Research and analysis of monitoring records to determine the causes of the disaster in underground mining

S Trenček and A Kozłowski
EMAG, Institute of Innovative Technologies, Leopolda 31, 40-189 Katowice, Poland
E-mail: stanislaw.trenczek@ibemag.pl; a.kozlowski@ibemag.pl

Abstract. At the beginning, several catastrophe events were recalled, occurring in underground mines, whose causes and circumstances were determined by a special commission appointed by the President of the State Mining Authority. Then, the range of registration of rockmass and air parameters in the case of natural hazards was discussed. On the example of the disaster at the Borynia-Zofiówka-Jastrzębie coal mine, the scope of research and analysis of the seismo-acoustic and micro-seismic systems, as well as mine air monitoring for the content of methane and carbon monoxide, were discussed. There was emphasized the importance of research results and analyses in determining the causes and circumstances of events and final conclusions were cited.

1. Introduction

Exploitation in underground mining plants is constantly associated with the risk of occurrence of catastrophic events. The increasing depth of exploitation works contributes to this - the deeper, mining and geological conditions are more difficult. This applies to all types of mining, including hard coal and copper ore mining.

Every disaster event is analyzed in terms of circumstances and causes of occurrence. In the last 10 years, the President of the State Mining Authority, pursuant to his powers, established special post-accident commissions, after events like [1]:

- 2009 - methane explosion in the Wujek coal mine - 20 fatalities, 25 heavy accidents, 9 light accidents,
- 2009 - unprecedented (in copper ore mines) discharge of gases and rocks at the Rudna copper ore mine - flooded excavation at the length of approx. 70 m,
- 2011 - methane explosion in the Krupiński coal mine - 3 fatalities, 9 heavy accidents, 2 light accidents,
- 2014 - methane explosion in the Mysłowice-Wesoła coal mine - 5 fatalities, 15 heavy accidents, 10 light accidents,
- 2015 - rock burst in hard coal mine - 2 fatalities,
- 2016 - methane explosion and construction disaster of the pit-head building in the liquidated Murcki coal mine - 1 fatality,
- 2016 - rock burst at the Rudna copper ore mine - 8 fatalities, 21 light accidents,
- 2018 - rock burst at Borynia-Zofiówka-Jastrzębie coal mine - 5 fatalities, 2 light accidents.

Depending on the type of event, the committees carry out appropriate research, analyzes. Sometimes also scientific experiments are carried out. Most often, these studies are related to the course of geophysical and geomechanical phenomena (in the case of rock mass tremors resulting in relaxation or...
rockburst), the course of gasogeodynamic phenomena (in the case of squealer and rock outburst, methane explosion, coal dust explosion), the course of aerological phenomena (in the case of endogenous fire). Sometimes there are examined the technological processes (mining, transport, drainage, ventilation), the correctness of the implementation and proper use of excavation workings (in the case of an embankment, collapse, rock mass tremor), the efficiency and condition of machines and electrical equipment.

The most important matter after explaining the causes and circumstances is to define such recommendations for mining entrepreneurs, which will avoid similar events in the future.

2. Control and registration of parameters in underground mines
In underground mines, it is carried out control and registration of these parameters, which demonstrate the level of safety and/or the level of threats. Usually it is called as monitoring, which concept is clearly associated with protection, security, but also with measurements and gathering information on various topics. Thus, it can be concluded that monitoring in the field of security is regular observation or measurement of a specific phenomenon for a certain period of time, as well as constant observation of people and property at risk to protect against the occurrence of any dangerous phenomenon.

In underground mines, monitoring systems are designed to constantly control the most critical places - usually specified by law - and react immediately to the emerging danger. Such controls relate to the geosphere, atmosphere and technosphere. The geosphere is monitored by a microseismological system and a seismoacoustic system. The control of the atmosphere by automatic mining aerometry [4] is more extensive, which consists of:

- in each underground mining plant: gasometry (measurements of basic gas concentrations - O₂, CO₂, CO, CH₄ - and control of the presence of smoke in the mine air), anemometry (measurements of air velocity), thermo-hygrometry (measurements of air temperature and humidity and rock mass temperature), barometers system (measurements of barometric pressure on the surface and underground, differential pressure measurements, including air-stopping, measurements for determining atmospheric pressure characteristics of the exploitation area, measurements and determination of aerodynamic potential),
- in mines with existing methane hazard - in addition: automatic methanometry (measurement of CH₄ concentration along with the safety-off function - after detection of a concentration above the limit), extensive gasometry (measurements of the methane-gas mixture, i.e. methane and other gases concentration, temperature and humidity and determining the size of the methane removal, the balance of demethanization, as well as the measurement of the parameters of the inert gas, i.e. expenditure, balance).

