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Requirements for the development of an effective autonomous methane detection system protecting against a sudden emission of methane

The paper features the development origin of a new methane measuring system whose main purpose is to provide quick protection of heavily saturated methane longwalls against a sudden emission of methane from goafs into the working area of the longwall. The concept of the new system was discussed along with its testing results. This work was the subject of task 8 of the project devoted to improving safety in mines. The focus was put on implementation conditions: from obtaining indispensable certificates and admissions, through the installation in the given exploitation area, to the system integration with already existing stationary gas measuring systems. The possibilities of the new system were stressed as far as the safety management of the mine was concerned. Here, the authors pointed at the significance of systematic risk analyses with respect to methane explosions in longwall areas.

key words: *mining, hazards, monitoring systems, methane mesurement*

1. INTRODUCTION

In 2009 there was a methane ignition and explosion in a Polish coal mine, in its longwall area. This area was equipped with automatic methane measuring devices, installed and exploited in compliance with valid regulations [2]. The accident investigation commission, appointed by the President of the State Mining Authority, declared [8] that the event had occurred due to a sequence of exceptionally unfavourable circumstances. The investigation showed that under certain conditions in exploitation areas the functioning monitoring systems could not provide enough protection against the consequences of methane explosion or ignition.

The event took place in a longwall area ventilated according to the *U* system and the most probable cause was the accumulation of methane of dangerous, explosive concentration which persisted directly behind power support units. This accumulation moved and appeared in the final part of the longwall working area, near the goafs, in the section from about 180 m to about 230 m, i.e. it moved to the crossing with the top road. The direct cause of the ignition and the following explosion of methane was, most probably, an electric arc (short circuit).

With respect to the above findings, the commission stipulated in its report [8] to develop a new measuring and protection system that would be able to prevent such incidents in the future. This issue was included into a package of research programmes for urgent execution. The package was formulated by an interdisciplinary team that was appointed in 2009 to deal with development projects aimed at better work safety in mines [7].

The materials prepared by the above mentioned team were the basis of a call announced by the National Centre for Research and Development (NCBiR) for a strategic project to improve work safety in mines (*Poprawa bezpieczeństwa pracy w kopalniach*). Task 8 of this project is devoted to the development of a gas measuring system that would immediately switch off longwall machines and electrical devices in case of a sudden emission of methane. The project is conducted by a consortium coordinated by the GIG Institute (Experimental Proof Ground – Barbara coal mine) and composed of the following organizations: three R&D institutions – AGH University of Technology from Krakow, Strata Mechanics Research Institute of the Polish Academy of Sciences from Krakow, Institute of Innovative Technologies EMAG from Katowice, and one commercial company –HASO S.C. from Tychy.

2. CONCEPT OF THE NEW GAS MEASURING SYSTEM

The general concept of the system was elaborated by the consortium already at the stage of the proposal preparation. The objectives of task 8 were taken into account along with the requirements stipuleted by NCBiR. In the course of the project this concept was specified, modified and adapted to legal regulations, technical possibilities and practical aspects of the system exploitation in hard coal mine conditions. The basic assumptions of the concept can be summarized as follows:

1. The developed system must enable continuous measurement of methane concentration inside the longwall excavation, including places which are difficult to access, e.g. the area near the goafs, behind the powered support unit.
2. New devices (sensors) will be developed to measure the concentration of methane; they will be intrinsically safe, their structure will be adapted to environmental conditions near the longwall, and their metrological parameters will ensure measuring accuracy and minimal response time in compliance with the standard.
3. To minimize the consequences of damages in the transmission grid, the measuring devices will be equipped with radio modules; the modules will allow quick data transfer resistant to electric disturbances in the longwall area as well as mechanical metal obstacles.
4. The measuring devices will have autonomous battery supply; this will allow to eliminate cable connections which are vulnerable to damages.
5. Data from measuring devices will be collected and analyzed by a switchboard located in the top road. The switchboard, equipped with proper control outputs, will produce signals to cut off the power supply of machines and devices in the longwall area.
6. The switch board will serve as a local, autonomous methane-measuring protection of the longwall. Additionally, it will be able to communicate with the central supervision unit of the mine monitoring system by means of copper cables or optical fibres.

The above assumptions show that the project aimed at developing a system of co-operating measuring and execution devices whose operation area was restricted to the longwall area, more precisely, the excavation in this area. The task of the new system is to execute security functions (measurement, data analysis, power supply cut-off) in an autonomous manner, independently of the all-mine security system. This way it would be possible to reduce response time in case of a sudden emission of methane inside the excavation whose volume could cause an explosion or ignition. Thus from the point of view of the overall mine supervision, the new system should be treated as an autonomous longwall gas measuring system.

