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CONTROL OF DUST EXPLOSIONS IN MULTIPLE-ENTRY GATE SYSTEMS

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ABSTRACT

Under the Maria Sklodowska-Curie Joint Fund II experimental studies were conducted at Experimental Mine Barbara in explosion research to control dust explosions in multiple-entry gate systems of underground coal mines. The research focused on: (1) the course of the explosion, especially weak explosions within the system of parallel entries, (2) performance of SOLAR detectors in conditions of coal dust explosions, and (3) the possible use of triggered barriers to suppress weak explosions within the system of parallel entries, especially barriers distributed at the crossing of entries. Flame sensors, pressure sensors, and SOLAR panels were deployed in the parallel entries associated with the 400 m underground experimental entry of the experimental mine. For collection of the test data and experimental control the HP 3852 Data Acquisition was used. To aid in data processing, digital filters from DADiSP, a versatile software package which facilitates performing advanced analyses of courses of individual explosion parameters, were employed.

Results clearly demonstrated the effectiveness of these systems in conducting large-scale underground explosion tests.
Detailed testing of the SOLAR panel under coal dust explosion conditions and characterization of its performance were achieved. An electronic system for use with the SOLAR panel was developed to enable the firing of more than one electric detonator which readily leads self for use with triggered barriers. Investigations on triggered barriers with the SOLAR panel in connection with water containers deployed on the mine floor indicated the effectiveness of the system in suppressing coal mine explosions.

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INTRODUCTION

Despite the considerable effort expended in recognizing, studying, and understanding methane and coal dust explosion hazards, these hazards have not been completely kept under control, for explosions still occur each year. For obvious reasons investigation and research could not address all the possible mining situations and configurations of mining workings. Increases in the rate of coal production and the growth of the power of the coal winning machines has increased both methane emission and coal dust release. Consequently, the growth in production technology has also increased the potential hazard in coal mining. Not only are the American and Polish coal mining industries interested in investigations about and how to suppress explosions occurring in a network of mine entries but also mining industries in other countries are also keenly interested investigation of explosions and their suppression.

Both the American and Polish mining industries have common interest in dealing with explosions in parallel and interconnected entries. In American mining practice entries are connected by cross-cuts, of which the first is open, the second closed by a ventilation barrier, and the third closed by a dam made of blocks. (These dams could be made of conventional solid concrete blocks, foamed concrete blocks, or gypsum blocks whose joints are strengthened with mortar.) In deeper American mines, not being worked by longwall, the pillars that remain typically range from 24 by 24 m to 30 by 30 m in size; and for not-so-deep mines the remaining pillars are typically 18 by 18 m. Although in Polish mining practices do not use a configuration identical with the American one, there are parallel entries connected by cross-cuts. Thus there is common interest in investigating the course of an explosion in multiple-entries and ways of suppressing it.

To address some of these common research issues in characterizing and suppressing multiple-entry explosions, a joint research project, entitled "Coal Dust Explosion Control in Multiple-Entry Gate Systems of Underground Coal Mines," was initiated in July of 1990 under the Maria Sklodowska-Curie Joint Fund II and completed in December of 1993; the experimental program was conducted at "Experimental Mine Barbara" in Poland.

This research investigation was aimed at examining: (1) the course of explosions, especially weak ones, within a system of parallel entries, (2) the reaction of the SOLAR detectors to coal dust explosions, and (3) the possible use of triggered barriers to suppress weak explosions at intersections within a parallel entry-system.

Investigations performed at the Experimental Mine "Barbara" with the SOLAR batteries were directed mainly at verifying the explosion detector's suitable performance in conditions of weak coal dust explosions.

Limiting the range of damage from a dust explosion and suppressing the explosion in parallel workings connected by cross-cuts is difficult if not impossible with passive stone dust or water tub barriers. As an explosion gets underway a dynamic pressure wave connected with the explosion flame develops. Rarely is there sufficient dynamic pressure to put a barrier unit into operation when the unit is close to the origin of the explosion. The minimum distance for the units from the origin of the explosion is 60 m and the so-called optimal distance being between 100 and 120 m. Intersections provide pressure relief, thus diminishing the pressure available to act on the passive barrier unit.