The structure of natural hazard monitoring systems is characterized by the following:

- in the bottom part:
  - enables: installation of devices for measuring parameters in places indicated in safety regulations and in the other - designated by the manager of the ventilation department of a mine, using two-state sensors and the use of devices equipped with outputs for automatic control (switching off) of machines and electrical devices,
  - has: intrinsically safe construction (enabling their continuous operation regardless of the concentration of methane in mine workings),
  - meets the requirements of electromagnetic compatibility,
  - has a continuous power supply, also when the underground power network is switched off due to operational reasons or due to increased methane hazard,
- in the surface part - it allows:
  - current visualization of measurement data,
  - signalling of pre-alarm (warning) and alarm states,
  - two-state control of underground power and signal devices,
  - cooperation with dispatcher support systems, by providing measurement data,
integration with alarm systems to automatically notify crews working in the affected area by generating alarm signals,
• integration with geophysical systems to enable the implementation of automatic leading power shutdowns in areas where energy tremors could have caused a rapid outflow of methane,
• data archiving and reporting.

For recreating the conditions preceding an event, the archived data plays the most important role.

In the event discussed in the article, i.e. rock mass and rock burst, which occurred on 5 May 2018 at 10:58, in the H-part of the 409/4 seam of the Borynia-Zofiówka-Jastrzębie coal mine - figure 1, the archived data served to clarify doubts about the initial which caused such a high-energy rock mass tremor.

Figure 1. Map of the H-part on seam 409/4 of the Borynia-Zofiówka-Jastrzębie mine [3].

In the H-part, in the area of hollow galleries - figure 2 - there was an impact of the rock mass with energy $E = 2.9 \cdot 10^9$ J. In addition to the rock burst, this tremor also caused 5 fatal accidents and 2 light accidents.
3. An example of explaining the causes and circumstances of a disaster in an underground mine

3.1. Analysis of monitoring systems records
To explain the causes and circumstances of this rock burst, the President of the State Mining Authority appointed a special commission whose task was to [5]:

- determination of the high-energy mechanism of rock mass tremor and the premises of this tremor,
- analysis of methane hazard, in the context of a tremor and rock burst,
- preparation the opinion on the impact of mining works on seismicity in the area of the existing rock mass tremor.

During the work of the commission, it turned out that more or less at the same time as the rock mass tremor and rock burst occurred, in the coal face of one of the hollow galleries, shooting was to be made using 7.5 kg of explosive material. After loading the blasting holes with explosive material, arming their igniters and after connecting them to the blasting line, all the miners should retreat from this coal face and from the special rockburst threat zone to launch explosives from outside. From a telephone conversation, conducted by a mine dispatcher at the Mine Geophysics Station with an employee employed in that coal face, it was apparent that before the blasting operations were carried out, they would be formally reported to the Mine Geophysics Station. However, until the tremor of the rock mass occurred, these blasting operations were not reported and the workers were killed. Therefore, there was a doubt as to whether the explosive was actually launched, which could have been the initial tremor of the rock mass.

The President of the State Mining Authority, in order to clarify these doubts, commissioned the Institute of Innovative Technologies EMAG in Katowice, which specializes in this type of expertise, conducting relevant research. Their aim was to answer the question of whether or not a blasting project took place?

