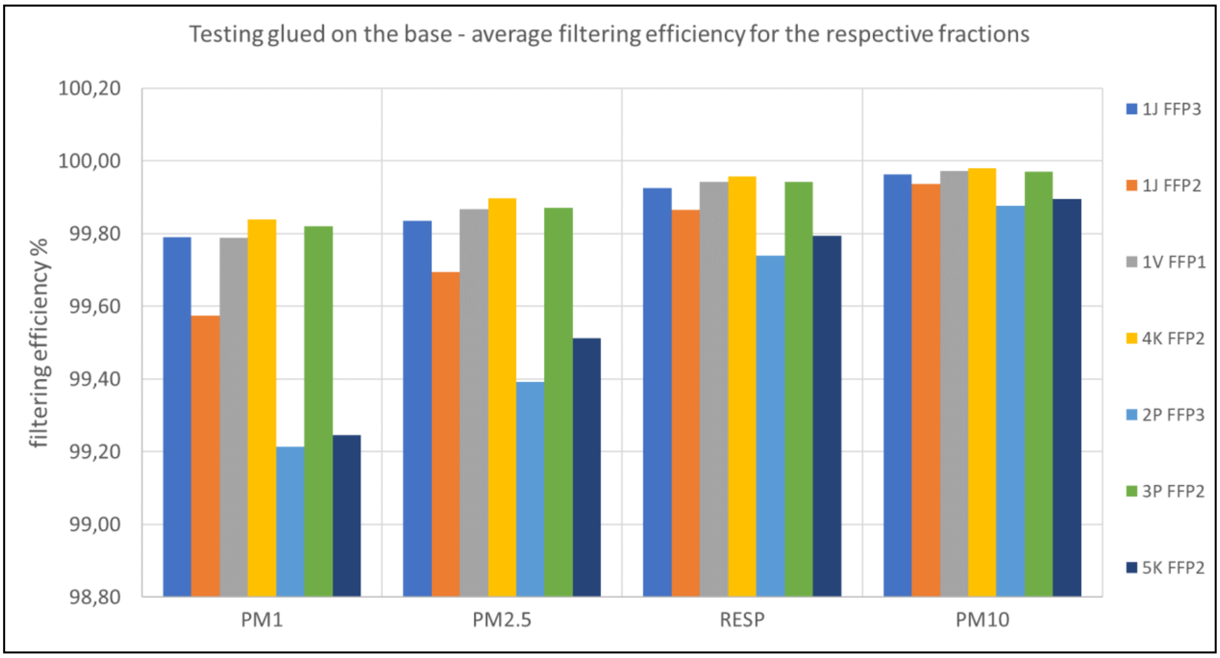

Fig. 17. Average filtering efficiency, for different dust particle size fractions, of masks fitted and glued to the artificial head

It was observed that:

- All masks have a good filtering effectiveness, over 99.2% but they must be tightly fitted, as observed in Fig. 17.
- Comparing Fig.16 and Fig.17, it can be concluded that poor fitting can cause reducing of filtering efficiency by a few percent.
- The masks represented by the yellow and green bars in Fig. 17 had the best results regarding filtering efficiency. It is worth noting that these are FFP2 masks, rather than FFP3 which, in theory, should be the best.
- In the tests of masks glued to the base of the auxiliary test stand, the FFP3 mask represented by the blue bar in Fig. 17 has the lowest efficiency, while the FFP1 mask marked grey has very high efficiency; this was a bit unexpected.

3.3. Workplace testing results

Table 2 shows examples of results from questionnaires completed by 61 miners from PGG mines. The question which is related to problems with sputum has never been the subject of an inquiry before but was considered very important for the correct assessment of mask effectiveness.

Table 2. Example results from questionnaires from 61 miners in PGG mines on the use of disposable half mask, type FFP3

Item	Tested parameter of useful feature		Number of results / % Score 0	Number of results / % Score 1	Number of results / % Score 2
1.	Face fit and tightness of the mask during the operation / tightness of filter on the reusable mask (rating: 0=bad : 1=moderate; 2 =very good)		**1** 1,64%	**34** 55,74	**26** 42,62%
2.	Stability of the mask structure (susceptibility to collapse, laxity) during work (rating: 0=bad : 1=moderate ; 2 =very good)		**3** 4,92%	**25** 40,98%	**33** 54,10%
3.	Interaction of mask with other types of protective equipment (e.g. glasses, helmet, goggles, earmuffs, etc.) (rating: 0=bad : 1=moderate ; 2 =very good)		**5** 8,20%	**24** 39,34%	**32** 55,46%
4.	Did you have to remove the mask due to too much breathing resistance? (rating: 0 = yes 1= rather rarely , 2 = did not happen)		**17** 27,87%	**4** 6,56%	**40** 65,57%
5.	Did you need to spit out sputum despite using the mask? (rating: 0 = yes ; 1= rather rarely 2 = no)		**12** 19,67%	**2** 3,28%	**47** 77,05%
	If yes, is your sputum dark? (rating: 0 = yes; 2 = no)		**6** 9,84%	**0**	**6** 9,84%
6.	Usable working time up to (hours)	2h	4h	6h	over 6h
	number of results / %	**24** 39,35%	**14** 22,95%	**21** 34,42%	**2** 3.28%

From Table 2, most miners i.e. 55.74 %, indicated that the mask tested offered a good fit-to-face and tightness. Most miners reported good structural stability of the masks, and 65.57 % good breathing resistance. 77.05% of miners did not feel the need to spit out sputum however 9.84 % gave an affirmative answer regarding its dark colour. The latter is worrying and shows that there is still room for improvement in the field of miners' health protection, especially for miners on the front line of dust exposure. The usable working time in a purchasing analysis should be treated wisely as longer working time could be the result of poor filtering efficiency. Such a new approach can have positive results for miners' health provided that it will be implemented in practice.

4. Discussion

From the results of tests using the artificial head, mask tightness on the face is crucial. As it turned out, testing of fitted and glued masks is valuable in assessing mask's quality as glued masks can be compared with masks which are well fitted on the head.

The auxiliary test stand enabled testing of sections of filter material and the gaining of additional information regarding filtering parameters, excluding the impact of other factors e.g. exhalative valves and mask-face seal leaks. All tested masks meet the filtering efficiency requirements.

Breathing resistance, especially inhalation resistance varies significantly and heavily depends on the intensity of breathing so this parameter should be taken into account when selecting a mask.

In situ tests allow for checking the masks functionality that cannot be sufficiently checked in a laboratory. In the interests of miners' health, the quality of the half-mask should be assessed on the basis of workplace and test stand tests.

The knowledge gained from research should contribute to best practice in the use of masks in areas exposed to dust. Researchers emphasize the need for a wide range of incentives and to provide the necessary knowledge to employees [19,20,21] to encourage the use of RPE because, according to their opinion, the use of masks, even where there are high dust concentrations, is often ignored.

The main cause, according to the authors, is breathing resistance which causes accelerated fatigue of the body.

5. Conclusions

As a result of the ROCD project, KOMAG designed and built a test stand to assess the quality of RPE equipment used in mines. From this they have created a database to compare the attributes of half-masks and their filters. The new test stand has provided invaluable information regarding breathing resistance and filter effectiveness. However, using the artificial head is problematic because the quality of the seal between the mask and artificial head is different in each test and depends on many factors.

The filtering efficiency of the different masks tested, which were either strapped or glued to the head, was always excellent, at over 99%. Taking into account that mask fitting is crucial in the aspect of filtering efficiency, the assessment and choice of mask should be based mainly on tests where inhalation resistance is measured, i.e. by incorporating a measurement of under-pressure.

In the interest of miners' health, and for those working in other high dust environments, the quality of the half-mask should be assessed on the basis of workplace and stand tests. The tests are complementary and both should be included to ensure the correct assessment of RPE.

Acknowledgements

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Assessment of rare earth elements content in the material from mine heaps

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Abstract:

The paper contains the results of laboratory tests aimed at determination of rare earth elements (REE) in mine wastes The material for testing was collected from mine heaps located in Lower Silesian Coal Basin (LSCB). Laboratory analyses of the material of different granulation (coal mud and the material of coarser granulation) were conducted with use of inductively coupled plasma mass spectrometry (ICP-MS) method. The tests were an extension of the scope of the projects aimed at searching for valuable elements in waste material from hard coal mining realized at the KOMAG Institute of Mining Technology. Basing on the results of laboratory analyses, the economic viability of the recovery of valuable elements from the mine wastes was formulated.

Keywords: rare earth elements (REE), mine wastes, Lower Silesian Coal Basin.

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1. Introduction

Rare earth elements (REE) belong to the group of raw materials of high economic importance, resulting from the perspective of the development of state-of-the-art technologies. The European Union includes REE among the group of 20 critical raw materials in economic terms. According to the analyses of the raw material market experts, the demand for rare earth elements will double by 2060. Due to the lack of deposits with valuable elements, the Community countries are forced to import the raw material. Recovery of REE from waste products an alternative solution is [1,2,3].

Analyses of rare earth elements content indicate for their presence in hard coal. Unfortunately, due to the low concentration, they cannot be an alternative source of REE from economic point of view [4,5]. The described tests were aimed at determining the concentration of REE in mine wastes and at identifying technologies that would allow increasing this concentration to the economically justified level to process them.

1.1. Rare earth elements

Rare earth elements are a group of 17 elements with specific physicochemical properties. They are used in state-of-the-art, advanced technologies. These elements are [6,7,8,9]:

- scandium - aviation,
- lanthanum - automotive industry (batteries of electric vehicles),
- yttrium - ceramics,
- cerium-metallurgy,
- praseodymium - glass dye,
- neodymium - laser technology, magnetic materials,
- samarium - cinematography,
- europium - nuclear technology,
- gadolinium - microwave technique,
- promethium - laser technology,
- terbium - laser technology,
- dysprosium - petrochemical industry,
- holm - electronics,
- erbium - optical amplifiers,
- thulium - materials with significant magnetic susceptibility,
- ytterbium - electronics,
- lutetium - ferrite products.

The term "rare" is misleading as the presence of REE in the earth's crust is common. The problem, however, is their considerable dispersion. The content of REE in a given material, due to its dispersion, is expressed in ppm. Consequently, recovery of rare earths is often economically unjustified. The largest deposits of REE are in China, the USA, Australia, Russia and India. The rare earths raw materials industry is dominated by China, which has 23% of the world's deposits and covers 93% of the world's demand [10,11,12].

Poland, like other countries of the European Union, does not have deposits of rare earth elements, hence the need to identify alternative sources. It is assumed that the following materials have some potential in Poland [1,10,11,13]:

- hard coal and lignite,
- mining industry waste,
- power plant waste (fly ashes and slag),
- mineral resources (sand and gravel),
- electronic waste.

Due to potential content of rare earth elements in mine waste (including the cerium content of 27.2 ppm) [4] and the possibility of giving the degraded post-mining areas economic importance, the KOMAG Institute of Mining Technology realized the research projects in this area (e.g. regarding power plant wastes) [4, 14]. Determination of REE content of in mine waste obtained from the Lower Silesian Coal Basin was this research project objective.

1.2. Mine wastes

For over 100 years, coal mining and coal processing in Poland have been generating significant amounts of mine waste. This type of waste, which includes mined rock with coal, is deposited in heaps, dump sites and sedimentary ponds. Currently, there are 153 such facilities in Poland (Śląskie, Dolnośląskie, Małopolskie and Lubelskie Voivodeships), with an estimated area of 11,304.8 hectares. In 2015-2017, 72,139.0 thousand tonnes of mining waste was generated [15,16,17].

Mining waste poses an environmental hazard by contaminating soil, surface and ground waters and air. The heaps containing a significant share of hard coal also pose a serious threat due to thermal activity. The endogenous fires, resulting from the tendency of hard coal to self-heating, emit fire gases (H_2S, CO, CO_2, SO_2), smoke and odour. Due to the high temperature, loosening the heaps overlayer is possible, causing material slides. It is possible to recultivate and make such objects harmless by recovering the hard coal deposited in them [17].

In connection with the above and rare earth elements found in hard coal, the material for analyses was taken from the thermally active heap located in the Lower Silesian Coal Basin.

2. Materials and Methods

The material for analyses of rare earth elements, came from the heap adjacent to the closed LSCB mine in Nowa Ruda. The mine exploited lean coal and anthracite coal deposits [16]. The heap has a significant content of hard coal, what was confirmed by numerous endogenous fires. The material being the subject of laboratory analyses was collected on June 16, 2020, from three selected locations on the heap (Fig. 1).

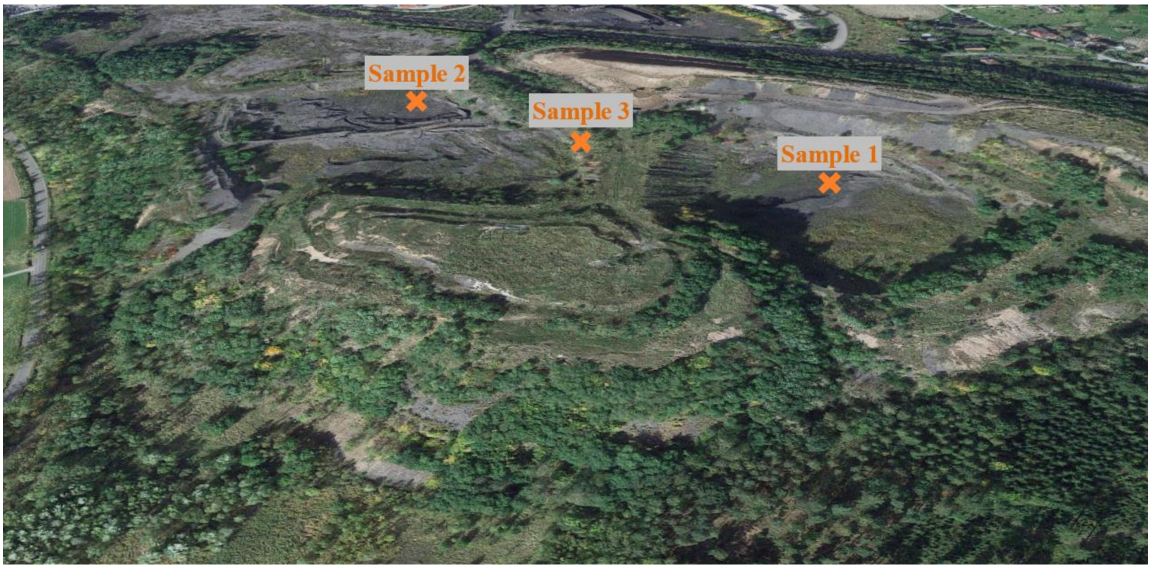

Fig. 1. Place of sampling the material from the heap [own source]

About 10 kg of material were collected from each of the three sampling points. The location in the heap and the characteristics of the collected material were as follows:

- sample 1 – mud in the upper part of the heap (Fig.2),
- sample 2 – mud in the lowest part of the heap (Fig.3),
- sample 3 - material taken from the vertical slope in the lower part of the heap (Fig.4).

The collected samples were transported to KOMAG for analysis of rare earth element content.

Fig. 2. "Nowa Ruda" heap – mud collected from the upper layers of the heap [own source]

Fig. 3. "Nowa Ruda" heap – mud collected from the lower layers of the heap [own source]

Fig. 4. "Nowa Ruda" heap – material taken from the slope [own source]

Due to the significant amount of water content in the mud, the first stage of preparatory work consisted in drying the samples 1 and 2 in a laboratory dryer (Fig. 5). Sample 3 taken from the slope of the heap, due big size of grains, was crushed in a laboratory crusher to the granulation of sand (Fig. 6). Necessity of crushing results from the requirements of the device determining the content of valuable elements.

Fig. 5. Laboratory dryer [own source]

Fig. 6. Laboratory crusher [own source]

Then the representative sample of 0.5 kg of the material for testing was selected using the sample divider (Fig.7).

Fig. 7. Jones sample divider (own source)

3. Results

Rare earth elements content in the tested samples was determined using the inductively coupled plasma mass spectrometry (ICP-MS) method. The IPC-MS spectrometer enables fast multi-element analysis of the tested material sample. The samples were mineralized prior to testing. Resulting solution was entered to plasma using the laser beam to verify share of REE in the analysed samples [18].

The results given in Table 1 were obtained using the developed testing procedure [19].

Table 1. Content of REE in the tested mining waste [19]

Item	REE content [ppm]							
1	**Sample 1 (P1)**							
	Sc	**Y**	**La**	**Ce**	**Nd**	**Pr**	**Sm**	**Eu**
	33.49	<1	7.52	14.0	29.03	9.23	21.56	10.34
	Gd	**Tb**	**Dy**	**Ho**	**Er**	**Tm**	**Yb**	**Lu**
	27.03	9.15	22.29	7.13	18.55	5.28	23.36	7.70
2	**Sample 2 (P2)**							
	Sc	**Y**	**La**	**Ce**	**Nd**	**Pr**	**Sm**	**Eu**
	40.49	<1	7.38	19.1	29.14	9.69	22.34	10.64
	Gd	**Tb**	**Dy**	**Ho**	**Er**	**Tm**	**Yb**	**Lu**
	27.93	9.55	22.99	7.54	19.13	5.56	24.13	8.19
3	**Sample 3 (P3)**							
	Sc	**Y**	**La**	**Ce**	**Nd**	**Pr**	**Sm**	**Eu**
	20.96	<1	4.56	38.4	17.91	5.82	13.54	6.50
	Gd	**Tb**	**Dy**	**Ho**	**Er**	**Tm**	**Yb**	**Lu**
	16.99	5.77	13.81	4.50	11.56	3.26	14.63	4.87

The laboratory analyses showed the presence of 15 rare earth elements. Distribution of each REE in the tested material samples is similar. The highest content of REE was found in sample P2, containing 40.49 ppm of scandium.