Triggered barriers do not have the serious shortcomings associated with passive barriers. Triggered barriers can be located fairly close to the likely initiation point of an explosion. They do not need a dynamic pressure to put them into operation. They can be designed to disperse their inert contents across wide entries. The time required for explosion detection (more appropriately the time for triggering the dispersal of inert material) and the time for explosion-assisted dispersal of the barrier's extinguishant to form a cloud are two key factors. Some barrier units require up to 200 ms to form the cloud of inert material. There had been a reliability problem with some proposed explosion detectors. Furthermore, not all proposed dispersing systems would be acceptable in mining practice. A mine-worthy triggered barrier system is needed that leads self to easy deployment and re-deployment.

In various countries, the mine operators have relied on generalized rock dusting to combat coal mine explosions. However, the use solely of generalized rock dusting can be a problem. As has been well-documented and demonstrated, it is difficult to offset some high rates of dust deposition and float dust accumulations just using rock dusting. Triggered barriers offer the best hope in off-setting the shortcomings from generalized rock dusting and/or passive barriers. Although triggered barriers do require a

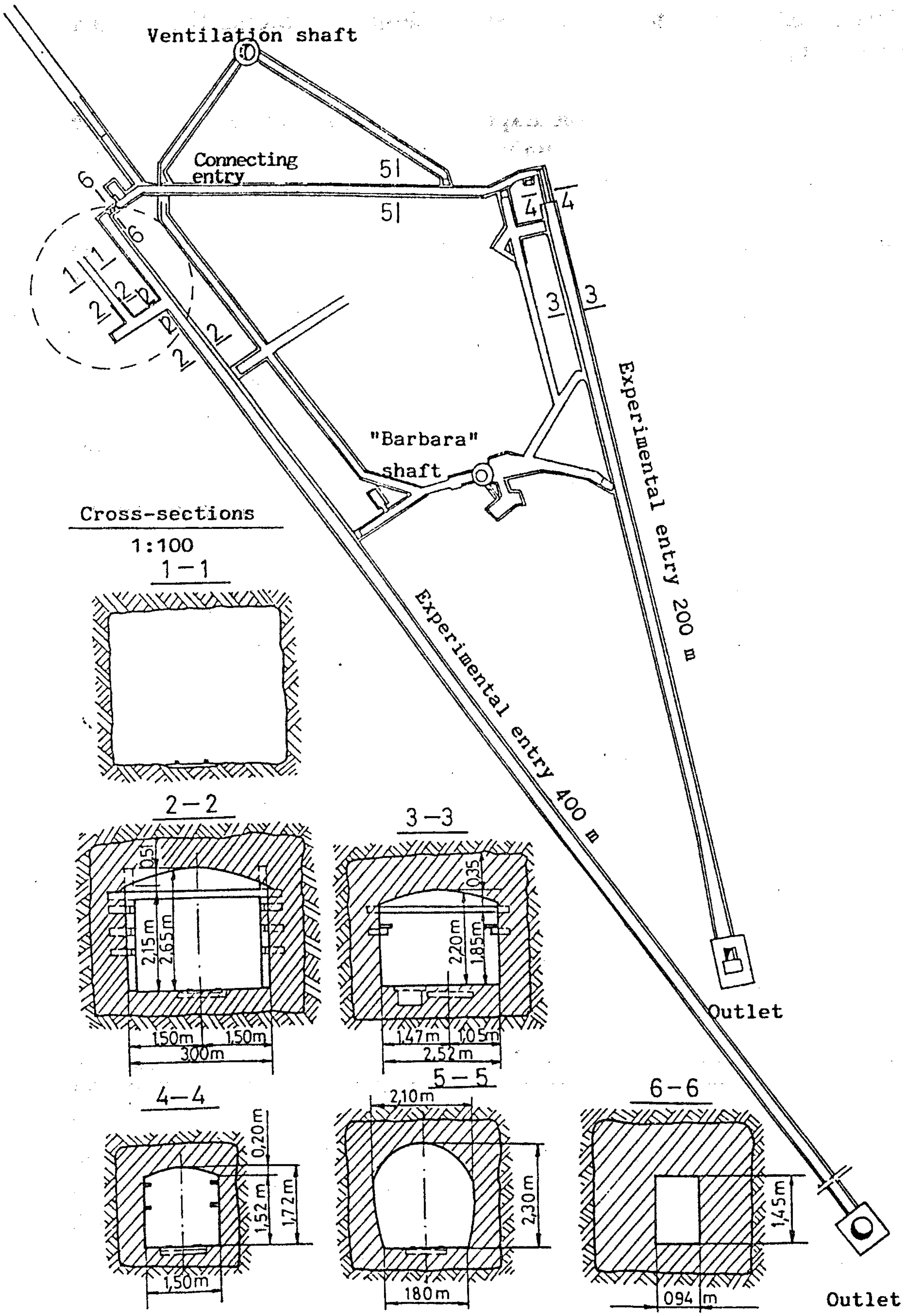

Fig.1. Scheme of experimental entries

maintenance effort, they are most attractive for use in a multiple-entry configuration with cross-cuts.