The first step was to obtain data from the period from 25/04/2018 to 06/05/2018 - i.e. before the collapse, archived by the monitoring systems operating in this mine:

- ARAMIS M/E system - in the field of microseismological observation,
- ARES 5/E system - in the field of seismoacoustic observation,
- CST-40 system - in the field of automatic CO-metry,
- SMP-NT/A system - in the field of automatic methane detection.
There were analyzed the documents such as maps of the seam 409/4 and higher seams, reports on seismoacoustic activity - shift reports (hourly), "Comprehensive project for the exploitation of seams threatened with rock bursts at KWK Borynia-Zofiówka-Jastrzębie for 2016-2018", map mining areas subjected to exploitation of coal seams by the Borynia-Zofiówka-Jastrzębie mine with sensors of microseismic and seismoacoustic systems - figure 3, ventilation diagram of the H-part with methane and carbon monoxide measurement sensors - figure 4, diagrams (descriptions) of gasometric and telemetry protections, records documenting tremors occurring in the analyzed period, as well as registration of reports of blasting works to Mine Geophysics Station from this period.

The first, analysis was made of 23 performed blasting works in hollow galleries in the H-part of the 409/4 seam, which caused rock mass tremors, in order to be able to compare the characteristics of their effects with the effects caused by high-energy impact of the rock mass causing the rock burst. The greatest energy was triggered by torpedo shooting - $E = 7.4 \cdot 10^4$ J, whose effects are shown in figures 5 and 6.

![Figure 3. Areas of exploitation carried out by the Borynia-Zofiówka-Jastrzębie mine with the applied sensors of microseismological and seismoacoustic systems [3].](image-url)
Figure 4. The ventilation diagram of the H-part of the seam 409/4 with the methane measurement sensors (MM ...) and carbon monoxide (M ...) [3].

Figure 5. A fragment of the "Hourly Report" for the period 30/04 - 06/05/2018, detailing the tremor record after the torpedo shooting - detail A [3].
Performing shooting or torpedo shooting generated methane from the rock mass, mainly from the coal seam 409/4, in which the excavations were drilled, and carbon monoxide was generated as a product of a fired explosive.

Comparing the record of microseismic phenomena after torpedo shooting - figure 5 - to record high-energy tremor - figure 7 - it can be concluded that these records are radically different. The CH$_4$ concentration changes recorded after the current rockburst are also quite different - the example is shown in figure 8 - in relation to the records after the torpedo shooting - figure 6.

Regarding the measurements of CO concentration after rockburst, only CO sensors M712 and M730 (figure 3) still had an efficient data transmission, which is why there were the reference point in the conducted analyzes. It resulted from them that after rock burst the increases in CO concentration were 15 ppm (M712) and 8 ppm (M730) - figure 9 - and were similar in character, but not in quantity, to changes caused by torpedo shooting - figure 6. They were very similar to the changes caused by standard blasting works, in which 7.5 kg of explosive were consumed. An example of such changes is shown in figure 10 - CO increments were 13 ppm (M712) and 8 ppm (M730).
Figure 7. Record of the rockmass tremor occurring on 05/05/2018 at 10:58:07 in the Borynia-Zofiówka-Jastrzębie mine [3].

Figure 8. Indications of the methane detector MM-187 in the period before and after the rockburst on 05/05/2018 [3].
From the above analysis, two preliminary conclusions could be written. The first, that the characteristics of the rock burst, registered by the microseismological observation system and the automatic methane-metanometry system, do not confirm the hypothesis about the firing shooting, which could be the cause of the rock burst. This does not confirm the hypothesis about the firing shooting. The second conclusion indicates that changes in CO concentration after rock bursts recorded by the active sensors M712 and M730 are very similar to the changes taking place after firing shots, which could confirm the hypothesis about the mining shooting, which caused rock mass and rock burst.

3.2. Analysis of geological and mining conditions
In order to explicitly refer to changes in CO concentration registered by the M712 and M730 sensors, the analysis of effects of other tremors - that is changes in CO concentrations on all sensors, which were not a consequence of blasting works - was performed first.

Analyzing the archival records during the analyzed period, several examples could be found for the occurrence of spontaneous tremors, which also generated carbon monoxide, although in much smaller concentrations - an example is shown in figure 11. There were cases where CO was generated in the whole H-part, because on each sensor there was an increase in CO, there were also those that generated a CO increase only on the M712 and M730 sensors, and also such that they generated an increase only in the area of hollowing excavations.
Then, the geological and mining conditions in the H-part in all coal seams were analyzed. It turned out, among others, that the H-part is bounded by three faults with a spreading range of 10 to 50 m. In addition, a 409/3 seam (in a large part after exploitation) above deck 409/4 is located. This meant that there could be various gases in the goaf, including CH$_4$ and CO.