Content of all rare earth elements in the analysed samples is as follows:

- P1 – 245.7 ppm,
- P2 – 263.8 ppm,
- P3 – 183.1 ppm.

Based on the literature analysis indicating for increased concentration of rare earth elements in the finest grain class <0.045 mm [20], this separated grain size class was additionally analysed to verify the literature information.

A set of two sieves with 2 mm mesh size and 0.045 mm mesh size were used for material classification. Due to the fine-granulation of the material, the grain class <0.045 mm was separated in water medium using the vibrating classifier (Fig. 8).

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Fig. 8. Wet vibrating classifier (own source)

The suspension, containing grains <0.045 mm, was transported by gravity to a tank for sedimentation. The clarified water was pumped out, and the material from the bottom of the tank was dried in a laboratory dryer. The material prepared in this way was then analysed to determine the content of rare earth elements.

Contrary to the expectations in the selected fine grain class, there was a decrease in the content of each rare earth element and a smaller number of elements, reduced to 13 (Table 2).

Table 2. REE content in tested mine waste for grain size classes <0.045 mm [19]

Item	**REE content [ppm]**							
1	**Sample 1 (P1)**							
	Sc	**Y**	**La**	**Ce**	**Nd**	**Pr**	**Sm**	**Eu**
	18.68	<0.1	2.00	8.39	2.60	1.31	0.75	0.82
	Gd	**Tb**	**Dy**	**Ho**	**Er**	**Tm**	**Yb**	**Lu**
	1.30	0.11	1.42	0.24	0.88	<0.1	0.99	<0.1
2	**Sample 2 (P2)**							
	Sc	**Y**	**La**	**Ce**	**Nd**	**Pr**	**Sm**	**Eu**
	14.73	<0.1	2.07	9.75	2.19	1.23	0.56	0.66
	Gd	**Tb**	**Dy**	**Ho**	**Er**	**Tm**	**Yb**	**Lu**
	1.02	<0.1	0.89	0.14	0.51	<0.1	0.52	<0.1
3	**Sample 3 (P3)**							
	Sc	**Y**	**La**	**Ce**	**Nd**	**Pr**	**Sm**	**Eu**
	15.23	<0.1	2.89	15.49	2.34	1.28	0.65	0.89
	Gd	**Tb**	**Dy**	**Ho**	**Er**	**Tm**	**Yb**	**Lu**
	1.19	<0.1	0.94	0.15	0.55	<0.1	0.59	<0.1

Content of each element is very similar, reaching the maximum for scandium in sample 1 (18.68 ppm).

Total content of REE in the analyzed samples in the grain class <0.045 mm is as follows:

- P1 – 39.5 ppm,
- P2 – 34.3 ppm,
- P3 – 42.2 ppm.

4. Results

Increased content of REE in samples P1 and P2 probably results from the washing out of these elements from the adjacent slope, so the concentration of REE in the slope is 60-80 ppm lower. Content of each rare earth element in the analysed samples are presented in Fig. 9.

Content of rare earth elements in the class <0.045 mm for mine waste is not as high as for the samples before classification (Fig. 10).

In the finest grain class, scandium and cerium makes the majority of all determined REE.

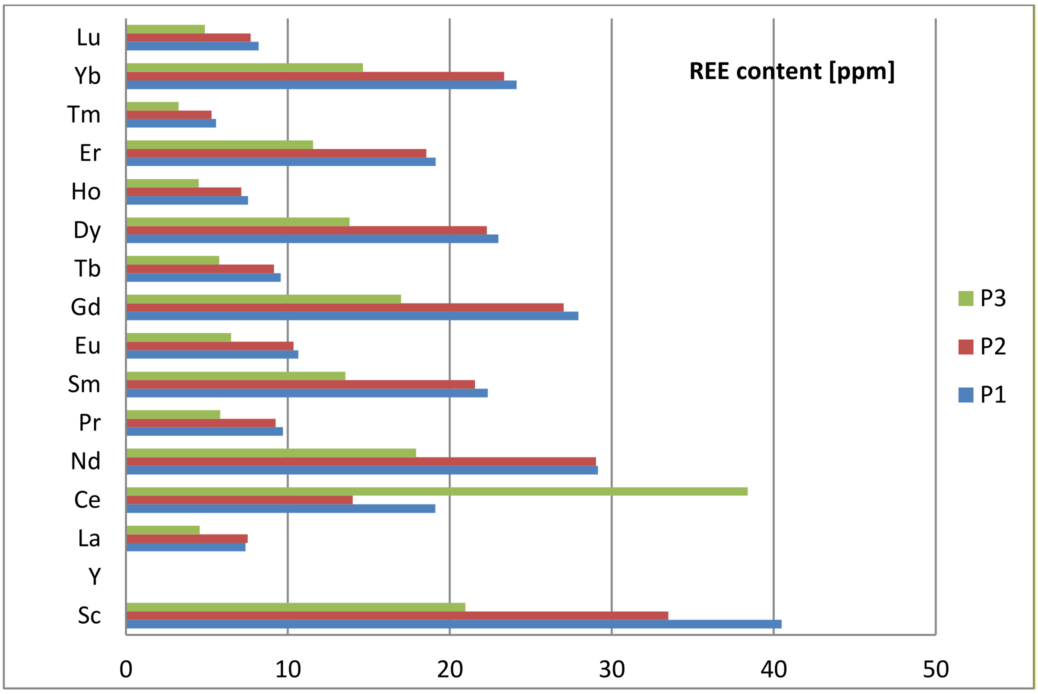

Fig. 9. Content of each rare earth element in the tested mine waste [own source]

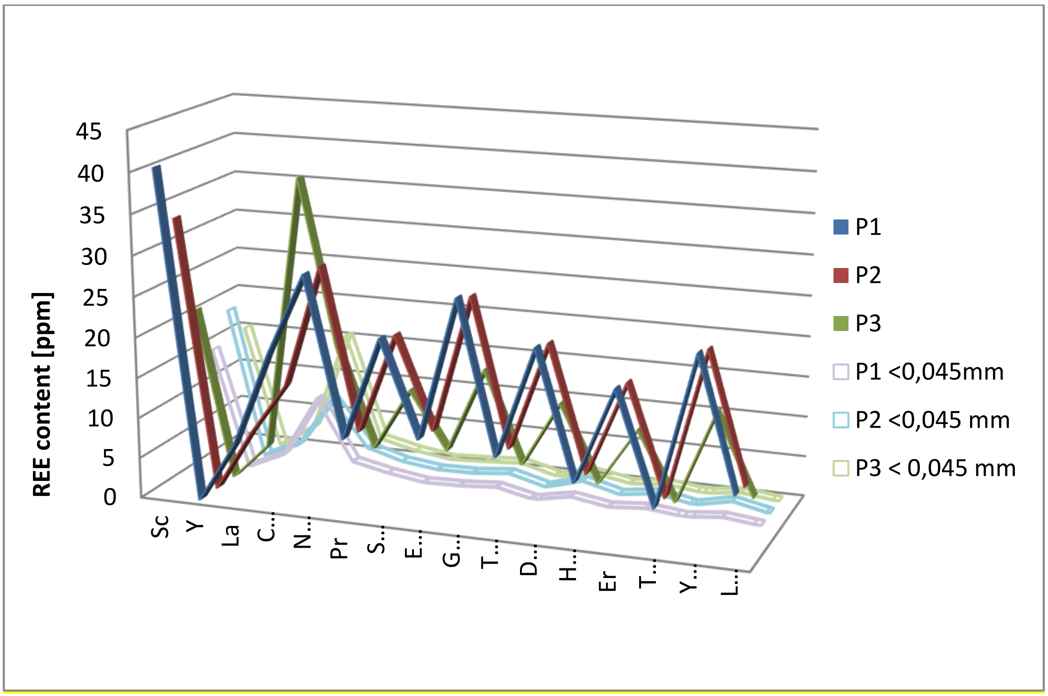

Fig. 10. REE content in the tested mining waste, depending on the grain size distribution of the samples [own resource]

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5. Conclusions

Research and development work related to determination of the REE content in mine waste from the heap located in Nowa Ruda, allowed for establishing cooperation, resulting in the acquisition of materials for testing. Preparation of materials, combined with the developed methodology for determining the content of valuable elements in the material with the use of a spectrometer (ICP-MS), allowed to determine the share of the REE in mine waste samples.

The paper shows that mining waste, which has no economic use, is a carrier of rare earth elements.

The content of valuable elements (about 260-180 ppm) in the collected samples, when compared with the estimated level for economic REE recovery (about 1000 ppm) [21], is, however, unsatisfactory. The REE content, for the grain class <0.045 mm, showed a decrease (about 40 ppm), contrary to the literature knowledge. The discrepancy shown indicates a different content of elements, depending on the grain size class of the material and its origin.

Therefore, the range of grain classes of the tested mining waste will be analyzed in the further part of the work on REE to determine the grain class with the highest REE content. Determination of such a grain class, if the economic condition is met, will allow for the management of devastated post-mining areas and for creating an alternative source of rare earth elements in Poland.

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The concept of a screw conveyor for the vertical transport of bulk materials

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Abstract:

Screw feeders and conveyors are mainly used in the following industries: minerals, agriculture, chemistry, pharmaceutical, pigments, plastics, cement, sand and food processing for transporting and mixing the granular materials.
The article presents a synthetic analysis of the conveyors used in the collection and transport systems of loose materials. It focusess on the solutions based on a srew shaft operating vertically or at an angle. A concept of a screw conveyor intended for vertical transport of loose materials is presented. Due to structure and transport properties, the conveyor can replace the oversized bucket conveyor, currently used in one of the industrial plants. A 3D model was developed, illustrating the manufacturing method and introducing the principle of the conveyor operation.

Keywords: power industry, vertical transport, screw conveyor

1. Introduction

Conveyor transport is used in the state-of-the-art production systems to move materials and raw materials over various distances with output of several thousand tons per hour. Conveyor transport units operating in this system may consist of belt conveyors, bucket and screw conveyors, ensuring the transport of material from storage sites to the processing plants [1].

Concept of a screw conveyor for vertical transport of loose material, based on the solutions of conveyor systems used in technological lines of industrial plants [2], as well as innovative solutions cited in the literature [3] are presented. The vertical working position means that the carried material is more compressed during lifting and occupies a larger part of the trough than in the horizontal solution [4,5]. The screw conveyor - which in this case plays the role of a lift - is to replace in the target project, the bucket conveyor currently used in one of the plants. This conveyor is positioned at an angle and due to its dimensions as it collides with state-of-the-art weighing devices installed for modernization of a part of the production unit. The screw conveyor of the lifting height 6.8 m, will be used to transport the raw material from the grate conveyor, operating on the lower level of the production hall, to the crusher installed on its higher level. Then the raw material will be directed for further processing.

2. Materials and Methods

Screw conveyors are used in the lime, cement, power, agricultural and food industries. As noted by the authors of articles about screw conveyors, the transport of loose materials is a complex process and depends not only on the parameters of the screw shaft or its enclosure, but also on the physical properties of the transported material. Traditional computational methods allow for the selection of each of the conveyor parameter with great precision for materials such as lime or cement, but when the transported material has a tendency to crumble or is highly abrasive, then there may be problems related to achieving the assumed efficiency [6]. The analysis of the screw conveyor efficiency depending on the type of loose material was described in [7].

Generally, conveyors can be divided into inclined (Fig. 1) and vertical (Fig. 2) ones.

Screw conveyors are used as devices collecting material from various types of tanks and silos. They are also used to dose the product in technological processes. Due to the closed structure, the transported material can be isolated from the environment.

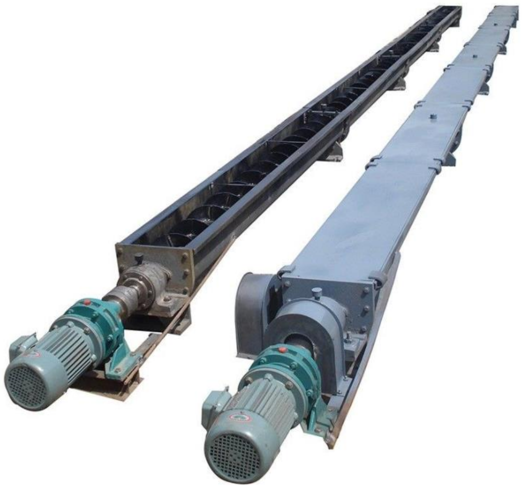

Fig. 1. Inclined screw conveyor [9]

Fig. 2. Vertical screw conveyor with a feeder [10]

Screw conveyors are divided into two types: with closed trough and open trough. The former usually have a trough in the shape of a tube or "U" shape with lids, while the latter have a "U" shape (without lids).

The screw conveyor consists of a trough inside which there is a shaft with a wound screw ribbon. The rotating shaft moves the transported material. The solution of screw conveyor is based on the so-called Archimedes screw.

The feeder is driven by the screw shaft or directly by the screw (in the case of shaftless screws) [8].

3. Results – concept of a new solution

The screw conveyor presented in this publication, serves as a vertical feeder in an industrial plant. The conceptual drawing of the conveyor is shown in Fig. 3, while its spatial model with its main components is shown in Fig. 4.

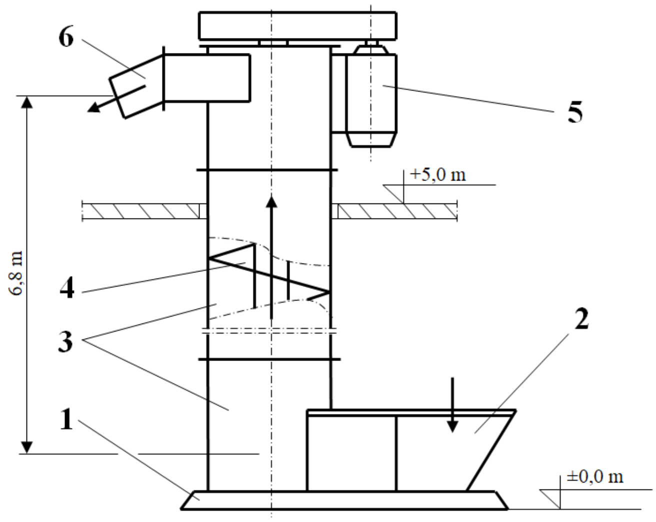

Fig. 3. Conceptual drawing of the screw conveyor: 1 – base, 2 – feeding chamber, 3 – trough segments, 4 – screw shaft, 5 – drive unit, 6 – outlet stub

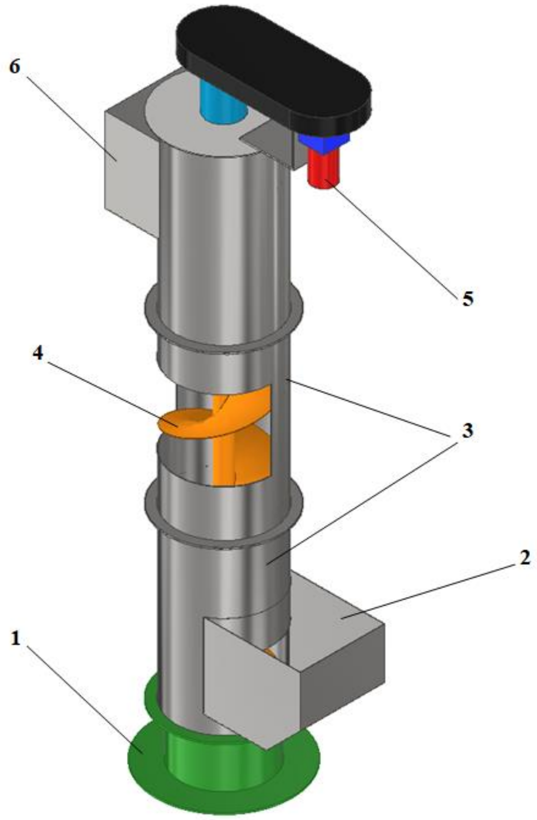

Fig. 4. The spatial model of the conveyor: 1 – base, 2 – feeding chamber,
3 – trough segments, 4 – screw shaft, 5 – driving unit, 6 – outlet stub

Development of the device concept and then the spatial model required adopting a number of assumptions regarding its technical parameters, assembly method and working conditions, such as the following:

– conveyor output	Q	20 t/h
– hight of material lifting	H	6,8 m
– suggested range of the screw diameter	D	400 ÷ 600 mm
– screw pitch equal to its diameter	S	S = D
– screw troughs	closed	
– working position of the screw conveyor	vertical	

- assembly and installation of the screw conveyor in accordance with the requirements of relevant standards and directives,
- operation of the device in a ventilated closed room,
- drive transmission from the motor to the screw shaft using a belt transmission.

The base of the conveyor (Fig. 4, Item 1) is made of two metal sheets and a steel block. The upper sheet is made of 0H18N9 stainless steel. The holes made in it will be used in detachable connection of the base with the trough segment. The steel block (rectangular or cylindrical) contains a bearing seat for the screw shaft and a lubricating channel.