It is important to note that the development of a set of new devices was not the only objective of task 8. Apart from the design and development works, the task comprised a series of research operations of analytical nature, laboratory tests, computer simulations, *in situ* measurements, and experiments in a mine. These operations were conducted to determine all aspects of practical use of the new system, particularly to specify regulations and conditions of its exploitation in mines.

3. EMAG'S PARTICIPATION IN THE RESEARCH TASK

Apart from the major objective, task 8 had six specific objectives. In order to achieve these objectives, the task was divided into 14 stages, different from one another in terms of their duration and contents [13]. As the Institute of Innovative Technologies EMAG is experienced in the realm of design, research, implementation and maintenance of systems for monitoring natural hazards, this institution was made responsible for two stages: stage 1 dealing with the review of legal and technical aspects of the task, and stage 13 in which the results of the whole task were summarized.

Within stage 1 of task 8 EMAG's project team made a comprehensive review of the geological and mining law [1, 9], mainly the decree of the Minister of Economy on occupational health and safety [2]. In the course of this stage it turned out that the analysis of other regulations and directives was equally important, i.e. those dealing with security systems and automatic methane measurement, for example: the decree specifying requirements for protection devices and systems to be used in explosive atmospheres [5], the decree on assessing the compliance of telecommunications terminals [3], the decree on radio transmitters and receivers that can be used without radio permission [6], and the decree on the admission of products to be used in underground mines [4].

Within stage 13 EMAG's team evaluated the developed solution with respect to its implementation and exploitation aspects. As a result of that, basic conditions were specified for production of the new system devices, as well as requirements and guidelines for their use in mines [13, 14].

4. PROTOTYPE OF THE SYSTEM

The prototype of the system, made by HASO S.C. [10,11,13], makes use of two devices developed within task 8 (Fig. 1):

1. CR-1 methane sensor, adapted for autonomous work, with its own battery-based power supply, equipped with a radio transmitting-receiving module.
2. CCR-1 switchboard which has the following functions:
   - collecting data from a set of radio sensors located in the excavation,
   - automatic switch-offs of machines and devices based on the analysis of the collected data,
   - communication with the surface unit of the mine monitoring system.

The CR-1 sensor has a methane detector – MIPEX made by Optosense. The detector makes use of infrared absorption. According to its catalogue description, the detector has very good dynamic parameters (quick response time) and very small energy consumption in comparison with pellistor detectors. These two features are of fundamental significance from the point of view of the task. The embedded battery enables the sensor to work uninterruptedly for over seven days.

Fig. 1. Devices of the new gas measuring system [11]

At radio communication the sensors can co-operate with the CCR-1 switchboard in a star network or "mesh" network in two independent channels [10]. The devices were equipped with radio modules working in the band of 868 MHz which, according to earlier tests, provides accurate propagation in the longwall area.

The devices were obligatorily tested for compliance with intrinsic safety standards and metrological properties. In addition, their operations were checked in the coal mines Budryk, Bolesław Śmiały and Borynia-Zofiówka [13]. During the testing stage, there were a number of experiments conducted with a view to verify the installation method, location of measuring points and interpretation of registered measurement results. The most relevant conclusions drawn from the operation tests and experiments were considered by EMAG's project team in stage 13, in which the results of the whole task were summarized.

5. GUIDELINES FOR INSTALLATION AND EXPLOITATION OF THE SUBSYSTEM DEVICES

5.1. Formal requirements

The above mentioned review of valid regulations showed that the autonomous gas measuring system, developed within task 8, is subject to the same laws as methane measuring systems that have been in use so far. Due to its measuring and executive functions (automatic power supply cut-off), the system belongs to the category of security systems. Therefore its implementation should take into account all regulations on the admission of products to work in underground mines [4].

The subsystem manufacturer is obliged to provide indispensable documents, including the operations and maintenance manual and declarations that the parameters of particular devices and the whole subsystem are in compliance with relevant standards and laws. The documentation delivered to the user should comprise information about the subsystem functions as well as detailed guidelines and conditions how to install and exploit the devices.

Before the subsystem implementation it is necessary to work out its installation scheme with information how to integrate the subsystem with the existing monitoring system. The installation can start after obtaining permission from a proper mining authority. The procedure must be carried out according to the approved installation plan and the operations and maintenance manual, under the supervision of the manufacturer or an authorized representative of the manufacturer. The launch of new devices usually needs some trials during which the operations, functionality and reliability can be assessed with respect to the whole system and particular devices.

The final stage of the implementation procedure is the system approval by a commission appointed by the mine manager. A positive opinion of the commission is the basis to get permission for the system exploitation in the mine.