Such high tremor energy - $E = 2.0 \cdot 10^9 \text{ J}$ - had to unseal the rock mass in the H-part and to migrate the gasses from goaf seam 409/3 to the excavations in the 409/4 seam. These excavations, despite partial destruction after rockburst, were subjected to the depression of the main ventilation fan. The proof for this was the generation of CH$_4$ in the amount of 545,000 m$^3$ [2]. Therefore, it is not difficult to imagine that CO was generated in the same way. The increase of CO concentration to the maximum value of 15 ppm recorded by the M712 sensor, and then the smaller and smaller values allowed to calculate the total amount of CO generated after the tremor - it was about 96 m$^3$CO. Therefore, the hypothesis that the blasting works were unconfirmed could be unambiguously stated.

4. Summary
An unambiguous explanation of the causes and circumstances of mining disasters requires a whole range of studies and analyzes carried out as part of the work of special post-accident commissions appointed by the President of the State Mining Authority.

An example of an event that occurred on May 5, 2018 at 10:58 in the "Borynia-Zofiówka-Jastrzębie" coal mine shows how tectonic disturbances and exploitation carried out in the above mentioned seam affect the balance and stability of the rock mass and the threat of rockburst.

Archiving of gas concentration records made by monitoring systems allows to conduct research and analyzes allowing to interpret the course of events and to prove or negate previously accepted hypotheses related to doubts about the course of mining works in a given region.

The high energy impact of the rock mass with extremely high energy - $E = 2.0 \cdot 10^9 \text{ J}$ - causes the destruction of the rock mass structure and allows the flow of gases to the workings subjected to depression of the main ventilation fan.

5. References
[1] Dokumentacja Wyższego Urzędu Górnictwa: BHP w górnictwie – Statystyki – opisy wypadków http://www.wug.gov.pl/bhp – 26.10.2018 r.
[2] Szlązak N and Trenczek S 2018: Analiza zagrożenia metanowego, w kontekście tąpnięcia ze skutkami w wyrobiskach wykonanych w pokładach 409/3 i 409/4, zaistniałego w dniu 5.05.2018 r. o godzinie 10:58 w JSW S.A. KWK „Borynia-Zofiówka-Jastrzębie” Ruch
„Zofiówka”, uwzględniająca stosowane metody prognozowania oraz działalność profilaktyczną. (Kraków: Documentation of the Faculty of Mining and Geoengineering AGH University of Science and Technology)

[3] Trenczek S 2018 Analiza wskazań czujników telemetrycznych zabudowanych dla obserwacji aerologicznych i sejsmicznych w rejonie wstrząsu o energii zaistniałego w dniu 5.05.2018 r. o godzinie 10:58, który spowodował tąpnięcie ze skutkami w wyrobiskach wykonanych w pokładach 409/3 i 409/4 w JSW S.A. KWK „Borynia-Zofiówka-Jastrzębie” Ruch „Zofiówka”, w aspekcie określenia przyczyn zmian ich sekwencji przed i po zaistniałym tąpnięciu, przy uwzględnieniu aktywności sejsmicznej, w tym powodowanej robotami strzałowymi. (Katowice: Documentation of the Institute of Innovative Technologies EMAG)

[4] Trenczek S 2005: Mechanizacja i Automatyzacja Górnictwa 43 (3) 11

[5] Zarządzenie Nr 41 Prezesa Wyższej Urzędu Górniczego z dnia 7 maja 2018 r. w sprawie powołania Komisji do zbadania przyczyn i okoliczności tąpnięcia oraz wypadku zbiorowego, zaistniałych w dniu 5 maja 2018 r. w Jastrzębskiej Spółce Węglowej S.A. KWK „Borynia–Zofiówka–Jastrzębie”, Ruch „Zofiówka” w Jastrzębiu-Zdroju. Dz. Urz. WUG poz. 100