The charging chamber (Fig. 4, item 2) is a tank made as a welded structure from 0H18N9 stainless steel, 2 mm thick and with overall dimensions depending on the surrounding conditions. It has been assumed that the upper edge of the chamber will be located above the inlet in the lower segment of the trough. Therefore, the feeding chamber also acts as a buffer for the material transported by the screw conveyor, used in the case of increased feed from the previous conveyor or storage tank.

The trough segments (Fig. 4, item 3) are tubular components made of 0H18N9 stainless steel with welded flanges for screwed connections. Flanges are made of two bent angles welded into a ϕ664 mm circle. Tubular components are made of metal sheet. After bending to form a pipe and welding, the sheets are installed inside the flanges. A rubber gasket is expected to be used at the joints between each segment. It has been assumed that all welded and screwed joints should be made as leakproof. Installation of three pipe segments are planned, the lower and upper one have openings at the place of the feeding channel and outlet stub.

The screw shaft (Fig. 4, item 4) is a rod, graded at the top and bottom bearings, and a pulley with indentation for a prismatic key. Screw blades are welded to the shaft, forming a screw outline. It is assumed that the method of joining each blade (e.g. butt or overlapping) will be determined in the final conveyor design. The screw shaft is also expected to be made of 0H18N9 stainless steel.

The drive unit (Fig. 4, Item 5) is a combination of a two-stage gearmotor with an electric motor. On the basis of preliminary calculations, to achieve the expected capacity of 20 t/h, use of the SK62-106M geared motor from NORD Napędy Sp. z o.o., with a power of 9.2 kW and rotational speed of the output shaft, equal to 201 rpm, was assumed. The driving torque will be transmitted to the screw shaft through a belt transmission to achieve the required output of the device. The gear ratio of the belt transmission was assumed to be approximately 1.09. The gearbox will be equipped with C-type V-belts. Parameters such as the length and wrap angle as well as the size of the pulleys will be specified in the final design. The gearmotor selected for use in the screw conveyor is shown in Fig. 5.

Fig. 5. SK62 type gearmotor [11]

The outlet stub (Fig. 4, item 6), similarly to the feeding chamber, is to be made of 2 mm thick metal sheet with dimensions depending on the surrounding conditions. 0H18N9 steel is a material used for manufacture. It is possible to make the stub coaxially with the feeding chamber or according to the turn of the production line, e.g. 45 degrees in the horizontal plane. Location of the outlet stub results from the functional features of the conveyor, which can not only change the capacity, but also the direction of the transport line.

4. Conclusions

Growing demand for various types of conveyors in many industries has resulted in the development of specialization in their production. Conveyors, like other machines and technological devices, should comply with specific requirements and principles of design, assembly and operation.

Screw conveyors are the conveyors used in many industries, including power, food and agriculture industry.

The article presents the concept of a screw conveyor intended for transporting the loose material in an industrial plant. Proper selection of components and the design of the conveyor enable achieving the main requirements regarding the raw material transport with the assumed capacity of 20 t/h. It is an alternative solution to the inclined scraper conveyor and bucket elevating system, currently operating on the modernized section of the technological line for processing loose material in an industrial plant. Replacing these two devices with one new generation transporter should bring the following benefits:

- additional free space will be created within the production hall, which can be used for the installation of other devices of the technological line,
- use of a vertical conveyor will enable reducing the operating costs and servicing of the modernized section of the technological line,
- the energy efficiency of devices operating in the area of the technological line will be improved,
- the risk related to unplanned production downtime will be limited,
- the drive used in the screw conveyor will allow for smooth adjustment of the speed of material feeding to the upper level of the hall, depending on the capacity required by production needs.

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Risk Management at the Notified Body in the Aspect of Its Impartiality

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Abstract:

State-of-the art management systems are oriented onto supporting a competiveness of organizations and a continuous quality improvement of products, services and processes.
One of essential elements of management is the risk management process which enables to manage uncertainty and risk in relation to the conducted activity by an organization.
Managing risk assists organizations in setting strategy, achieving objectives and making informed decisions. Managing risk is part of governance and leadership, and is fundamental to how the organization is managed at all levels. It contributes to the improvement of management systems. A competent use of risk management mechanisms enables each organization to use its potential to a full extent and undertake proper decisions.
The issues concerning a standardization of requirements in the case of standards from the management scope; in particular from the point of view of issues connected with risk management, are presented in the first part of the article.
A model of the process, oriented onto a risk in the quality management system which enables to conduct managing activities in the situation of uncertainty and to take decisions oriented onto preventing mistakes in managing the organization and onto ensuring the appropriate quality, is described.
The subject – matter concerning risk analysis, in particular from the point of view of meeting the EA Guidelines, concerning horizontal requirements related to the bodies assessing the conformity for notification purposes, is brought nearer.
The most essential requirements, which must be met by such a body to guarantee a competent and impartial process of the product assessment, are described.
In the following chapters the basic elements of the risk analysis process are discussed and an exemplary description of the risk assessment methodology is presented.

Keywords: quality management system, notified body, process approach, risk analysis

1. Introduction

The changes taking place in the environment of each organization cause a necessity of a continuous adaptation to changing conditions of their functioning. Due to the fact that quality management is the key issue in the scope of a continuous improvement, so organizations more and more commonly implement state-of-the-art management conceptions based on standardized quality management systems.

At present the quality management system has become a common practice and it is mainly implemented for an improvement of internal processes taking place in an organization.

One of the most popular and most universal standards from the management scope, the standards which can be used by each type of organizations – from producers, servicers, state authorities to non-profit organizations is the Standard *ISO 9001 Quality management systems - Requirements* [1].

This standard is aimed at ensuring and maintaining the organizational system through fixed procedures and attributed authorizations.

The first version of the ISO 9001 Standard was published nearly 35 years ago and it was subject to multiple amendments [2] but a popularity of this standard does not decrease and organizations all over the world still certify their managements systems.

Each year *The ISO Survey of Management System Standard Certifications* conducts an analysis oriented onto indicating a degree of popularity of management systems, defined by the number of edited certificates according to the management standards [3].

According to the official data, *The ISO Survey of Management System Standard Certifications*, in 2019, there were 883 521 certificates from the ISO 9001 scope in power all over the world.

A more detailed analysis indicated that in 2019 12951 organizations, having valid ISO 9001 certificates, were active in Poland.

For example in the same 2019 year there were:

– 60480 certificates in Germany,
– 21782 certificates in France,
– 26226 certificates in the United Kingdom of Great Britain and Northern Ireland [4,5].

It is worth highlighting that the statistics only included the organizations which have quality management systems confirmed by certificates, whereas also the organizations which implemented the mentioned system in the framework of other standards e.g. connected with the bodies, assessing conformity or conducting inspections or performing tests, such as the standards: EN ISO / IEC 17020, EN ISO / IEC 17025, EN ISO / IEC 17065, should be added to them.

In the case of the last three standards, it should be emphasized that before the year 2012, each of them had a different structure and contained different requirements. Some attempts of standardizing these documents were undertaken many times, but only the ISO / TMB / JTCG Joint Technical Coordination Group on MSS achieved an agreement in this scope [4].

The basis for this agreement was the document called the Annex SL, which standardized the principles of constructing the structure of standards from the scope of the System Management (MSS). The approved structure of standards is presented in [6].

In the result of accepting new principles gradual changes and amendments of a series of standards from the scope of management systems, including the scope of certification, were introduced [7].

In the result, still in the same year it was possible to implement the EN ISO/IEC 17065 Standard, concerning competences, coherent activity and impartiality of the bodies certifying products, processes and services [8].

The EN ISO/IEC 17020 Standard, concerning the requirements related to an operation of various types of bodies performing inspection, was issued in a further order, and in 2015 the agreed structure was also used in the EN ISO/IEC 17021-1 Standard concerning the certification of management systems [9, 10].

In 2015, the Working Group ISO / CASCO WG 44, established for up-dating the EN ISO / IEC 17025 Standard, decided that the planned changes in the standard should be directed towards its structure and content adaptation to the CASCO requirements, concerning the possibilities of using the quality management system, based on the requirements of ISO 9001 Standard in the management system of laboratories.

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In 2018, the activities were finished and the new edition of EN ISO/IEC 17025 Standard was published. Therefore, the majority of standards, connected with an assessment of products was standardized as regards the structure [11].

The work on the following amendment to the ISO 9001 Standard itself was conducted in parallel.

In the same year, the work on the up-dated ISO 9001 Standard from the scope of quality management system, was finished.

In this standard, not only the structure of the document, but also the main requirements were changed. The scope of the most essential changes in the new standard edition is described in [12].

In this document the requirements, concerning a process approach based on a risk, appeared among others and they are used for:

- taking decisions,
- determining the scope of a planned process and of an indispensable supervision,
- improving the efficiency of the quality management system.

Risk assessment is a part of the risk management process, which provides systemic identification of hazards and assessment of their impact on the organization's projected goals.

An approach, based on a risk, was to ensure an identification, an analysis and supervision of the risk both during the designing as well as functioning of the quality management system [13]. Similar aspects appeared in the standards cited earlier.

2. Materials and Methods

2.1 Impartiality and independence of the notified body - legal and standardization grounds

In parallel with the activities, oriented onto standardizing the basic requirements in the scope of management systems, some work was undertaken to standardize the conformity assessment system concerning a market introduction of machines and equipment on the European Union level.

According to the assumptions of this system, before an introduction to the European Union market, each product must be subject to a procedure of conformity assessment, given in the directive, which a given product is subject to.

In some cases, determined in regulations, producers (importers and distributors) can choose from a few available modules (variants of procedure).

Some of these modules are based on testing each single product, others- on approval of the type, and sometimes an assessment of the whole production quality assurance system is required. The conformity assessment procedures, occurring in directives, are so differentiated that in relation to the category of products which they concern, the production method or potential hazards, a participation of independent notified body are settled [14, 15].

The role of a notified body is to conduct a conformity assessment under the relevant EU Directives. The notified body conducts the conformity assessment against the relevant sections of the applicable Directive.

Notified bodies are third parties, independent from their clients. The legal status of these bodies is essential as far as their independence and impartiality are guaranteed and they constitute independent legal subjects.

To guarantee a realization of activities on the same level and according to the conditions of fair competition by all notified bodies in the European Union, two regulations aimed at a framework formulation as well as at a determination of their accreditation criteria, were edited. They were:

- 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 [16],
- Decision No 768/2008/EC of the European Parliament and of the Council of 9 July 2008 on a common framework for the marketing of products, and repealing Council Decision 93/465/EEC [17].

The legal frames, included in the documents mentioned earlier, accepted in 2008 were oriented onto an increase of trust for the European Union conformity assessment system due to a transparent system of principles and requirements for conformity assessing notified bodies.

These principles also foresee an increase of using accreditation as a tool supporting activities of the notifying body.

For a clarification, which accreditation standards harmonized with Regulation (EC) No 765/2008, correspond with the requirements contained in the Decision No 768/2008 / EC, the European Co-operation for Accreditation elaborated an obligatory document EA-2/17, to be applied by accrediting bodies [18].

The Guidelines EA2/17 in Item 3.1 highlight clearly that, ”…*competence, impartiality, independence and consistent operation of the CAB to perform the tasks it is notified for the fulfillment by the CAB of the requirements established by each UHL within the scope of accreditation”.*

In the same document, in Table 6: *Map of HS Requirements* in Sub-section *Management of impartiality;* the most important elements, decisive as regards the notified body impartiality, are mentioned.

And therefore among others:

- The notified body should have documented procedures for the identification, review and resolution of all cases where conflict of interest is suspected or proven. Records of such reviews and decisions should be kept.
- The notified body should require all staff acting on its behalf to declare any potential conflict of interest.
- If the notified body, or any part of a larger organization to which it is linked, provides consultancy services, then the documented quality system of the notified body should include a policy statement and documented procedures ensuring that assessment and consultancy services are separated. The notified body should ensure, by means of a documented agreement, that its subcontractors are aware of this guidance.

Summing up, all the aforementioned documents constitute not only the basis of activity and assessment, but they also draw an intense attention to maintaining a widely understood impartiality and confidentiality.

Therefore, an activity of notified bodies is assessed not only in the aspect of their competences and technical capabilities, but also in the scope of identification, analysis and minimization of hazards; both in the area of impartiality as well as of the whole operational activity of the body.

That is the reason why, a risk analysis, according to the decisions of the ISO Committee on Conformity Assessment (CASCO) and with the rules given in the ISO / IEC Directives, Part 2, was so to say included in the requirements of the inspection body, certification body of products and services as well as in the requirements of the body certifying system management.

2.2. Risk analysis in the aspect of notified body impartiality

The basic element of the management strategy in the notified body includes ensuring stability and safety of the conduct activity. One of the tools, supporting a correct realization of the management process, is an aspect of risk management mentioned in Chapter 2.

One of the main changes, introduced during a revision of the EN ISO/IEC 17065 Standard, at present constituting the basis of the notified body activity, was precisely an establishment of a uniform approach to risk assessment. This approach consisted in an earlier identification of problems (hazards) and in taking actions, i.e. in preventing or reducing unwelcome effects.

In relation to the issue concerning impartiality of the notified body, the most essential requirement is included in Item 4.2.3 of the EN ISO / IEC 17065 Standard, where it is stated that: „ *The certification body shall identify risks to its impartiality on an on-going basis. This shall include those risks that arise from its activities, from its relationships, or from the relationships of its personnel. …*

A relationship presenting a risk to impartiality of the certification body can be based on ownership, governance, management, personnel, shared resources, finances, contracts, marketing (including branding), and payment of a sales commission or other inducement for the referral of new clients, etc…….” [8]

In the scope of conducting the risk analysis itself, the authors of the quality standards did not impose any suggested means or method. However, the following standards were mentioned: ISO

31000, *Risk management - Principles and guidelines and ISO 31031 Risk management - Risk assessment techniques*, which can be helpful for a realization of these activities [19, 20, 21].

These standards present techniques which can be applied and they present forms of risk procedures realized by [12]:

- avoiding the risk by deciding not to start or continue with the activity that gives rise to the risk,
- risk elimination,
- changing the likelihood of the risk occurrence,
- changing the consequences of the risk,
- retaining the risk by informed decision without taking any activities.

The mentioned ISO 31000 Standard also establishes principles of risk analysis determined as a comprehensive process comprising the determined elements (Fig. 1).

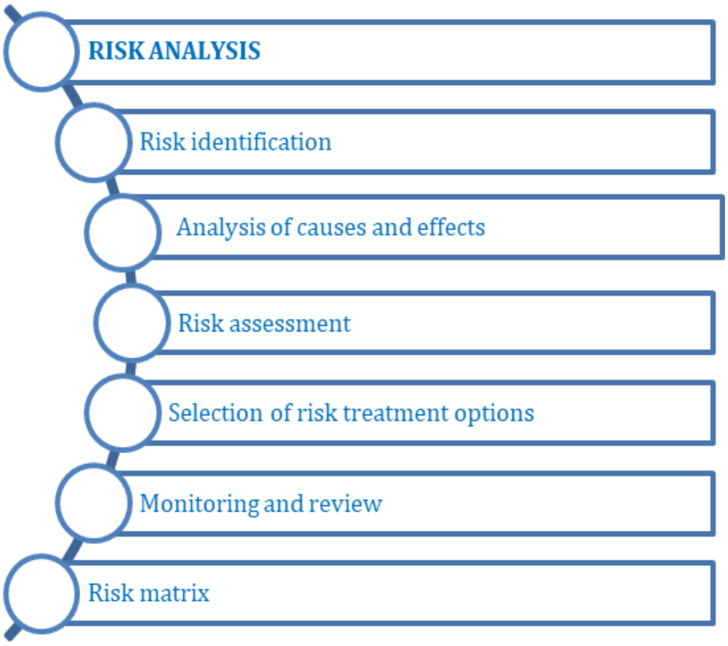

Fig. 1. Elements of risk assessment [19]

Therefore in the process approach, each risk assessment should take into consideration at least the following stages:

- risk identification - the stage to determine which risk factors affect the organization,
- qualitative analysis - the stage at which risk factors are classified according to their importance,
- quantitative risk analysis - stage of the analysis of the selected factors,
- planning the reaction to risk - the stage of taken activity connected with the risk,
- risk monitoring and control - the stage of implementing supervision and control.

It can be stated without hesitation that each risk in a notified body can be analyzed in two contexts: <u>in internal context</u>**,** which can include [20]:

- organizational structure,
- policies, objectives, and the strategies,
- the capabilities, understood in terms of resources and knowledge (e.g. capital, time, people, processes, systems and technologies,
- information systems, information flows and decision-making processes (both formal and informal),
- the organization's culture,
- standards, guidelines and models adopted by the organization,

and in external context, which can include:
- environment, international, national, regional or local;
- competitive organizations,
- factors having an impact on the organization activity objectives.

Analyzing both contexts; external and internal context, the notified body must prove meeting a series of requirements having an impact on its credibility, i.e. among others competences or impartiality of its activity (Fig. 2).