5.2. Conditions and guidelines for the installation of the subsystem devices

According to the assumptions of task 8, the developed devices should serve as extensions of the existing gas measuring systems which are used in mines with exceptionally serious methane explosion hazards, particularly those in which it is possible to have sudden methane emissions from goafs and/or solid rock mass. Thus the potential users of the system are mines which exploit coal seams of category IV, or those which belong to category III of methane explosion hazards. It is especially recommended to use the devices in longwalls which are ventilated by means of the *U* method, along the solid rock mass where the methane emission from goafs (especially in the upper part of the longwall) is the most probable. Independently of that, the devices can be used in other facilities where there are conditions that justify their exploitation.

The installation of extra measuring and monitoring devices is not subject to any conditions. Polish mining regulations stipulate only some minimal requirements about the location and functions of measuring equipment which is part of the mining monitoring system. It is not forbidden to add extra devices which, in the user's opinion, can improve the mine safety. However the installation should be conducted in compliance with the guidelines provided by the manufacturer in a proper manual. Here it is important to note a methane measuring sensor used in the system prototype. This sensor is sensitive to negative changes in the environment. Thus during its installation, as it is stipulated in the prototype documentation [10], one has to pay special attention to minimizing the influence of such factors as salt water, aggressive substances, strong vibrations and shocks, dustiness, or other influence of solids. The conclusion is that, while producing the real system, the manufacturer should provide better protection of the sensor detection element than in the prototype, i.e. to protect it against dust and moisture. This way the devices can work reliably in difficult conditions of the longwall area.

5.3. Location of extra sensors

As it has been already mentioned, the developed subsystem should be able to monitor the methane hazard level in particularly dangerous places which, at the same time, are beyond the control of currently used monitoring systems. Therefore one of the fundamental conditions to improve the security level is that the mine ventilation manager or the hazards team should conduct systematic and regular analyses of methane explosion risks. The objective of these analyses is to identify zones which are particularly hazardous in this respect. The new system will enable to monitor risk levels in such places without the necessity to provide a costly cable grid. Additionally, the range and efficiency of security management procedures are likely to improve.

In the operations related to risk analysis of methane explosion hazards in longwall areas it is possible to make use of more and more common 3D computer simulation methods. The simulation results, verified by measurements conducted in real facilities, can be the basis to decide about the installation of extra sensors and to locate them in certain places. A good example of such use can be seen in Fig. 2. The figure illustrates how a hazardous methane-emission zone is formed when methane is emitted from goafs in the upper part of the longwall ventilated with the use of the *U* method [12].

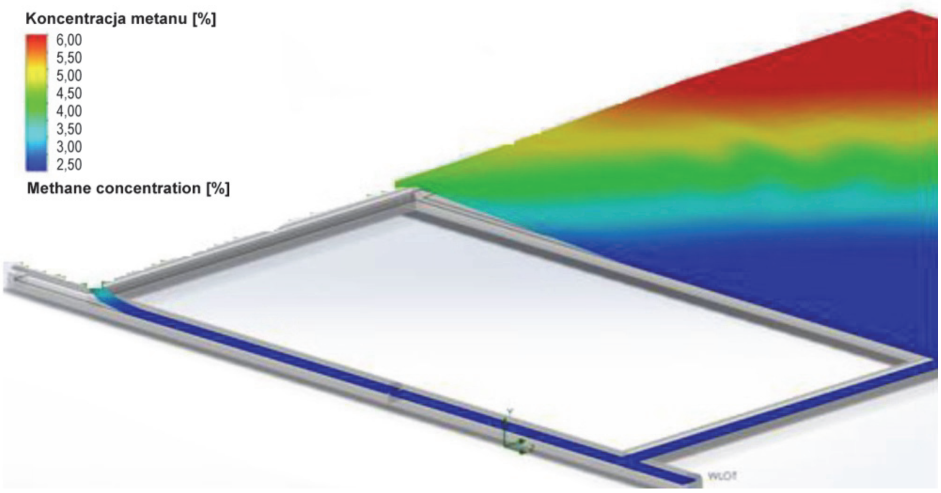

Fig. 2. Simulation of methane distribution in goafs of a longwall ventilated with the U method [13]

In the operating principles of the new system [13], worked out by the task team, there are places indicated which should be particularly protected by extra sensors. These places are the following:

– in the longwall areas ventilated with the use of the *U* method, along the solid rock mass (see Fig. 2) – the crossing of the longwall with the air roadway as well as a 20-50 metre section of the excavation, including its exit and the last power support units;
– in the longwall areas ventilated with the use of the *Y* method, with waste air removed along the goafts – the whole section of the air roadway maintained along the goafs as well as the section of the air roadway located near the wall of the goaf.

There is no doubt that these are not the only places where the devices of the new system can be used. The occurrence of explosive zones depends on many factors, such as: type of exploitation system, inclination of the coal seam and the excavation, type of roof rocks, frequency and energy of rock bursts, field distribution of aerodynamic potentials, etc. The contents of gases in the air, in turn, depends on the methane content of the exploited coal seam, thickness of the seam, thickness of the extracted coal layer, methane content of over- and underlying seams and their distance to the exploitation area. Practice shows that the level of the methane explosion hazard during the longwall exploitation is subject to changes, often wide-range changes. Therefore the possibilities of the new system may constitute an important element in efficient safety management in areas with methane explosion hazards.