EXPERIMENTAL PROCEDURE

The tests were conducted in the 400-m underground experimental entry at the 46-m level of the experimental mine. Figure 1 shows a plan view of the workings at the 46-m level. At a distance of 34 m from the closed end, a drift of 11 m in length connects the "parallel" and "main" entries. The beginning of the "parallel" entry is 8 m from the cross-cut. The "parallel" entry is 54 m in length and the "main" entry is 400 m in length, with both entries having a cross-sectional area of 7.5 m^2. The place of the tests, as shown in Figure 1, is marked with a ring. The explosions were initiated at either the closed end of the "main" entry or at the end of the cross-cut, using methane (9.5 % methane in air) or a dust ignite (mortar with a 500 g black powder charge used to produce and ignite a "Barbara d 85" dust in air cloud with a 300 g/m^3 concentration.

The instrumentation in the 400-m "main" entry, "parallel" entry and cross-cut included (fig. 2):

- Flame sensors (18 in the "main" entry and 4 in the "parallel" entry and cross-cut for detecting flame arrival and determining flame arrival times;
- Piezoresistive pressure transducers (eight Kistler 4045-A10 and two 4045-A20) for measuring static pressure rises;
- Thermocouples (3) for measuring gas temperatures behind the flame front;
- Optical pyrometer (developed at EMB) for measuring explosion flame temperature; and
- Dynamic pressure sensor (developed at EMB) for use with static pressure rise to give total pressure connected with the gas flow.

The instrumentation lines were connected to a lower switching station (RKD). The data was transmitted through cables to the surface where the upper switching station (RKG) to the input side of a special connecting box. A loop oscillograph for registration of explosion parameter measurements was located nearby the connecting box. The computer station (KSAD) for data acquisition was attached to the output side of the connecting box. The HP 3852 Data Acquisition and Control System, accommodating up to 24