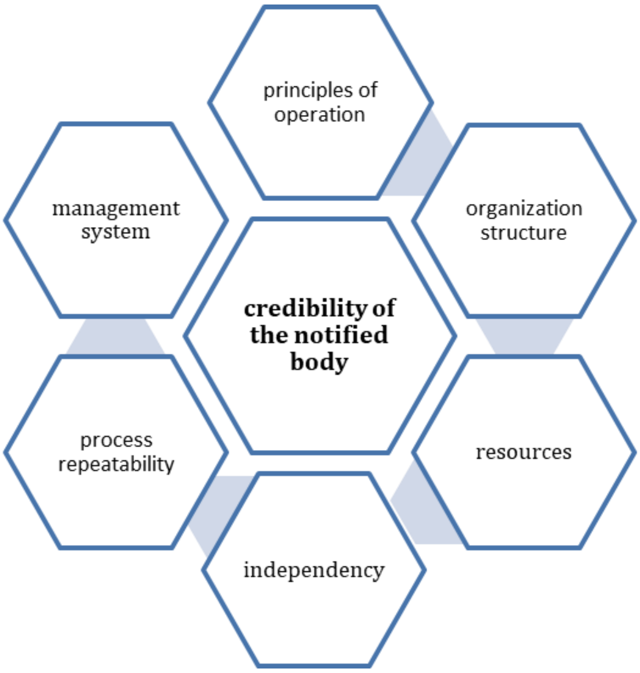

Fig. 2. Factors having an impact on credibility of the notified body [22]

Exemplary hazards to impartiality are mentioned below. They are as follows:
- the notified body is dependent on another organization (it is a part of a bigger structure or a dependent company),
- the notified body is excessively dependent on an agreement for services or on charges, or it is concerned about a loss of a client,
- the notified body is engaged in designing, producing or introducing to the market of the products under assessment,
- the notified body assesses the effect of other services, delivered by itself such as consultations,
- the notified body or its personnel declare for or against a given company, which simultaneously is its client,
- the notified body personnel has relationships with clients, there is a too close familiarity between the notified body and a client,
- a demand for the personnel of very specialistic expert knowledge limits the availability of highly qualified personnel.

3. Results – Risk Management in the Aspect of Impartiality in the Notified Body No 1456

Notification is an act whereby a Member State informs the Commission and the other Member States that a body, which fulfils the relevant requirements, has been designated to carry out conformity assessment according to a directive. Notification of Notified Bodies and their withdrawal are the responsibility of the notifying Member State [23].

Lists of Notified Bodies are on the NANDO web site. The lists include the identification number of each notified body as well as the tasks for which it has been notified [24].

In Poland about 80 notified bodies are active in relation to different directives and EU regulations. All of them are obliged to identify and document hazards to impartiality of their processes and demonstrate the methods of eliminating or minimizing their effects.

One of such bodies is the Notified Bodies No 1456 situated in the structure of the KOMAG Institute. It acts within three directives [25]:

- 2006/42/EC Machinery,
- 2009/48/EC Safety of toys,
- 2014/34/EU Equipment and protective systems intended for use in potentially explosive atmospheres.

The impartiality aspect of the Notified Bodies No 1456 has been declared since very beginning of its activity; nevertheless at the moment of introducing regulations, on the European Union level, some activities, oriented onto conducting a detailed risk analysis in the area of impartiality on all the levels: starting from the strategy and policy ending on directly conducted processes, were undertaken.

Additionally, the Notified Body extended the risk analysis in other areas, which included:

- management, including internal processes,
- operational activity,
- resources incorporating the researchers` potential and possibilities of the Notified Body staff.

For a risk identification the following tools were used:

- brainstorming,
- nominal group technique,
- analysis of the results of controls and audits,
- analysis of received complaints and other negative events taking place at the Institute.

Risk comprises two components: likelihood and impact. The likelihood-impact matrix offers a good way to categorize risk events qualitatively in terms of their probability of occurrence and their consequences.

A comprehensive risk identification enabled to elaborate a list of risk factors connected with the conducted activity, a description of likely consequences of effects in the result of their occurrence, as well as an indication of the owners of individual risks.

Determining sources, causes and drivers of risk

The conducted analysis enabled to determine:

- the likelihood of an event or consequence,
- the probable effects of mistakes in relation to the client,
- the effects of generated losses,
- the level of risk, which can be accepted by the Notified Body.
- the internal communication and reporting mechanisms.

Qualitative Risk Analysis

Based on the list of identified hazards, connected with the conducted activity, a probability assessment of its occurrence and of the impact on the Institute was performed.

In the analysis the method of determining probability in a simplified form, assuming the following criteria was accepted:

- likelihood: *0 – lack of occurrence possibility*; *1 – absolute certainty of the risk occurence*,
- frequency – the following frequencies of occurrence of events were accepted: *sporadically, rarely, often, continuously,*
- effects of losses - *to be omitted, low, big, very big.*

Estimation of Risk

For the activities of the Notified Body, the following hierarchy of risk was established:

- <u>acceptable</u>, not being an essential hazard to the activity,
- <u>tolerable</u>, which can be a reason of a hazard (quick preventive activities can be taken),

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– intolerable which can cause significant losses.

The analysis enabled to develop the risk matrix presenting individual risks in a graphical form, which enabled to undertake activities oriented onto a risk reduction in critical areas.

Risk treatment

Dealing with risk is a process consisting optionally in:

– removing the risk source,
– changing the likelihood,
– changing the consequences,
– sharing the risk with another party or parties (including the agreements and financing the risk),
– retaining the risk by informed decision (acceptance of potential benefit or load of loss).

Monitoring and review

The final element of the process is a constant monitoring and control of risk, which consists in a continuous observation and supervision of identified risks, an identification of newly generated hazards and a systematic assessment of the efficiency of undertaken preventive activities.

Techniques for recording and reporting- risk matrix

Information about the magnitude of a risk can be reported in a number of different ways.

The risk analysis, conducted in the Notified Body requires an elaboration of a risk matrix. This matrix ensures a standard methodology of recording all essential information concerning the risk.

There is no determined forced, format; the records can be conducted in a paper form, in a form of calculation sheet, database or in a specialistic software.

A risk register brings together information about risks to inform those exposed to risks and those who have responsibility for their management. It can be in paper or data base format and generally includes:

– a short description of the risk,
– probability of occurrence,
– sources or causes of the risk,
– actions to control risk.

The most common method uses the consequence/likelihood matrix and this model was accepted at the KOMAG Institute.

In the elaborated record of risk factors the most essential identified risk factors, important from the point of view of conducted activity (Fig 3), are included.

		Elements of risk analysis									*Estimation*	*Risk procedure*	
				Consequence									
Risk ID	*Risk areas /area of occurrence*	*Risk factors*	*Risk*	*Financial effects*	*Effect for reputation*	*Management effects*	*Owner of risk*	*Probability*	*Frequency*	*Effects of losses strat*	*Estimation of risk*	*Reduction of risk /form of reaction*	*Risk after reduction*

Fig. 3. Structure of Risk Matrix elaborated for the Notified Body at the KOMAG Institute

In relation to each of the factors, the risk was estimated with use of the matrix. A classification of frequency (a number of events occurring in a determined time interval) and of potential effects, according to the matrix presented in Fig 4, was accepted.

Fig. 4 shows a possibility of completing a risk matrix. As an example, the matrix 4x4 is selected. Organizations choose different matrix formats (3x3, 4x5, 6x4, 5x5, ...) depending on the context of the company and the details of the risk assessment. Weighing coefficients for the consequences and frequency of events should describe real situations. Fig. 4 is just an example of applying eq.1.

4x4 Risk Matrix	Potential consequence			
Probability/Frequency	Insignificant	Minor	Severe	Major
Rare				
Unlikely				
Possible				
Likely				

Fig. 4. Example of Risk Matrix (4x4)

The Notified Body calculates risk level, choosing the limitation, and in addition, risk level is marked with colour:

- acceptable (green),
- tolerable (yellow),
- unacceptable (red).

Combinations of risk assessment and management quality supply the management of the Notified Body with the information which risk factors may be omitted and which require paying a special attention due to their negative impact on the processes. The effect of work, connected with an analysis and assessment of risk, is their arrangement according to the determined criterion. In the case of each of them, an analysis is performed and an appropriate mechanism of supervision, which enables to check if a control of hazards is ensured in a sufficient way, is applied. For most essential types of risks or risk or those which can generate a special hazard for a realization of qualitative objectives, appropriate activities are undertaken.

4. Conclusions

One of the basic elements of effective management in each organization is an efficient management of risk, which is an integral part of the organization culture [14]

An inseparable element of the management strategy, also in the case of a notified body, includes ensuring the safety of the conducted activity. One of the tools, supporting the management process, is risk management, oriented onto a probability of disadvantageous events or circumstances which have a negative impact on objectives of the notified body

In the case of notified bodies, an impartiality plays an important role because it means an independent conducting of processes from the perspective of the so-called " *third party*" .

This is a reason why an introduction of risk management to the management system of the notified body is an essential element which guarantees meeting the requirements, imposed on the notified body.

The Notified Body, acting in the structure of the KOMAG Institute, undertakes numerous activities to guarantee impartiality of activity, by implementing risk management system. These activities are oriented onto: an identification of hazards, an elimination of risk source, a change of probability of their occurrence or a change of consequences. The Institute established mechanisms which enable monitoring of implemented solutions and making an assessment of their efficiency.

The Notified Body, implementing the elements of risk management into its management system, applied a commonly used principle of the Deming`s cycle (PDCA) "Plan-Do-Check-Act" [12, 19, 26].

The experience of the Notified Body, reached so far, has enabled to state that the applied means such as:

- a creation of independent teams groups supplying opinions and advices,

- administrative decisions, a big set of internal regulations, procedures and system instructions,
- a clear and documented division of authorizations and responsibilities determined in: regulations, codes of ethics, scopes of duties of individual employees and in letters of procuratory,
- a self-control determined in regulations, and control of: work quality, quality of services,
- annual reviews of the management system in organizational areas and processes,
- internal and external audits,

guarantee a maintenance of risk on acceptable levels.

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LabVIEW based software for verification of the new idea of lining for mine shafts located in salt rock mass

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Abstract:

High values of salt rock mass convergence might cause serious problems with maintenance of shaft lining located in salt rock sections. The most efficient existing method of negative convergence influence prevention is periodic removal of creeping salt from shaft walls. However, the process of salt removal is problematic in terms of shaft and hoisting system typical operation. A new shaft lining idea allows removal of creeping salt by leaching without the need for stopping the shaft operation. Following paper presents a software, developed in LabVIEW environment and applied in the framework of test facility, designed for purpose of verification of theoretical assumptions of new construction of shaft lining. Developed software consists of applications for data acquisition, based on Event-Driven Queued State Machine pattern, and data processing, designed as Producer-Consumer pattern.

Keywords: shaft lining, software for mining engineering, salt mine, mine shaft, LabVIEW, data acquisition, data processing, Event-Driven Queued State Machine

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1. Introduction

An idea of utilization of the salt's characteristic feature, which is high water solubility is not a new concept. Actually, evaporation of salty water was a first historic method of the salt production. This way of salt sourcing was in use for ages in numerous places all over the world, utilizing surface and underground salty waters and rock salt dissolved in water [1-3]. Borehole leaching is the most modern and efficient, as well as the most popular nowadays method of the salt production [2, 4-6]. In 20th century caverns leached in salt deposits were recognized convenient tanks for storage of carbohydrates, hydrogen and other liquid or gaseous substances. Some of this caverns are made for purpose of storing only. Brine is then just a by-product of leaching [4-5].

Convergence of salt rock sidewalls might be a reason of very strong pressure acting on the shaft lining [7-11]. Convergence rate is an indicator of a need for undertaking prevention activities to minimize its destructive influence on the lining.

Numerous solutions of shaft lining preventing the influence of the convergence were used in salt rock mass in different countries. The basic approach is very high load bearing capacity steel shaft lining [12-13]. Another approach is a high lining yielding. Such construction was applied in SW-4 shaft of Polish copper mine Polkowice-Sieroszowice, a part of KGHM Polska Miedź SA [14-15]. Concept of a hydraulic yielding support, comprising of watertight lining and water column between the lining and shaft sidewalls, was also presented [16].

Specialized research indicates a possibility of excessive load of the shaft lining occurrence as a result of rheological deformations of salt rock mass [14-15]. It is then necessary to remove the creeping salt from the shaft. The idea of the new shaft lining construction is based on use of fresh water for purpose of the creeping salt removal. As the salt is easily dissolved in fresh water, a contact of the whole area of salt rock mass with water poured behind the shaft lining should be provided.

The new construction of a shaft lining, called the tubing-aggregate lining consists of:

- preliminary sidewalls bolting,
- watertight tubing lining,
- porous material filling –coarse grained aggregate of high compressive strength,
- a system of pipes, pumps and tanks for water circuit.

The key element of the shaft lining construction is the aggregate filling, because its task is to provide contact between shaft sidewalls and lining. Moreover, it forms a porous structure, which is freely penetrated by leaching medium. It also plays a role of deformable and equalizing layer for point loads [17-18].

2. Testing facility

Research for purpose of verification of the shaft lining construction and operation presented above was conducted using specifically designed test facility, which was widely described in works [18-19]. The idea of its work, comprising data flow between its components is presented in Fig. 1. Blue line represents a water flow forced by a pump. Temperature was regulated by a heater assembled in a water tank, while the value of the water flow was measured by an indicator. A system of rock sample's loading (a pump with a cylinder) and main chamber for salt sample and aggregate are shown in the central part of the figure. Data was gathered using notebook via suitable connectors. Tests were also registered by a time-lapse camera.

Testing compartment was made of 12 mm thick S355 steel sheet and it was divided into open and closed part. The closed part is a sealed system equipped with a sleeve for hydraulic cylinder assembly. Cylinder's piston with a plate loads a salt sample. Pressure is transferred through the sample and aggregate to a test plate, where stress and strain is generated. Their values, measured by a strain gauge and displacement sensor, located in the measuring unit. Inflow and outflow valves allow to control direction and velocity of water flow through the testing compartment. Overflow container with capacity of 70 litres allows water to circulate in a testing compartment – pumping unit – water tank cycle [19].

The pumping unit comprises of a plastic filter, a membrane pump of maximum discharge of 11.3 l/min, a flow meter and a set of valves - suction valve, inflow valve and outflow valve. The construction of the membrane pump ensures its safe operation in salty environment (internal part of the head is made of ethylene propylene diene monomer - EPDM and Santoprene®, while the external part of polypropylene) with maximum pressure height of 10 m. Depending on a way of connecting, the pumping unit allows water to flow from the top or from the side of testing compartment [18].

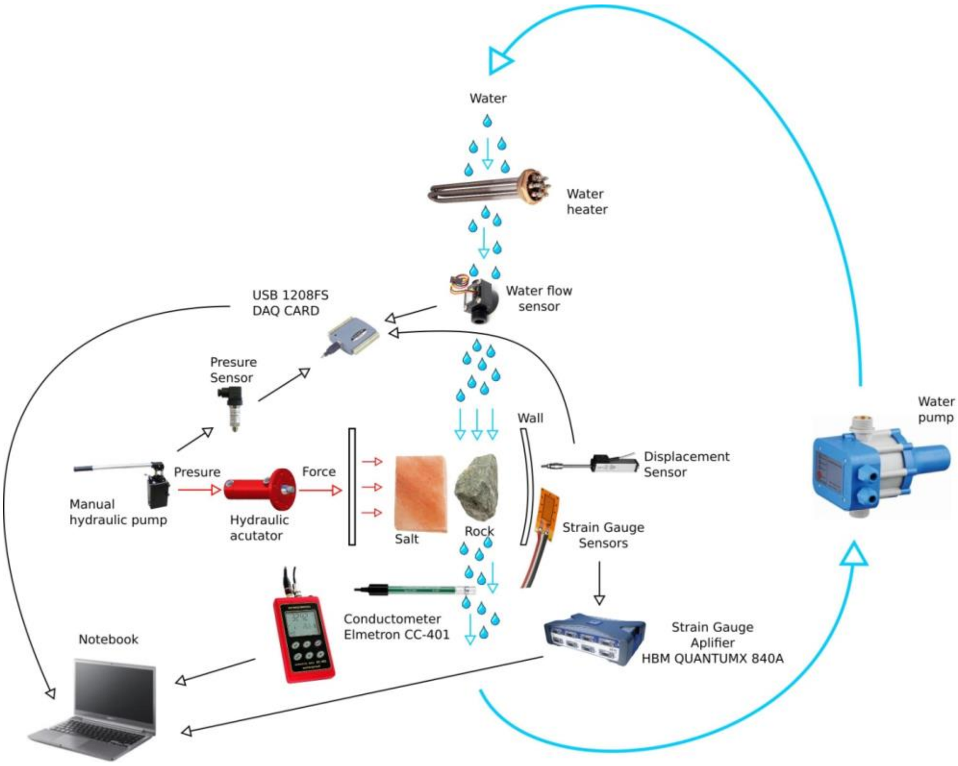

Fig. 1. Operation scheme of the test facility [18]

A hydraulic unit consists of a manual pump (max 250 bar), hydraulic pipes, a hydraulic cylinder and a hydraulic fluid pressure sensor. System was designed to provide pressure of 80 kN for maximum pump operation pressure (180 bar). Pressure sensor allows to calculate load [18].

3. Electrical system

Testing facility was equipped with an electrical system, which was needed to supply devices such as pump and heater. To provide proper level of safety of the operator and the test facility itself, additional electrical components became necessary. Fig. 2 presents the electrical diagram [18].