6. NEW SUBSYSTEM INTEGRATION WITH THE EXISTING SYSTEM

6.1. Connecting extra devices to the monitoring system

In order to make full use of the new solution in the safety management system, extra methane measurement devices should be embedded into the all-mine monitoring system on the same terms as the existing measuring and cotrol devices. The sensors of the radio system should be treated in the same way as cable-based sensors. The system should provide such functions as alarms, warning signals and automatic switch-offs. Additionally, all breakdowns of registration and switch-off sensors in the system, or all breakdowns in the radio transmission of data, should automatically cut off the energy supply in the areas protected by these sensors..

Though the new system ensures full automomy of operations (automatic, immediate electricity cut-off in the longwall area with no necessity to contact the surface unit), it is necessary to keep the function of the so-called unconditional switch-off of control outputs of the CCR-1 switchboard, in the same was as it is done in the case of other executive devices. This function enables to switch off the outputs irrespective of the methane sensors indications.

6.2. Maintenance of devices in operation

The new devices should be subject to the same regular check-ups and maintenance as other stationary devices of the mine gas measuring system. The maintenance operations can be done only by authorized personnel and the maintenance details, including the frequency and range of the maintenance, are determined by the operation and maintenance manuals.

There is a crucial difference between the new system and the monitoring and measuring devices used in the Polish mining industry. CR-1 sensors are powered by embedded lithium-ion batteries with the capacity enabling continuous operations for 7 days. The switchboard is supplied from a local power supply with a battery. Thus the manufacturer stipulates to exchange internal batteries of sensors every week – this refers to those batteries whose charging can be done only in the surface, with the use of a special charger provided by the manufacturer.

CR-1 sensors, equipped with detectors based on infrared absorption, should be calibrated every four weeks. However, due to environmental conditions of the mine, especially inside the working excavation of the longwall, it is recommended to have weekly check-ups in the installation place, including the cleaning of the detector casing and supplying testing gases.

6.3. Other remarks about the new subsystem

There may be a problem related to the use of the new system, i.e. valid regulations on methane concentration threshold values above which the machines and devices should be switched off – this value is max 2.0% CH_4 in Poland now. The concentrations of that value, and higher, detected in the upper section of the longwall near the goafs, occur almost every time. Therefore while keeping this criterion value, due to specific locations of the new-system methane meters, one should expect much more frequent cut-offs of power supply for longwall machines and equipment. For this reason, before the new system is implemented, it would be advisable to determine new criterion values of the concentration of methane near the goafs, which, when exceeded, would make the system switch off all devices in the longwall area.

The main objective of the sensors installation near the goafs is quick detection of sudden gas emissions from the goafs. Therefor one can consider to couple the switch-off decisions with the speeding increase of the methane concentration signal. However, this issue needs further research.

7. CONCLUSIONS

According to the assumptions of research task 8, the newly developed system is to extend the range of monitoring methane hazards to places where a sudden methane emission can occur. These places are beyond the operation range of the existing monitoring systems with cable-based measurement data transmission. The conducted analyses show that from the legal point of view there are no obstacles to use new gas measuring devices with wireless data transmission. The implementation of the new system into the mining practice requires that certain conditions should be fulfilled. The most important of these conditions are the following:

1. Extra devices can be used on the condition that the manufacturer provides complete documentation which confirms the system compliance with standards and regulations on the use of devices in underground mines with methane and coal dust explosion hazards. Particularly, the complete documentation indispensable to implement the devices should be supplemented with electromagnetic compatibility certificates.
2. The new sustem should suplement, not replace the existing gas measuring systems whose application is obligatory according to the valid regulations and whose functions are strictly determined. Therefore it is necessary to take care of proper integration of new devices with the systems that already operate in the mines. This particularly concerns the functions related to data archiving, alarms in supervision units and a power supply cut-off system.
3. The implementation of new devices provides new possibilities in the protection of areas where it is likely to have an accumulation of factors that may cause methane explosions. However, this way the exploitation costs of the mine are likely to rise. Therefore the use of the new devices should be preceded by a risk analysis which should justify the installation of extra measuring and executive devices and indicate their optimal locations. Here it is helpful to make use of computer simulation methods with respect to methane migration in goafs and gases emissions to the excavation areas.

The results of the simulations, verified by object measurements, can be the basis to make a decision about installing extra gas measuring apparatus.

4. When the new system sensors are installed in the longwall area near the goafs, there is a danger that electricity will be cut off too often and not always justifiably. Thus it seems advisable to make some tests in order to determine different criterion values of methane concentration than the 2% stipulated in regulations.

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