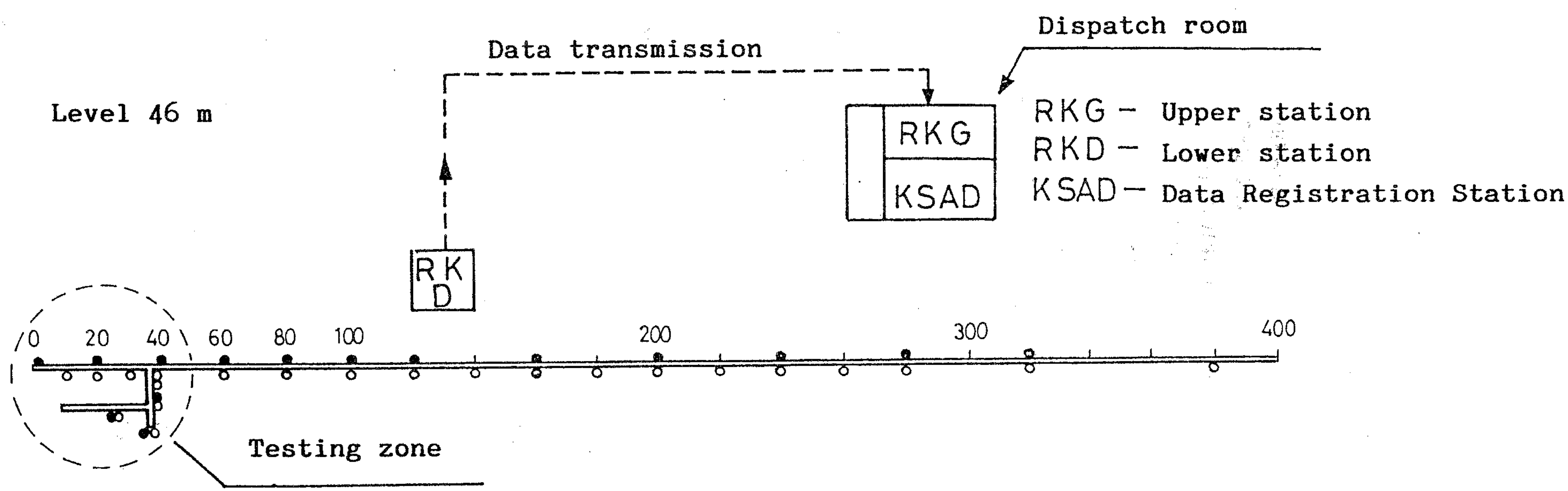

Fig.2 Scheme of measuring system and data transmission system.

data channels, which was produced by Hewlett Packard, constituted the basic unit of the KSAD station; it consisted of the following components (placed in a common housing):

- An acquisition and control unit,
- A high-speed voltmeter with buffer storage for 64,000 records with a sampling rate of 100,000/sec,
- A high-speed 24 channel multiplexer, and
- Serial interfaces, providing RS-232 and RS-422 capability.

For 24-channels, with a sampling time of 1 ms, the HP 3852 allows for the registration of events over a 2.5 s window of explosion events; and for slow explosion events the sampling time can be extended to accommodate a longer window of events without adversely affecting the precision of the results. The HP 3852 unit converts the analog signals to digital for storage.

- Control/Activator System for Mine Shot
- Explosion initiated from control desk of the dispatch room, For the KSAD data registration system, the electrical signal for the detonator's firing also provides the releasing pulse for activation of the data registration.
- The Control Desk provides controlling function for protective systems (dam locking, attachment of exploder), communication with servicing personnel preparing the mine for shot, providing security near outlets for shaft, and staffing rescue station. The initiation of the explosion follows directly after Initiating the alarm signal starts the explosion process by switching on the system which sends an electrical pulse to the detonator and simultaneously starts the data at zero on the time axis
- Program ENTRY written for the HP 3852 unit provides for all operations connected the setting of the data collection system, sensors, data entry transmission, and registration in the data base.

    + Info on kind of test being conducted,
    + Conditions of the experiment,
    + Degree of measuring system utilization,
    + Calibration of individual measuring systems

- At the moment explosion initiation, data is read into the HP 3852 memory.

- Immediately after the explosion the data is transferred from the HP 3852 memory through the HP-IB component and registered in the computer's memory. Once this transfer has been completed, the changes in physical parameters characterizing the explosion with time can be displayed on the PC's monitor. At this stage data for such things as the thermocouples and pyrometer can be processed.

- The commercially available software package enables the time dependent course for each explosion parameter to be displayed in a separate viewing window and processed. Digital filters were applied to refine the output from the sensors. DADiSP enabled an advanced analysis of the time dependent course for each data window to be performed. There is a display window for each of the 24 data channels.

SOLAR PANEL & PRESSURE SWITCH

- The solar panel, constructed from photo-voltaic cells, provides a reliable, simple, and inexpensive detector for use in triggered barrier systems (1). Not only does it function as a flame detector but it also provides the power to activate the triggered barrier system without requiring an external source of power. The solar panel takes the radiant energy (comprised of ultraviolet and far infrared components) from the explosion flame and converts it into electrical energy to activate the dispersal units in the triggered barrier system. No external power lines or batteries are needed; thus, the barrier system reliability is greatly enhanced.

- An explosion detector reacting exclusively to flame radiation is susceptible to different kinds of false light stimuli -- lighting elements and other sources of infrared radiation. An explosion detector reacting exclusively to a pressure increase is next susceptible to disturbances of mechanical type, as tremors, air jets, and so on. In an explosion there is both a rise in radiant energy and static pressure. The most "objective" explosion detector is a compound one – one that reacts to particular levels of flame radiation and static pressure increase; a detector hat simultaneously detects both greatly reduces the tendency for a false alarm -- detecting an event which is not a gas and/or dust explosion. Such a detector was designed by the USBM and is composed of an electrical converter of flame radiation, connected in series with a pressure switch, which feeds electrical power to the activation device in a triggered barrier system.
The power from a solar panel can be used to initiate a small explosive charge, which in turn, can start the dispersal of small to massive amounts of extinguishant, to form a cloud with which the explosion flame has to

interact. The extinguishing cloud may just act as an inert thing (which operates primarily by heat absorption), or act as a chemical action agent (which operates by removing free radicals from the flame), or act both in an inert and free radical "grabbing" manner.