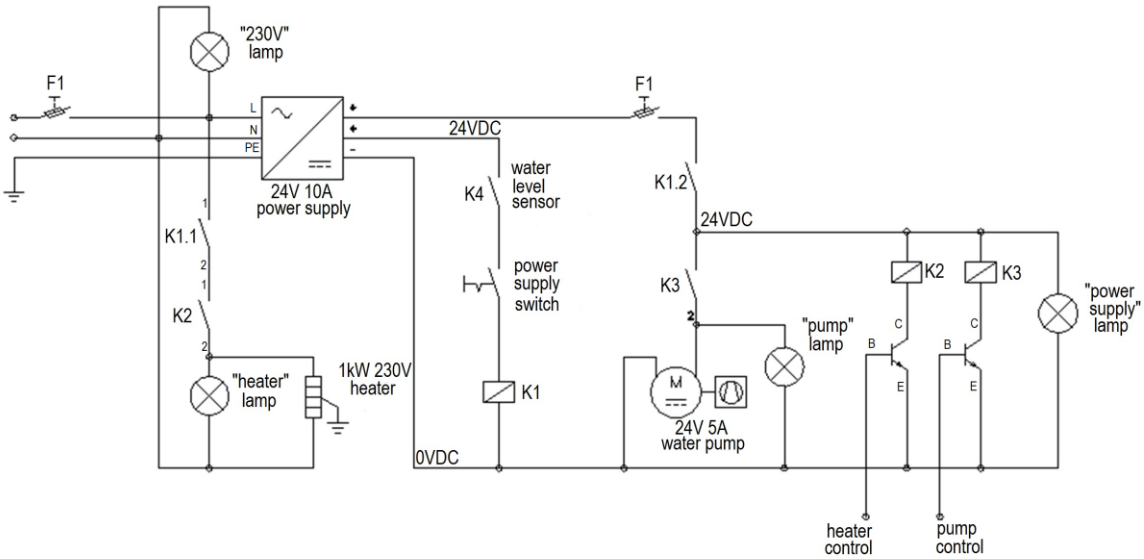

Fig. 2. Electrical diagram

Electrical system comprises of following components:

- fuses protecting from short circuits,
- 24V pump and sensors power supply,
- level control relays for pump and heater,
- indicator lamps,
- water pump,
- 240V 1kW water heater,
- Darlington circuit ULN2003 for coils control with USB 1208FS-Plus card.

4. Data acquisition and processing

Within the formwork of the research programme it became necessary to design an application for control of the testing facility and data acquisition. Because of the complexity of the issue and requirement for communication with HBM, National Instruments and Elmentron measuring devices, LabVIEW environment was chosen to develop needed software.

Requirements defined for the dedicated software were communication with measuring devices, data acquisition and control of water pump and heater work.

4.1. Measuring devices

Testing facility was equipped with following measurement devices:

- HBM Quantum MX840 – an eight-channel measuring amplifier allowing data acquisition from seven load cells connected in half bridge circuit and temperature sensor PT100 with Ethernet interface.
- Measurement Computing USB-1208FS-PLUS – eight-channel measuring card, recording data from displacement, pressure, water flow sensors and controlling water pump and heater work with USB 2.0 interface.
- Elmetron CC401 – conductivity meter allowing to measure water salinity with RS232 interface.

4.2. Data acquisition application

Analysis of requirements for the data acquisition application indicated Event-Driven Queued State Machine as a suitable pattern for this purpose.

It is one of the most complicated and the best functioning behavioural software design patterns. It combines architectures of state machine, queued system and event system. This design pattern captures events of application user, like start of measurement, queues events/states and handles them in one state machine process in order in which they were added to a queue. Event-Driven Queued State Machine allows to properly capture and handle all user's event, even if other processes are in progress [20].

Fig. 3, 4 and 5 show diagrams of sample features implemented in the application.

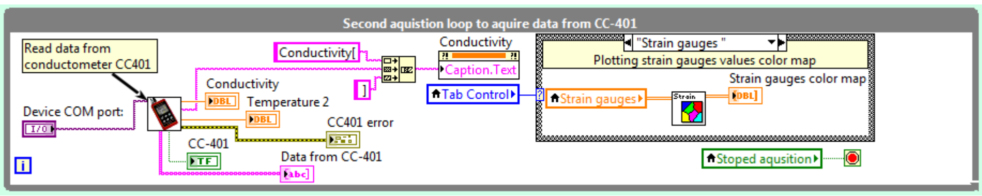

Fig. 3. CC401 Conductivity meter operation

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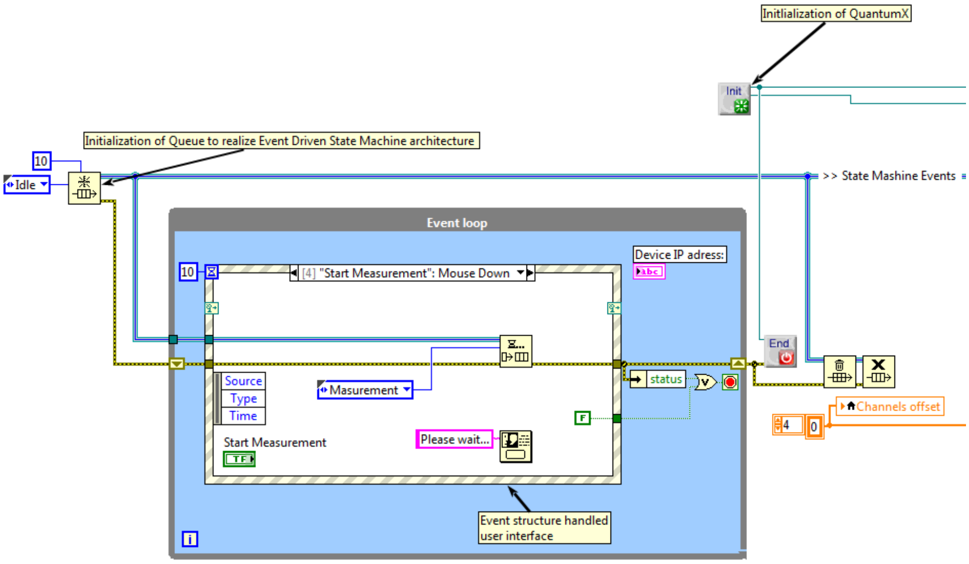

Fig. 4. Event case structure capturing user's events

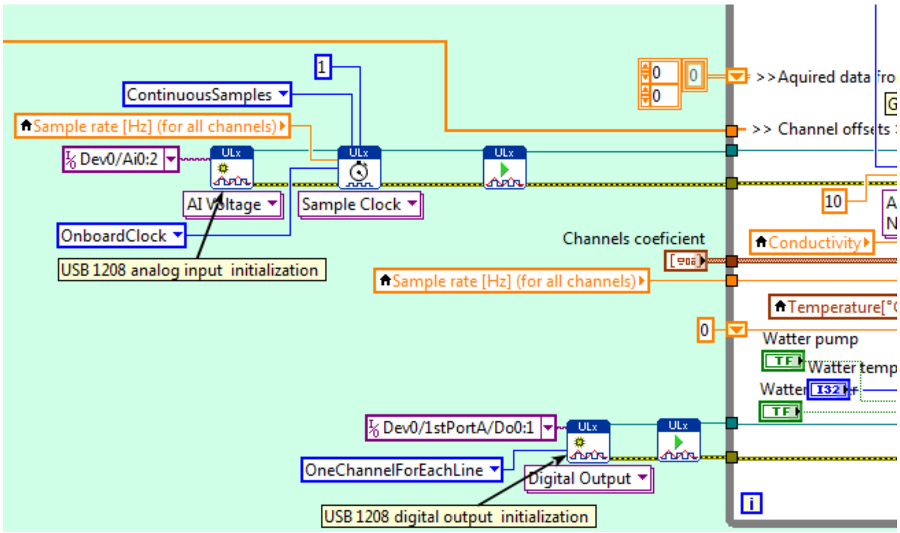

Fig. 5. USB 1208FS-Plus measuring card configuration

Graphical user interface (GUI) was divided into two main parts:

- Top right section of the window consists of four buttons:
  - ZERO – zeroing the measuring system; functionality implemented for displacement sensors to always begin the measurement from 0mm,
  - START – measuring session start,
  - STOP – measuring session finish and automatic data record,
  - EXIT – exit from data acquisition app.
- Top left section of the window (buttons/tabs of TabControl) responsible for switching between main functionalities:
  - application main window,
  - stress diagrams,
  - detailed diagrams,
  - configuration panel.

Application main window, presented in Fig. 6, comprises of:
- main graph in the central part of the screen with current data courses,
- indicators in the bottom left section presenting values of measured quantities, such as pressure, displacement, temperature, water flow and salinity in an easy and convenient way,
- temperature regulator and water pump control in the right bottom section.

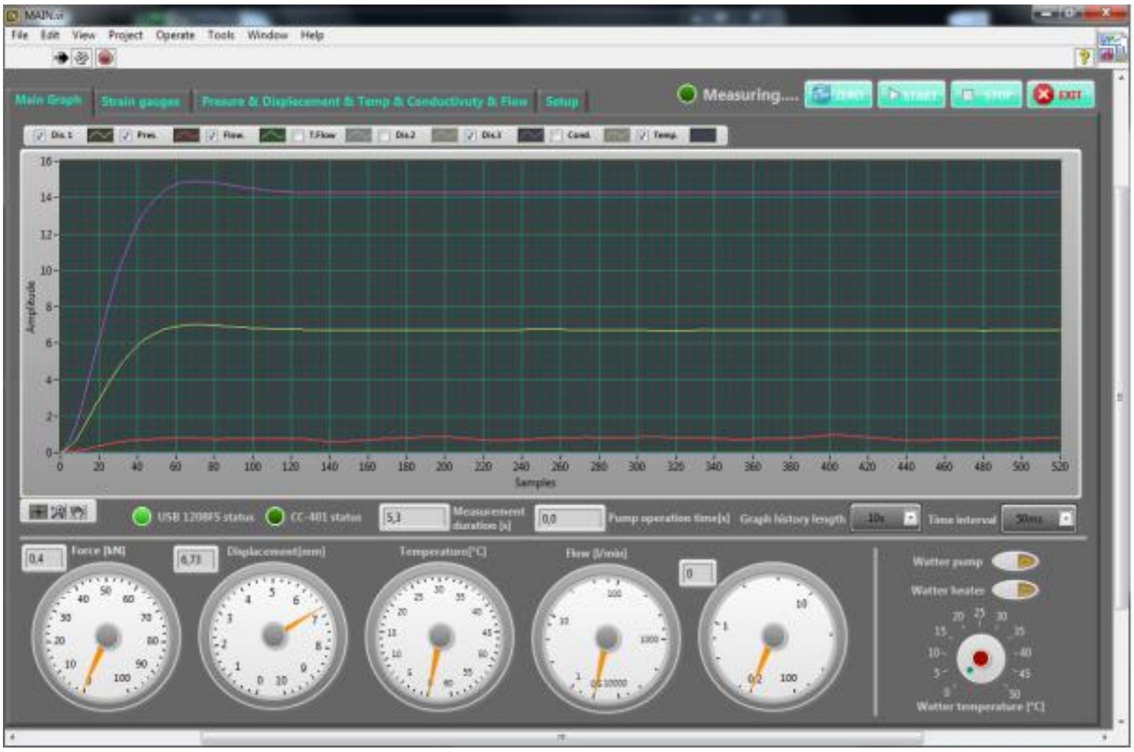

Fig. 6. Application main window

Configuration panel shown in Fig. 7 allows to:
- configure USB 1208FS-Plus measuring card (entering sensors constants, setting sampling frequency),
- read real values from sensors,
- read measuring channels offset after zeroing the system,
- set communication port and preview data of CC-401 conductivity meter.

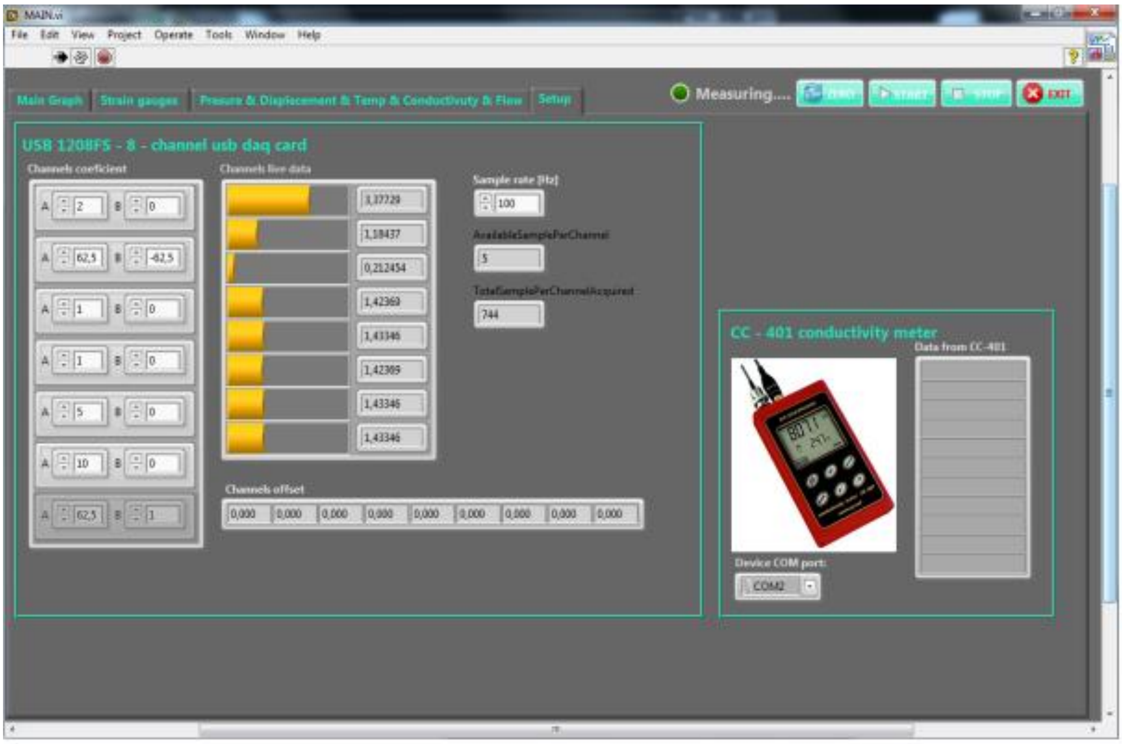

Fig. 7. Configuration panel

4.3. Data processing application

The main reason of development of dedicated data processing application was lack of suitable solutions available on the market. Requirements for the application were as follows:

- analysis of huge amount of data,
- comparing and summarizing of measurements' results, which are rarely synchronized in time, because of non-repetitive characteristics of the experiment process,
- ability to generate identical sets of diagrams for different entry data,
- data recording during its processing, including verbal notes,
- ability of duplicate analysis.

After an analysis of software available on the market, a decision was made to develop dedicated application. Simplicity of implementation and previous experience (data acquisition application development) LabVIEW environment was chosen for purpose of development of data processing application meeting the demands.

Functional requirements to implement were as follows:

- data loading from external files,
- data resampling (sampling frequency adjustment due to low processes characteristics),
- ability to select pieces of data,
- ability to merge pieces or full data from different measurements and comparing them,
- generation of separate diagrams and ability to designate approximate curve characteristics of presented data,
- ability to generate diagrams of measuring signal sequences and X/Y diagrams to present relationships between different quantities,
- ability for curve development and adding them to existing data according to measurements not included in the measuring system, like measurement of sample's contact area.

Basing on the analysis of listed requirements, architecture based on the Producer-Consumer design pattern was selected. This pattern perfectly fits an application which transfers data between a number of threads.

Producer thread is handled by user interface in case of the developed application. It reacts on buttons and other controls, which might be used by application's user. Sample functionalities of Producer thread are:

- loading data from a file,
- selection of piece of data from the loaded file and its transfer to Consumer thread,
- closing an application.

Producer thread architecture was shown in Fig. 8. As it can be seen, its key element, connecting threads of Producer and Consumer is a queue (marked with 1). Consumer dequeues data (2) and transfers it to further processing (3) under the thread, where it is added (4) to a cluster array. Cluster consists of a set of measuring data loaded from a file as a multidimensional array, sampling frequency data and verbal notes, written by user during data loading.

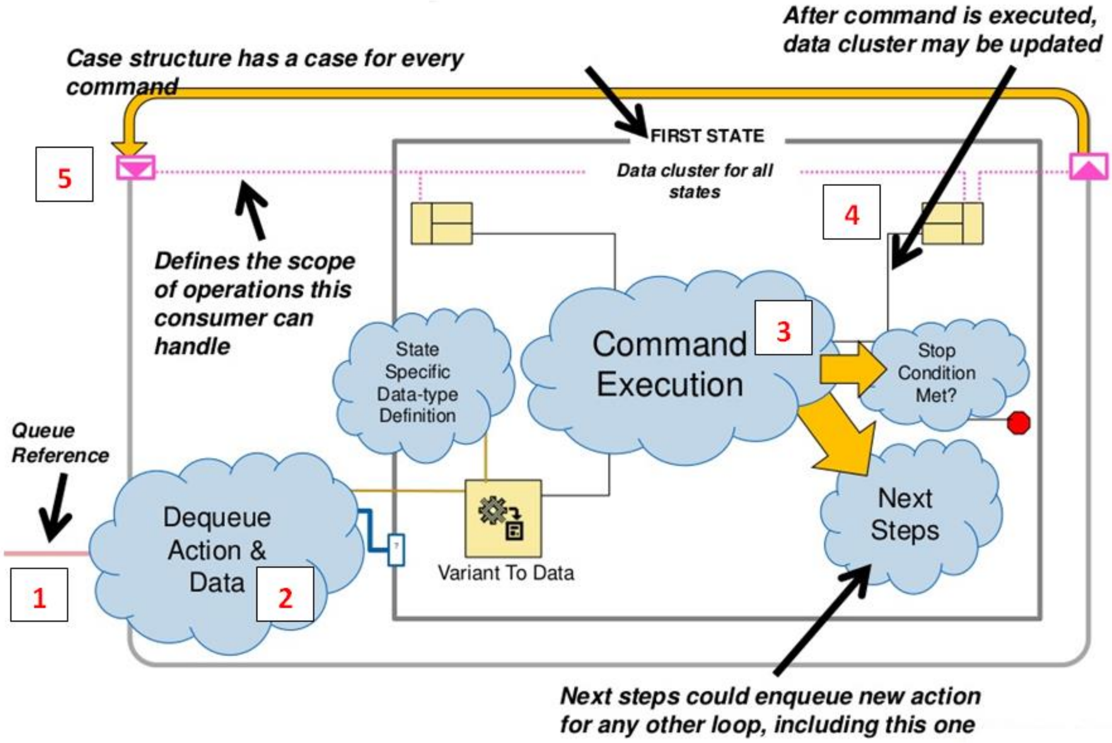

Fig. 8. Diagram of the Consumer thread

Data availability in subsequent iterations of thread main loop is possible thanks to shift register (5). Sample functionalities of Consumer thread are:

- dataset creation,
- data displaying on graphs,
- designating approximation curves using selected data.

User interface was divided for few subsections. Fig. 9 presents a screen of loaded measuring data preview. A top window presents summary graphs of dataset. Bottom windows contains a selected curve and its approximation (bottom left; in the figure displacement course in time and its linear approximation is shown) and X/Y graph (bottom right), which can be freely modified by a user by selecting a dataset for graph generation (in the figure a displacement course in displacement function is presented).

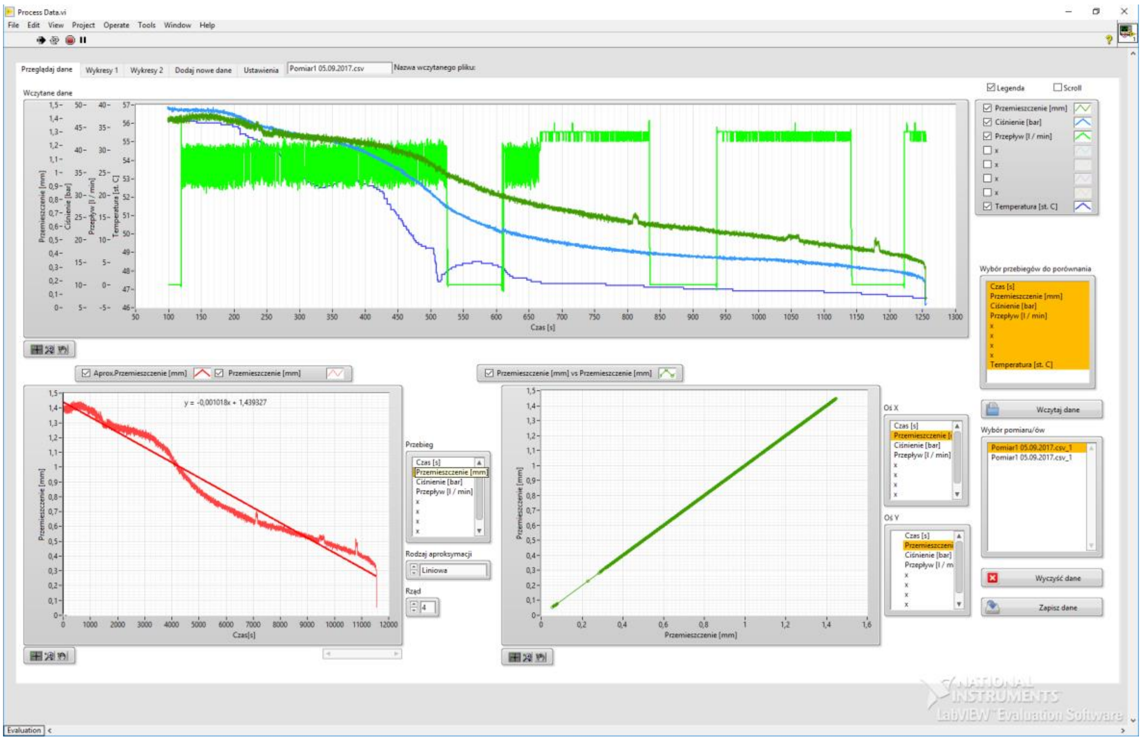

Fig. 9. A view of the main window of processing application

Figures below present user screen previewing graphs according to settings (Fig. 10) and a view of data loading interface (Fig. 11). A graph with loaded data can be seen in the Fig. 11. Cursors A and B, used for data fragmentation, are displayed on the graph. There is a table in the bottom left corner, where a user can enter measurement data other than loaded, like sample's area. The graph in bottom right corner presents data entered in the table and its approximation (in the figure there is no data entered in the table and the graph shows quadratic function approximation curve). Different settings can be applied using settings window presented in Fig. 12.

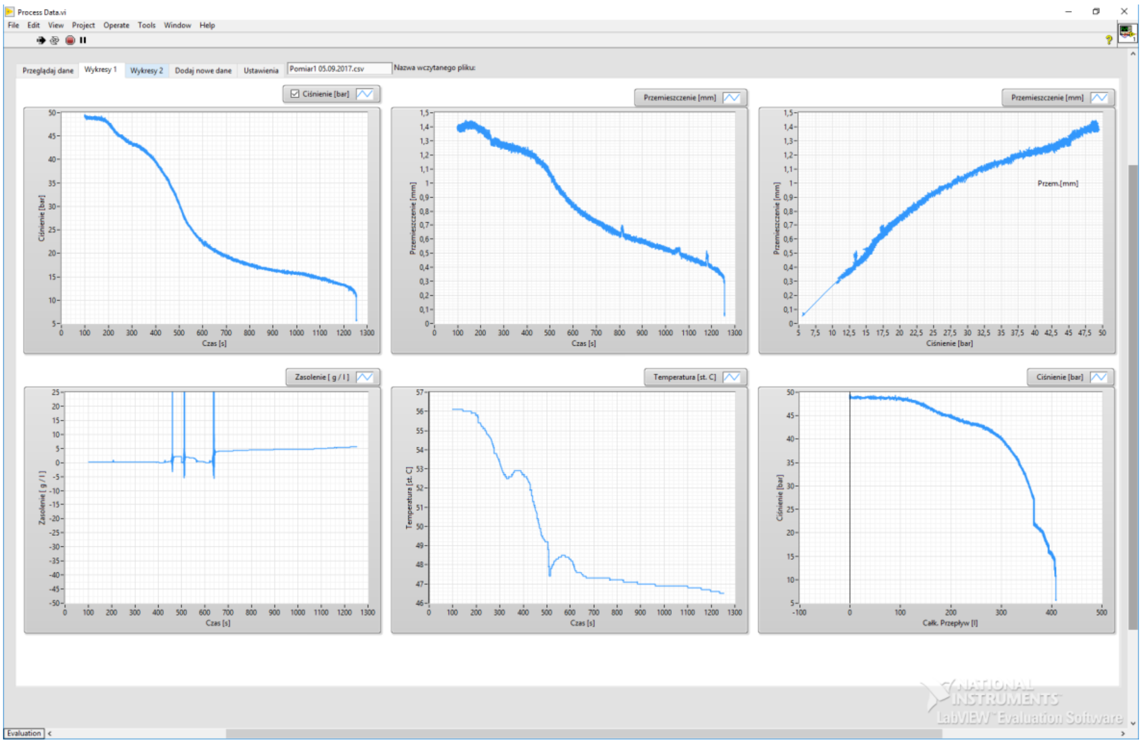

Fig. 10. A view of the window of graphs

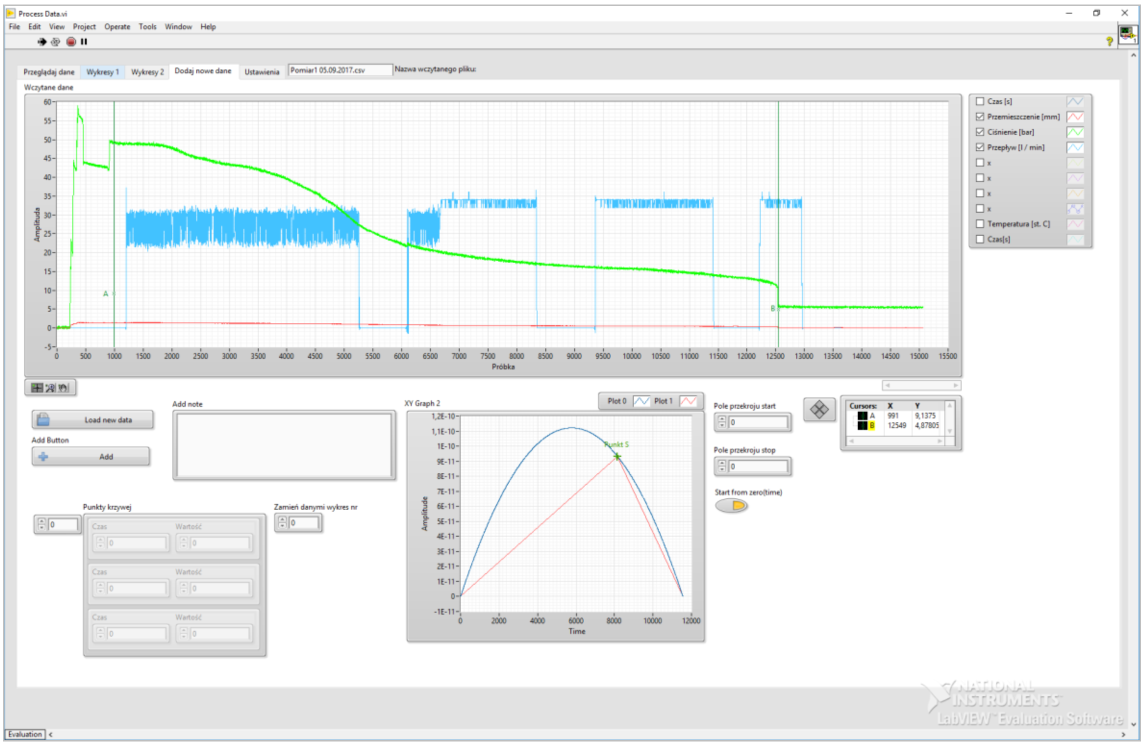

Fig. 11. A view of the data loading

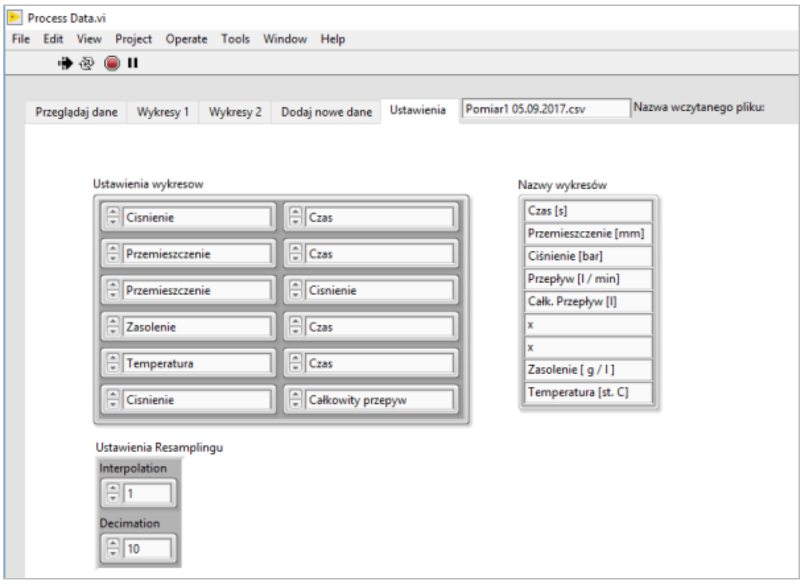

Fig. 12. A view of settings window

5. Results

The main goals of research carried out were:

- Validation of the thesis that periodic salt sidewalls leaching, supported with coarse grained porous material is possible and allows to regulate (reduce) loads acting on the shaft lining.
- Initial research on processes occurring during salt side walls leaching and an impact of load reduction on the shaft lining.

It was observed during tests that on the contact between the salt sample and aggregate a salt tenon (bridge) is developed. Its shape is truncated cone or pyramid like, dependent on the process of the test. Moreover, an influence of the contact area between the salt and aggregate on the salt bridge development was observed. Thus an attempt to simulate different conditions of contact between the salt sample and aggregate was undertaken.

Conducted tests allowed to obtain formulas describing a process of salt tenon development. These formulas are presented below.

$$a = -0.0232 * \sqrt{t} + T + 0.0456 + U \quad (1)$$

where:
a – percentage salt tenon surface, %,
t – time, s,
T – temperature, °C,
U – flow discharge, dm3/min.

Preceding formula was adapted to measurements, thus in time T=0, 100% is not always obtained. This relationship presents general tendencies with respect to temperature and flow discharge, and it indicates approximate time of growth of the salt tenon of a specizized area.

In result of formula (1) transformation, leching time to achieve critical surface $A_{critical}$ was obtained:

$$t = \left(\frac{0.0376 * T + 0.0456 * U - a}{0.0232}\right) \quad (2)$$

where:

$$a = \frac{A_{critical}}{A_{wall}} \quad (3)$$

$A_{critical}$ – critical surface, mm^2,
A_{wall} – salt wall surface, mm^2.

The ultimate relationship is as follows:

$$P = \frac{h_S}{v_{wall}} \quad (4)$$

where:
h_S – salt tenon height, mm,
v_{wall} – side wall advance rate, mm/day.

Factor P informs about the time (in days) needed to create salt tenons of critical surface, which are then destroyed with rate adapted to the side wall relocation. Leaching time is calculated from former equation (2).

On a basis of the salt tenon height, block wall flushing rate was determined. Similary to the previous case, linear regression was applied. Salt rock leaching rate was assumed as constant and it was expressed as a ratio of the flushed salt height and its leaching time. Explanatory variables comprised flow discharge in litres per minute and temperature. It was observed that salt is also flushed out from the frontal tenon surface on the salt block contact with the obstacle. Height of the leached salt was is about 20%.

Accordingly empirical formula for the salt wall leaching rate was combined with leaching time formula, which allows to determine dissolved salt height H [mm]:

$$H = V_{leaching} * t \quad (5)$$

where:

$$V_{leaching} = 0.66 * t + 2{,}15U + 89.42 \quad (6)$$

6. Conclusions

The issue of the stability of mine workings located in salt rock deposit was analysed and presented in numerous publications by different authors and researchers in many countries all over the world [7-11].

Further development of copper mines of KGHM Polska Miedź SA, located on the Pre Sudetic Monocline and advance of mining areas to the north requires development of new vertical and horizontal workings, including mine shafts which sections are to be located in salt rock mass. In order to provide proper level of safety of the mine and staff working underground, it is necessary to ensure sufficient stability of mine shafts for the period of few decades and proper geometry of the shaft furniture to provide safe and fast transport with conveyances.

Further research carried out to solve this problem has lead, among other solutions, to project of the new shaft lining construction and method of regulation of loads acting on it, presented in [17-19]. To verify assumptions on which described construction of the shaft lining is based, it was necessary to design a test facility of special construction, briefly presented in this work and described in details in [18-19]. This research required also software, which had to be designed and developed especially for this purpose, because of lack of suitable programmes available on the market.

Software designed for purpose of this project was developed in LabVIEW environment and it consists of two application, of which one is used for data acquisition during investigations using test facility and another is responsible for processing of this data. The application cooperating with measuring devices is based on Event-Driven Queued State Machine pattern and allows full control of test facility elements and convenient near real time data acquisition using clear and convenient graphical user interface.

Similarly, for purpose of processing of gathered data, another application was developed using LabVIEW environment. It was based on Producer-Consumer pattern. It provides convenient data processing and analysis.

Analysis of gathered data allowed to describe behaviour of salt rock mass acting on the design shaft lining and process of salt leaching, which is an inherent element of proposed solution. Laboratory research with use of custom designed test facility showed promising results [18], which indicates a possibility of application of the designed lining in the mine shaft. However, it has to be verified in the real life conditions.

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Longwall shearer haulage systems – a historical review. Part 3 – Chainless haulage systems with drive wheel and rack bar

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Abstract:

Chainless shearer haulage systems with rack bar are currently the most popular group of this kind of solution. The first type of rack bar was captivated chain. In 70-ties great number of different solution of chainless haulage systems with drive wheel (sprocket or pin) and different rack bars were implemented. Afterwords some of them were abandoned for different reasons, but some are still in duty and under improvement. This article is the third and the last part of shearer haulage systems technical review, concentrated on chainless haulage system. Beginning from the british Rollrack with pin drive wheel and toothed rack bar through similar solutions with sprocket drive wheel in Europe and China and solutions with vertical or horizontal ladder type of rack bar is reflect technical development of shearer haulage system till contemporary solutions and trials of improvement.