- The Solec SM-25 Solar panels used in this study consisted of 48 (12x4) photoelements of 5 cm x 10 cm nominal surface; the size of the panel, including the frame is 698 x 368 x 9.5 mm; and the weight is 2.95 kg; the active surface area for the panel is 0.146 m^2. The flame temperature for dust explosions range between 1400 and 1900 K and for methane explosions the temperature range is 1500 to 2250 K. An analysis o f heat flux data conducted by the USBM showed that the dust flame temperature peaked in 250 ms to the value 1750 K and decayed rapidly behind the flame front.

  With 146 W of radiation the panel generates 20 W of electrical power at an efficiency of 13.7 %. The gas flame, being optically thinner that the dust flame, provides sufficient radiative power for the panel to enable the electrical output to fire a detonator. Even for a minimal flame temperature of 1400 K, the electrical power (at the 10 W level) is sufficient to fire a one W detonator.

- Because the casing of the pressure switches obtained from World Magnetics had a relatively weak air-tightness, the switching over of the contacts did not occur with a slight outer pressure increase. To get around this problem, Experimental Mine Barbara put the pressure switch into an additional casing, isolating the outer surface of the switch from the surrounding atmosphere; this enabled the switching over of the contacts by a pressure increase amounting to 5 to 7 kPa.

- To minimize damage to the SOLAR panels from repetitive explosions, they were covered by 3-mm thick sheets of organic (Plexi) glass. These they organic shields attached with a gasket to the panel frame could be easily cleaned and/or replaced. Registration of the signals from the SOLAR panel and other sensors in the investigation (test) zone was made with the help of a multi-channel loop oscillograph, having a 250 mm/s tape feed.

- In the evaluation of the performance of the SOLAR panel under conditions of weak coal dust explosions, up to five SOLAR panels were deployed in the main entry, "parallel" entry and the cross-cut.

- To enable the output from the SOLAR panel to be used to fire numerous detonators, a capacitive circuit was deployed to facilitate the storage of energy.

The example of Solar response is shawn on fig 3

RESULTS

The course of weak explosion in the parallel entry system was investigated in four tests.In all experiments the same nominal dust concentration was used. The varying factor was the energy of weak primary explosion.Their parameters are given in table 1.The strength of primary explosion is characterized by average value of static pressure and pressure pulse defined as integral $\int pdt$ for the pressure measured by the sensor placed in the primary explosion zone .

Table 1. The characteristics of primary explosions

test number	explosible mixture	volume of the mixture m^3	Pressure pulse kPa s	Average pressure kPa
CH 2437	9.5% CH_4	7.5 x 5.3 = 40	2.40	20.1
CH 2438	9.5% CH_4+ 2kg/m^3 coal dust	7.5 x 2.5 = 18.8	4.02	33.5
CH 2439	9.5% CH_4	7.5 x 1.85 = 13.9	1.82	14.0
CH 2441	10m of coal dust , 0.5kg/m^3	7.5 x 10 = 75	3.22	24.8

There are three distinctive paths of the flame:
- from the ignition source , along the drift and main gallery towards the open end
- from the ignition source , along the drift and main gallery towards the closed end
- from the ignition source towards the parallel gallery . Summary of tests results is given in the table 2