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

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1. Introduction

In modern mechanized longwall systems with shearer loaders, chainless haulage systems are applied, almost exclusively especially those based on the idea of a toothed rack bar a solution developed in the 1970s by Eickhoff in the form of a horizontal "ladder", i.e. a double bar connected by means of profiled pins (crossbars). However, before theEickotrack and solutions based on its idea mastered the mechanized longwall systems, a number of other solutions had been developed, which became popular over time and gradually lapsed after some better solutions became widespread.

2. Haulage systems with drive wheel and rack bar.

Fig. 1 shows the basic groups of technical solutions of the chainless shearer haulage systems with a drive wheel captured with profiled tracks.

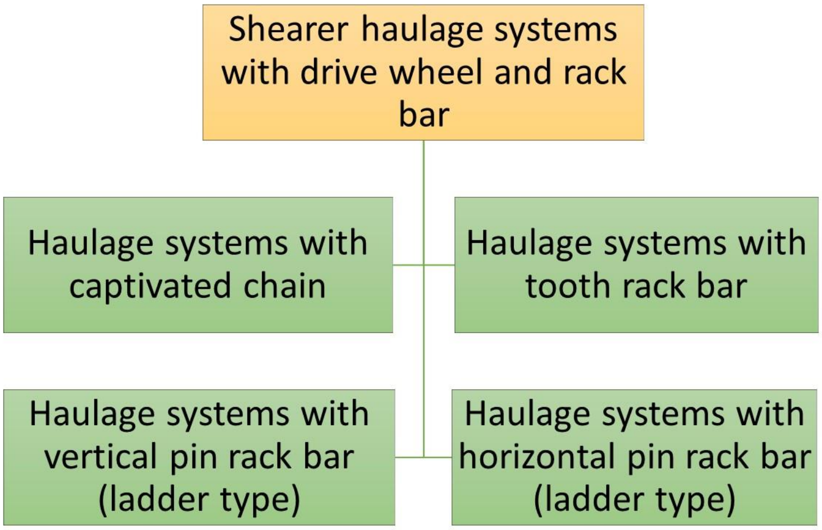

Fig. 1. Typology of the shearer haulage systems with drive wheel and rack bar

The captivated chain systems were discussed in the previous article [1].

At the beginning of the search for solutions for the shearer haulage systems with a drive wheel and a rack bar, the idea interfering to as less as possible extent with the shearer carriage's structure was dominant. This was due to the search for solutions that could be applied in already operating shearers [2,3].

3. Haulage systems with toothed rackbar

The first haulage systems with a drive wheel and a toothed bar were developed in Great Britain [4, 4,5]. in the mid-1970s.

3.1. Rollrack haulage system

First haulage system with toothed rackbar was the british Rollrack. In this system, the "teeth" were placed on a special structure of the armoured' face conveyor's spill plate on which the driving wheel of the longwall shearer was rolling. The vertical wheel (with a horizontal axis of rotation) was doubled with pins (Fig. 2).

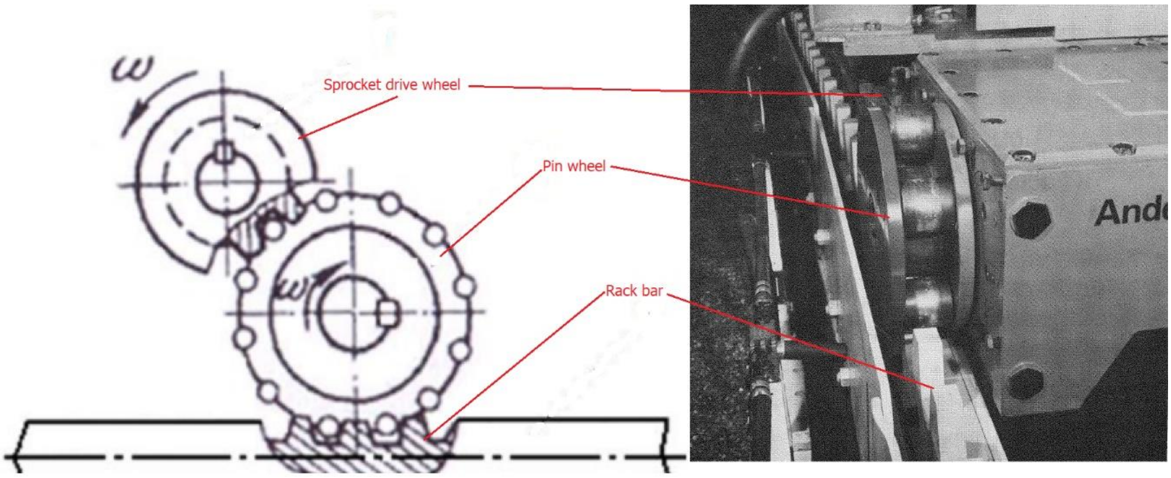

Fig. 2. Idea of the Rollrack chainless haulage system

The disadvantage of the original solution was the lack of forced guidance of the longwall shearer and thus the possibility of the wheel falling out of the toothed bar - it eliminated the possibility of using this solution in inclined or folded longwall faces, but in the case of British mines it was not a problem.

On the basis of operational experience, a trapping shoe was implemented afterwards to prevent the drive wheel from falling out of the toothed bar, thus extending the scope of application of the shearers with this haulage system (Fig. 3), including folded longwalls and walls with a greater inclination gradient (slope).

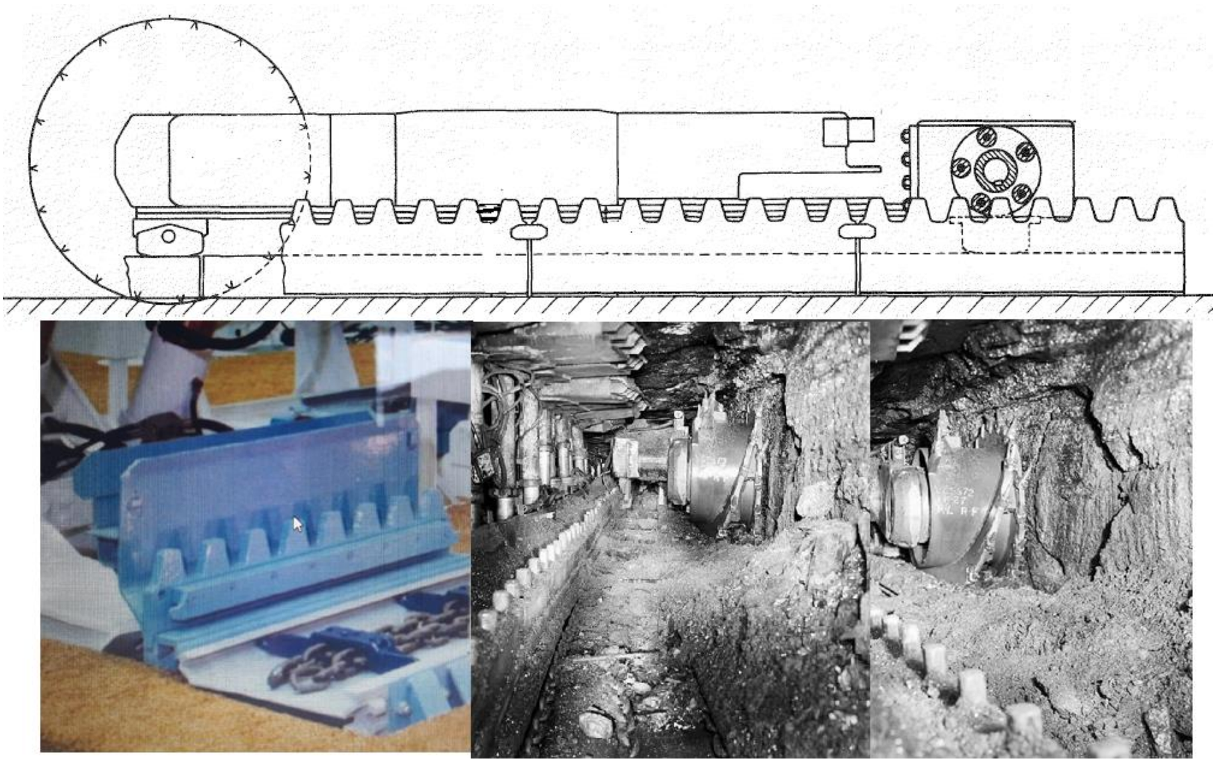

Fig. 3. The Rollrack chainless shearer haulage system

The Rollrack system was widely used in the British mining industry, and this solution was still offered in the 90s of the last century. The Rollrack haulage systems were also used in British double-drum shearers, including those with ranging arms [6].

The idea of shearer haulage systems with a rack bar and a drive wheel (with transverse pins or profiled toothed drive wheel) was later applied in various variations described below.

3.2. The Saartrack system

A haulage system with a profiled toothed bar attached to the armoured face conveyor pan route was developed in the German Saar Basin (Fig. 4) [7].

Fig. 4. The Saartrack chainless haulage system [7]

The structural complexity of the Saartrack haulage system and the high manufacturing costs prevented this haulage system from becoming widespread. This system was very sensitive to changes in the longitudinal inclination in the longwall, which was its additional constraint. In addition, a high sensitivity to the horizontal bending of the AFC route (e.g. during advancing) occurred in this solution.

3.3. Toothed rack bar systems in Poland

In the 1980s, attempts were made to develop an effective shearer loader intended for low walls in the Polish coal mining industry. The first to be developed were shearer loaders with external chain haulage drives with forced "endless" chain guidance and control of the haulage system by means of a frequency converter (KGS150, KGS200).

Based on the experience with these shearers, a new generation of shearers was later developed with electric, chainless haulage system with a toothed bar placed on the armoured conveyor from the coal face side (Fig. 5). The cast toothed bar, forming a whole with the toe (runway) was screwed to the side profile of the AFC pan [8,9,10]

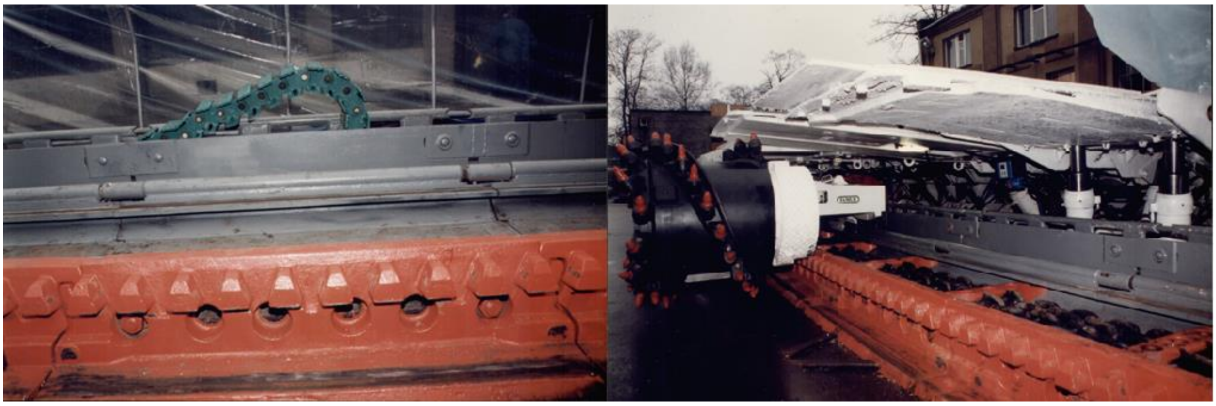

Fig. 5. The KSE-360 Polish shearer with chainless haulage system along the toothed rackbar embedded on the armoured face conveyor from the coal face side

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The KSE-344 shearers with such a feed system were applied, several of which worked in the Polish hard coal mines (i.a. Dębieńsko, Gliwice, Bolesław Śmiały). In 1997 as part of the work on a new longwall system for low coal seams, a prototype of the KSE-360 shearer (FAMUR S.A.) with this feed system was developed and manufactured. It was tested at the Dębieńsko mine. A similar solution had been previously developed by Eickhoff.

3.4. Chinese solutions.

Haulage systems with a toothed bar and a toothed drive wheel for low walls were also developed in China [11], where various solutions were created (mainly for low walls), such as:

- System with a vertical toothed bar from the coal face (Fig. 6)

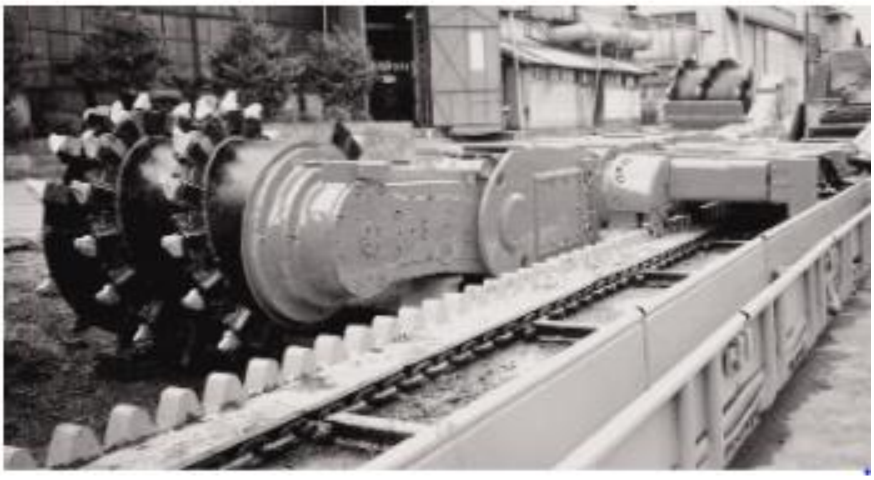


Fig. 6. Haulage system of a low longwall shearer with a vertical toothed rack from the coal wall side [11]

This solution made it difficult to load the excavated material onto the armoured face conveyor, although its main part was loaded over the shearer arm.

- To improve the uniformity of the haulage system operation, double toothed bars with the mutual offset (shift) of the teeth by ½ pitch and the drive wheels with a similar phase displacement (shift) of the teeth were implemented. Such solutions were used with vertically (Fig. 7) and horizontally positioned teeth of the rack.

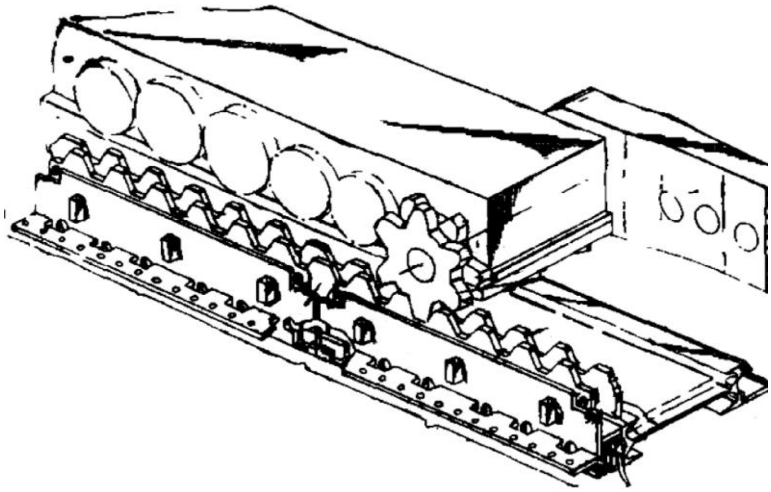


Fig. 7. Chainless shearer haulage system with double vertical toothed rack [11]

A similar solution with a double horizontal toothed rack (Fig. 8) applied to low coal shearers significantly limited the clearance between the armoured face conveyor and the longwall shearer.

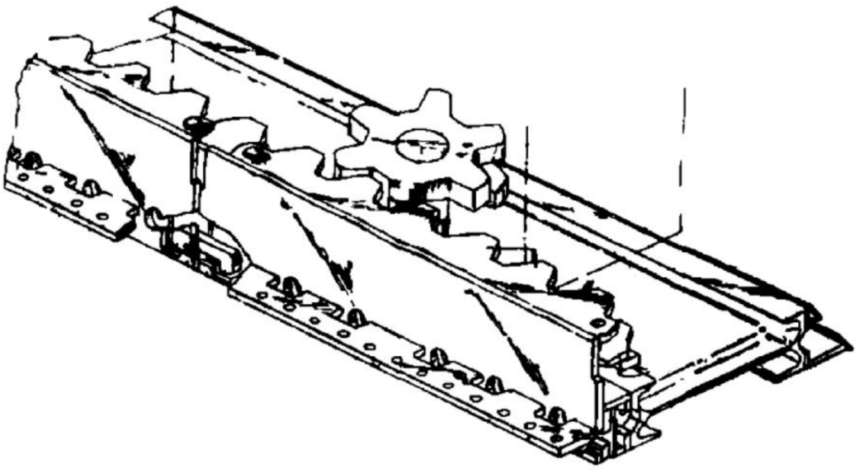


Fig. 8. Chinese chainless shearer haulage system with double horizontal toothed bar [11]

Any experiences with this system are not known.

3.5. Contemporary systems with toothed bar.

Nowadays, chainless feed systems with a drive wheel and toothed bar are still rarely encountered.
As an example, in 2021 a solution of this type was provided to one of the Ukrainian mines by the Corum Group (Fig. 9] [12].

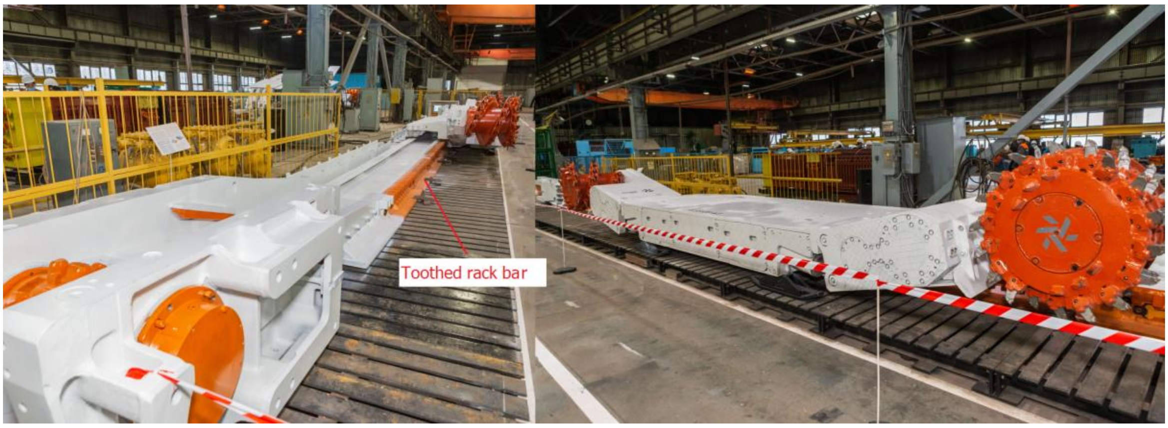


Fig. 9. The CLS550P shearer loader with electric haulage system with a toothed bar on the dedicated armoured face conveyor SPC271M from the coal face side [12]

This complex is intended for the exploitation of walls with a height from 0.85 m. The cast toothed rbar forms a whole with the runway (toe) fastened to the AFC pan route (similarly to the Polish KSE344 and KSE360 shearer loaders - Fig. 5)

4. Haulage systems with vertical rackbar.

Haulage systems with a vertically positioned ladder bar were implemented in the mid-1970s, first in British mines, and then in Poland.

4.1. Pin/Wheel haulage systems

Development and implementation of longwall shearer haulage systems with vertical pin rack bar ladder was initiated by the National Coal Board in the mines of the southern part of County of Nottingham, where this haulage system with a hydraulic drive was applied (Fig. 10) [2].

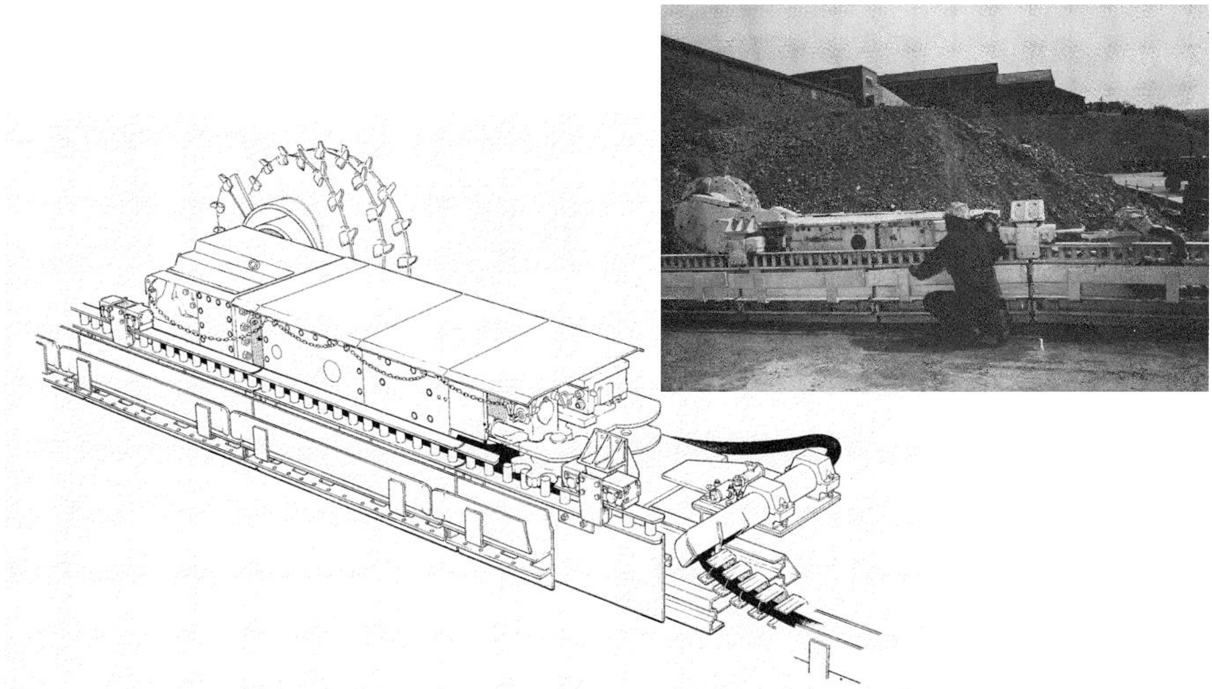


Fig. 10. Chainless haulage system Pin/Wheel with vertical pin rack bar (ladder type) developed in the National Coal Board (NCB) [2]

The idea of this solution was to fasten a vertical ladder composed of two flat bars connected by pins to the armoured conveyor's spill plate. The length of the ladder segment was the same as the length of the face conveyor pans. The horizontal drive wheel rotations resulted in the shearer moving along the face. In flat walls, where there were no changes in the transverse and longitudinal slope, this solution worked properly, and therefore already in 1977 in British mines there were 14 longwall shearers equipped with such haulage systems. The presented haulage system revealed its disadvantages when used in longwalls with varying transverse and longitudinal slopes. At the bends of the floor, the longwalls operating relatively high above the floor became damaged or the drive wheels were damaged due to a change in the pitch of the crossbars/pins at the links/joints. These problems escalated with increasing force and haulage speed. For this reason, this solution was abandoned quite quickly, especially since more forward-looking solutions were already available.

4.2. Polish haulage system Poltrak II

In the Polish underground hard coal mining, which was very modern at the turn of the 1970s and 1980s, problems and threats related to the longwall shearers' chain haulage systems, occurred with great intensity. Moreover, for economic and political reasons, an access to many technical solutions developed in the most advanced countries of Western Europe was difficult. An additional problem was the fact that the Polish coal mining exploited mechanized longwall systems in a range of conditions wider than elsewhere, especially inclined ones and in geological disturbances. In longwall faces with greater longitudinal slopes, it was necessary to prevent the shearer with a chain haulage from sliding down in the event of a chain break. Under these conditions, the work was undertaken on the Polish chainless haulage system, using the idea of a vertical pin rac kbar ladder type. The first solutions similar to the pin/wheel system were tested in mines to finally develop the Poltrak II system eliminating the disadvantages of the British solution [9,13,14].

The idea of the Poltrak-II solution consisted in using a vertical pin rack bar ladder type, which was not rigidly attached to the AFC spill plate. The rack bar ladder was connected to the conveyor by means of rigid strands with flexible connecting joints/links (Fig. 11)

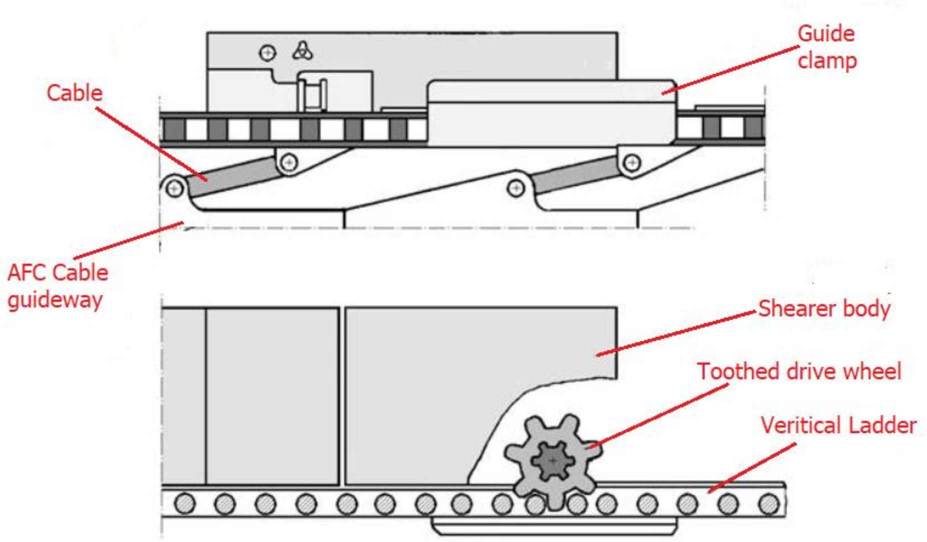


Fig. 11. Polish chainless haulage system Poltrak II – general idea.

The rack ladder segments were interconnected by means of articulated clips that allowed for an adaptation to local changes in the floor deposition. The solution was implemented into common use in the Polish coal mining industry and it was subject to export. In single-drum shearers solutions with a single drive wheel were applied. In the case of double-drum arm shearers, it was necessary to use systems with two drive wheels driven by independent hydraulic motors, but with a single hydraulic feed pump. Through this solution, the conditions of cooperation of drive wheels with rack ladders improved, but the maximum haulage speed decreased by 50%, which was 3.8 m/min. An application of the Poltrak II haulage system allowed (due to the use of hydraulic disc brakes in the haulage system) to eliminate safety drawing equipment (winches) in inclined longwalls. Due to the low haulage speed limiting the shearer efficiency and the availability of the Eicotrack haulage system being easier to operate, the Polish coal mining industry was begun to abandon this solution since the beginning of the 1990s, but in 2002 there were still 13 longwall shearers with the Poltrak II haulage system operating in the Polish mines.

5. Haulage systems with horizontal ladder

At the beginning of the 1970s, the German company Eickhoff [15] started working on a chainless haulage system with a profile bar in the form of a horizontal ladder (two flat vertical bars connected with horizontal pins – a pin rail). Compared to the haulage systems with a vertical ladder, this solution largely eliminated the impact of vertical bending of the conveyor pan route on this type of rack bar. The structurally set clearances allowed for the mutual adjustment of the drive wheel and the ladder while the conveyor was moving and, to some extent, an adjustment to changes in the seam deposition and the positioning (stratification) of the longwall floor. The idea of the Eicotrack haulage system is shown in Fig. 12.

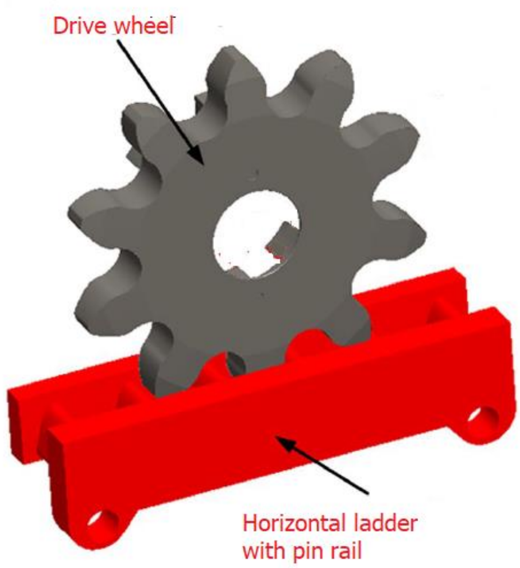


Fig. 12. Eicotrack chainless haulage system– general idea [11].

The Eicotrack was produced with a 125 mm pitch of teeth in the form of segments at the length corresponding to of half-length of the armoured conveyor pan. The production technology has changed, but the segments made with the casting technology dominate today.

With the increase of forces in the haulage systems and the haulage rate of the longwall shearers, functional defects of the system appeared and solutions based on the idea of the Eicotrack system, but adapted to the new conditions appeared, such as Megatrack, Jumbotrack and similar [16,17,18].

5.1. Looking for improvements of haulage systems with horizontal ladder

Despite the fact that the haulage systems of shearers with a horizontal ladder turned out to be much more functional than all the previous solutions, their disadvantages revealed in the long period of operation. As an example, one can point out premature wear and damage to the drive wheels due to a failure to keep the pitch at the connection of the ladders, especially in the case of folded walls or as a result of failure to comply with the technological regime.

Therefore, at the end of the 1970s, some attempts were made to improve this solution. One of the ideas was to replace the ladders with the systems of connected profiled fittings with elements forming the teeth or the pins of the ladder cooperating with the drive wheels of the shearer haulage system. Ideologically, there is some similarity to the haulage systems with captivated chain.

Probably the first solution of such type was patented in the USA in 1982 by one of the British companies (Fig. 13) [19].

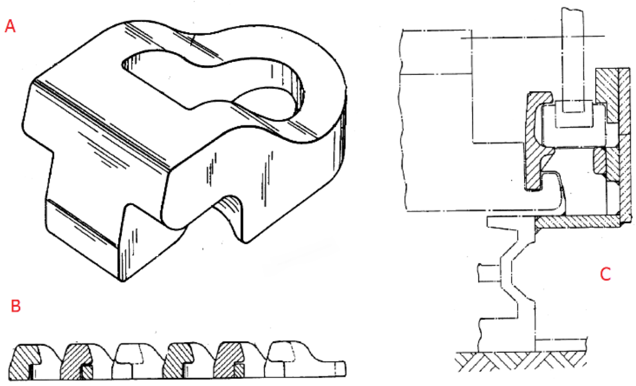


Fig. 13. Modification of the haulage system with a horizontal ladder presented by Pitcraft Summit Ltd.: A – single profile, B – method of profile connection, C – solution idea [18].

The applications of the described solution are not known.

5.2. Flextrack and Komtrack

An attempt to eliminate the disadvantages of the haulage system solutions, based on the Eicotrack idea, was undertaken in the 21st century in Poland by developing the Flextrack haulage system (2012-2015), later developed into the Komtrack haulage system [20,21,22].

By definition, the new system was intended to:

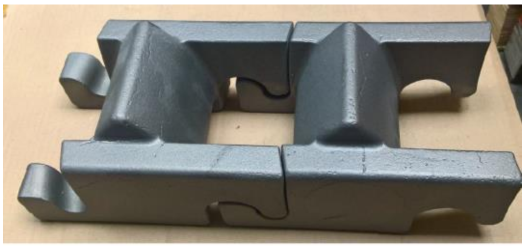
- improve the durability and reliability of the longwall shearer haulage system,
- reduce time losses caused by the Eicotrack haulage system failures,
- facilitate an adaptation to changes in the longitudinal and/or transverse slopes of the armoured face conveyor,
- reduce the energy consumption of the haulage system.

An additional objective was to limit the exposure of mining operators to mining hazards during repairs of the longwall shearer haulage system.

In view of the widespread use of haulage systems based on the Eicotrack concept, it was rightly assumed to minimize structural changes in other devices of the longwall system. The armoured face conveyor remained unchanged, and the changes in the shearer haulage system actually concerned only minor changes in the geometry of the drive wheel (sprocket wheel) and the associated components.

The idea of the solution shown in Fig. 14 was to replace the classic Eicotrack pin rack with a guide in which, similarly to the solution shown in Fig. 12, specially shaped cast fasteners with a specially adapted geometry were installed.

It should be noted that the widespread use of longwall shearer haulage systems based on the Eicotrack concept, may be an obstacle to spreading of the Komtrack system, even if the field tests prove the benefits of this solution. It is difficult to expect that the Komtrack system will significantly affect the productivity of the longwall systems in the Polish hard coal mining industry, and in the most technologically advanced countries, high-performance longwall systems are used in conditions where the disadvantages of systems based on the Eicotrack concept (Megtrack, Jumbotrack) do not have a significant impact on the reliability of the entire longwall complex.



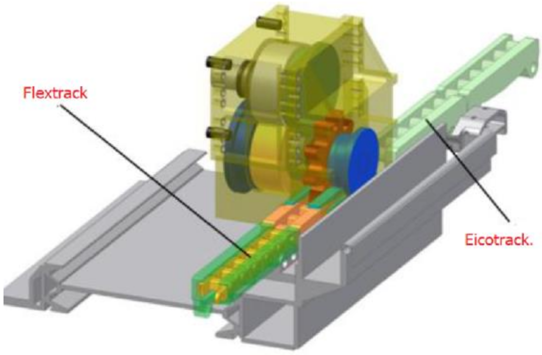


Fig. 14. Eicotrack and Flextrack/Komtrack – idea [21]

Developing the concept of the Flextrak haulage system resulted in the Komtrack haulage system, which, after tests on the surface of one of the Polish mines, has been awaiting to be used in underground conditions.

5. Summary

After several decades of searching for a safe and reliable system of longwall shearer haulage system, the Eicotrack haulage systems and solutions based on the same idea/concept that enable their application in increasingly faster and stronger shearer loaders are now used. The currently abandoned solutions were created in times when the shearers with one cutting drum often embedded in the shearer body (without an arm) were the dominant ones. These first shearers had a limited range of cutting height. With the development of drum shearers, the requirements for haulage systems have changed, and this was one of the first reasons that some solutions were abandoned. The accumulated operational experience concerning the longwall shearer haulage systems, resulted in the search for new solutions or an improvement of the existing ones.

Today, the dominant longwall shearer haulage system, regardless of the drive type, includes systems with a horizontal ladder (pin rack bar ladder type), ideologically derived from the Eickhoff solution and developed in order to use increasingly greater installed power in the shearer haulage systems and enable a development of increasingly higher speeds in haulage systems.

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