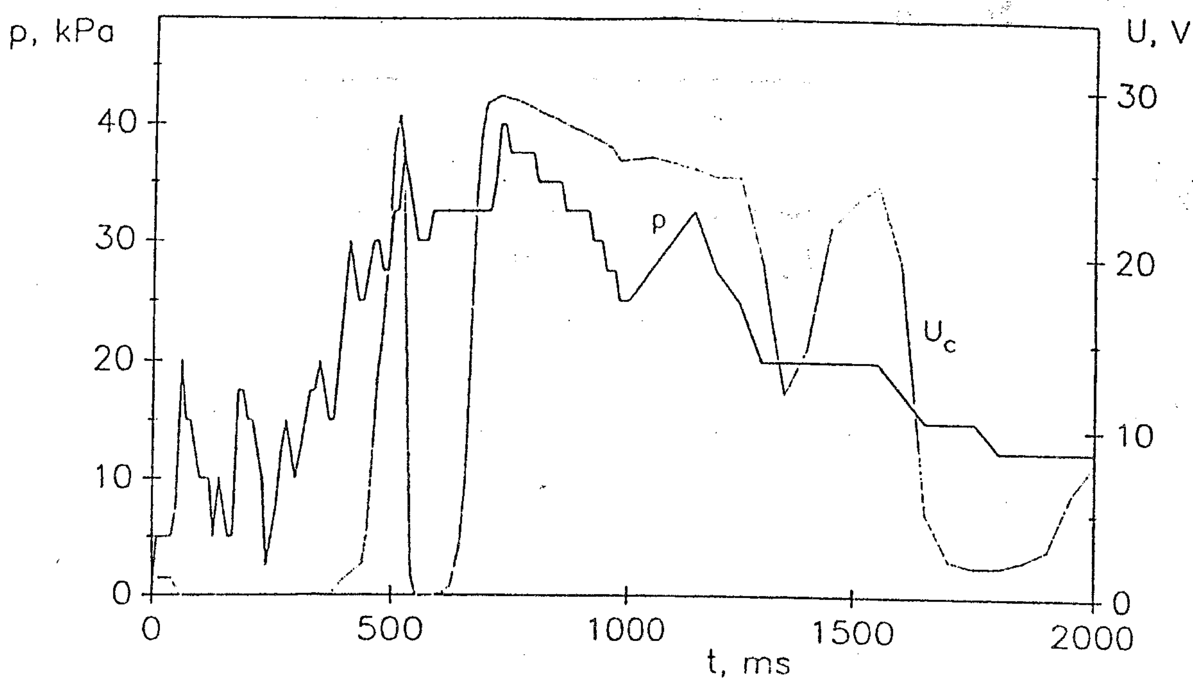

Fig.3. Explosion CH 2441, WI station , static pressure p and voltage Uc at 1000 V condenser, at SOLAR panel output through pressure switch.

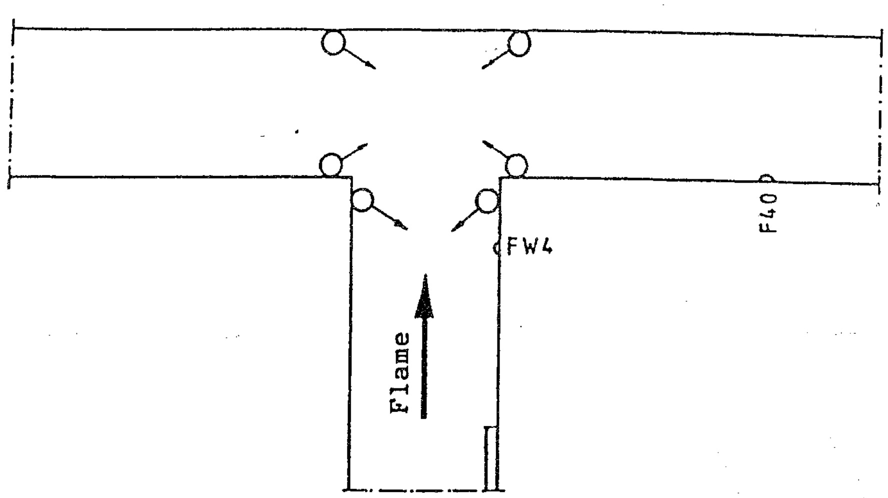

Fig.4. Scheme of water barrier (distribution of containers).

Table 2. The results of experiments with weak explosions

Test number	V_d m/s	maximum pressure in the drift kPa	maximum pressure in the parallel gallery kPa	maximum pressure at the main gallery face kPa	maximum pressure at the main gallery kPa
CH 2437	67.5	80.0	80.0	80.0	67.5
CH 2438	45.0	45.0	50.0	50.0	37.5
CH 2439	17.5	20.0	17.5	17.5	15.0
CH 2441	56	40.0	37.5	37.5	30.0

The value V_d is average flame velocity in zone 40 - 60 m from the closed end of gallery. This is the velocity with which flame leaves test site.Because of existence of blind gallery , the influence of reflected pressure wave could be expected.The analysis of the pressure course at the gallery cross - road revealed that flame propagation is not affected by abnormal pressure distribution.

There were three tests with triggered barriers performed. The Solar Panel with pressure switch was used as detector . The barrier itself was composed of six cylindrical plastic containers with volume of 30 liters each , filled with water placed at the cross - road (fig 4) To obtain proper directioning of the water dispersion the containers were cross cut.Water was poured to the plastic bags placed inside of the container. In each container the 0.5m long detonating cord was emerged.. The Solar Panel was placed in the drift at the distance of 10m from the geometrical center of the barrier.Two kinds of primary explosion were used:

- 10 m long zone with fine coal dust distributed uniformly on the floor , ignited by the 750 grams of gun powder from the cannon 9 (10m PII)

- as above , enforced with $20m^3$ of stoichiometric methane - air mixture

(hybrid mixture). Dust was distributed in small galleries and in the main gallery up to 80 m.The tests results are presented by set of two graphics showing separately the flame and pressure distribution. The delay between the first swelling (beginning of the barrier action) and flame arrival to the barrier location , marked by τ is the most important parameter , deciding on the barrier efficiency. The course of two explosions with 10mPII are shown on figures 5 and 6.In both cases the flame velocity between the detector and barrier was about 40m/s and the delay times were respectively 110 ms and 112 ms..Flame was detected at F40 station only, just round the corner of the main gallery.In the test with stronger primary explosion (figure 7) the

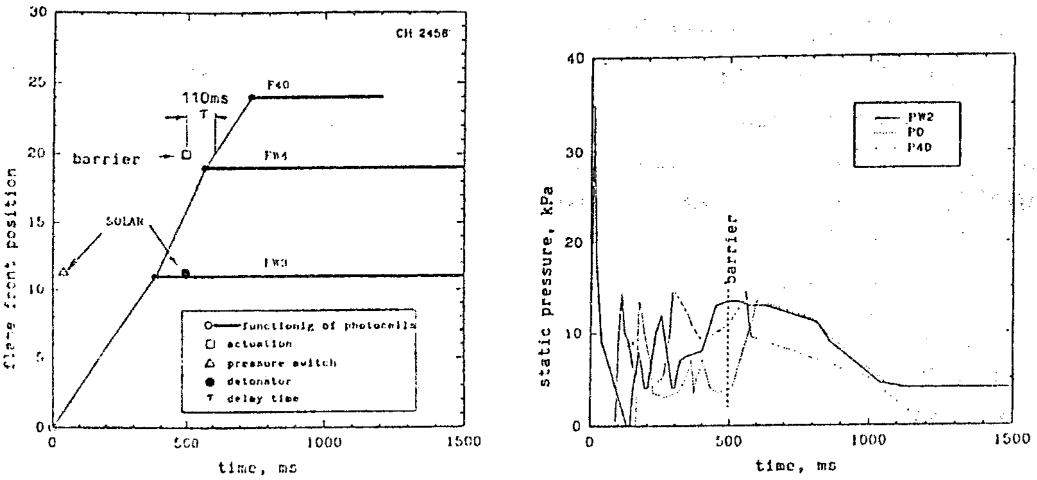

Fig.5. Suppression of coal dust explosion through water barrier steered by means of SOLAR detector,CH 2458 test
left: reach and duration time of flame
right: pressure course at three sides of the barrier (placed at the crossing)

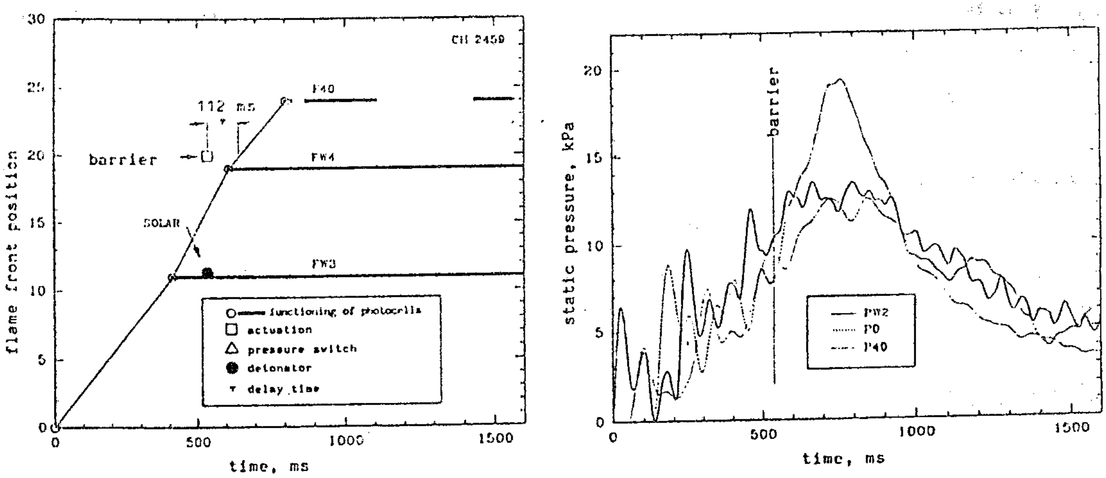

Fig.6. Suppression of coal dust explosion through water barrier steered by means of SOLAR detector,CH 2459 test
left: reach and duration time of flame
right: pressure course at three sides of the barrier (placed at the crossing)

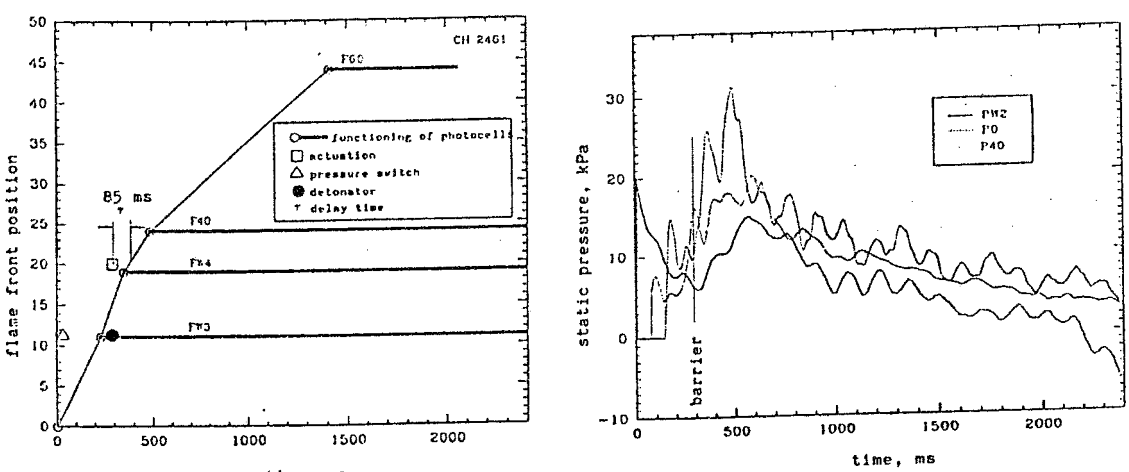

Fig.7. Suppression of coal dust explosion through water barrier steered by means of SOLAR detector,CH 2461 test
left: reach and duration time of flame
right: pressure course at three sides of the barrier (placed at the crossing)

respective flame velocity between detector and barrier was almost the same as previously (42.5m/s) but the delay was considerably shorter - 85ms.It is not enough to fill the whole gallery cross - section with water and consecutively the flame passed the longer path reaching station at 60m in the main gallery.The flame was extinguished further than in previous cases.It was probably because the flame radiation was less intense and then the energy needed to fire the detonators was reached later.The course of pressure shows that barrier efficiency is the same however in the third test the highest pressure growth , up to 33kPa was observed. It was due to the longer burning of coal dust resulting in pushing the flame into parallel gallery what was observed in previous tests.

CONCLUSIONS

Tests of dust explosions in a system of parallel entries of the EMB were successfully carried out. Tests were conducted with "points of initiation" being at the front of the main entry and in the cross-cut.

The DAS for the EMB which was upgraded by means of the HP 3852 significantly improved data acuisition and storage and through the use of DADiSP effective data processing (filtering, etc.) and data reduction was achieved.

Detailed testing of the SOLAR panel, determing its performance under conditions of weak coal dust explosion conditions was achieved for the initials being at the front of the main entry and in the cross-cut. An electronic system for formation of an output signal that enables the firing of more than one electric detonator was developed.

Investigations on triggered barriers with SOLAR panel in connection with water containers indicated the effectiveness of the system in the field of explosion suppression. From the test results, the advance time of action of the detonating fuse ahead of the flame front to the localization of the barrier location should not be smaller than 100 ms for weak coal dust explosions. This condition determines the location of the barrier regarding the possible place for the explosion initiation.

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