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# TRANSIENT STATES OF AIR PARAMETERS AFTER A STOPPAGE AND RE-START OF THE MAIN FAN

# STANY PRZEJŚCIOWE PARAMETRÓW POWIETRZA PO POSTOJU I ZAŁĄCZENIU WENTYLATORA GŁÓWNEGO

A stoppage of the main ventilation fan constitutes a disturbance of ventilation conditions of a deep-mine and its effects can cause serious hazards by generating transient states of air and gas flow. Main ventilation fans are the basic deep-mine facilities; therefore, under mining regulations it is only allowed to stop them with the consent and under the conditions specified by the mine maintenance manager. The stoppage of the main ventilation fan may be accompanied by transient air parameters, including the air pressure and flow patterns. There is even the likelihood of reversing the direction of air flow, which, in case of methane mines, can pose a major hazard, particularly in sections of the mine with fire fields or large goaf areas. At the same time, stoppages of deep-mine main ventilation fans create interesting research conditions, which if conducted under the supervision of the monitoring systems, can provide much information about the transient processes of pressure, air and gas flow in underground workings.

This article is a discussion of air parameter observations in mine workings made as part of such experiments. It also presents the procedure of the experiments, conducted in three mines. They involved the observation of transient processes of mine air parameters, and most interestingly, the recording of pressure and air and gas flow in the workings of the mine ventilation networks by mine monitoring systems and using specialist recording instruments.

In mining practice, both in Poland and elsewhere, software tools and computer modelling methods are used to try and reproduce the conditions prior to and during disasters based on the existing network model and monitoring system data. The use of these tools to simulate the alternatives of combating and liquidation of the gas-fire hazard after its occurrence is an important issue. Measurement data collected during the experiments provides interesting research material for the verification and validation of the software tools used for the simulation of processes occurring in deep-mine ventilation systems.

**Keywords:** mining aerology, coal mine ventilation, transient ventilation conditions in deep-mines, recording air parameters in a monitoring system

Wyłączenia wentylatora głównego stanowią zburzenie warunków przewietrzania kopalni głębinowych, a jego skutki mogą powodować poważne zagrożenie generując stany nieustalone przepływu powietrza

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i gazów. Wentylatory głównego przewietrzania stanowią podstawowe obiekty podziemnych zakładów górniczych stąd w przepisach górniczych zatrzymanie wentylatora głównego może nastąpić jedynie za zgodą i na warunkach określonych przez kierownika ruchu zakładu górniczego. Wyłączeniu wentylatora głównego mogę towarzyszyć stany nieustalone parametrów powietrza, w tym rozkładu ciśnień i rozpływu powietrza, a nawet możliwość odwrócenia kierunków przepływu powietrza co w przypadku kopalń metanowych może stanowić poważne zagrożenie szczególnie w rejonach kopalni, w których występują pola pożarowe czy rozległe przestrzenie zrobów.

Równocześnie zatrzymanie wentylatora głównego w kopalniach głębinowych stanowią interesujące eksperymenty badawcze, a prowadzone pod kontrolą systemów monitoringu dostarczają dużo danych o procesach przejściowych ciśnienia, przepływu powietrza i gazów w wyrobiskach podziemnych.

W artykule przedstawiono obserwacje parametrów powietrza w wyrobiskach kopalni w czasie eksperymentów zatrzymania wentylatora głównego. Omówiono sposób przeprowadzenia eksperymentów w trzech kopalniach, w czasie których obserwowano procesy przejściowe parametrów powietrza, a w szczególności rejestrowano ciśnienia i przepływy powietrza oraz gazów w wyrobiskach sieci wentylacyjnej kopalni w kopalnianych systemach gazometrii oraz za pomocą specjalistycznej aparatury.

W praktyce górniczej zarówno w kraju jak i za granicą coraz częściej wykorzystuje się narzędzia programowe i metody symulacji komputerowej do próby odtworzenia warunków przed i w czasie katastrof w oparciu o aktualny model sieci oraz dane z systemów monitoringu. Ważnym zagadnieniem jest również wykorzystanie tych narzędzi do symulacji wariantów zwalczania i likwidacji powstałego zagrożenia metanowo-pożarowego po zdarzeniu. Zebrane w czasie eksperymentów dane pomiarowe stanowią interesujący materiał badawczy do weryfikacji i walidacji narzędzi programowych wykorzystywanych do symulacji procesów w systemach wentylacji kopalń głębinowych.

**Słowa kluczowe**: aerologia górnicza, wentylacja kopalń węgla kamiennego, stany nieustalone przewietrzania kopalń głębinowych, rejestracje parametrów powietrza w systemie gazometrii

## 1. Introduction

Transient states of the mine ventilation process are caused by natural factors and usually happen at random, or occur as a result of a change in the operation mode of ventilation devices during adjustment or experiments (Wasilewski, 2005). Under certain conditions, transient states are characterised by sudden changes in air and gas pressure and flow conditions, often with large amplitude. Such changes may be periodic (Bystroń, 1961; Trutwin, 1968) (e.g. during the so-called fan pumping) or have the qualities of transient flow, i.e. flow in which, in consequence of minor disturbances to flow conditions, major uncontrolled changes occur in pressure and flow velocity in the mine ventilation system (Kruszyński & Trutwin, 1972). Transient states with the properties specified above are particularly likely to occur during the start or stoppage of a fan, with mine characteristics changing because of the opening and closing of the gate (Litwiniszyn, 1997; Trutwin et al., 1997).

The existing studies (Krawczyk, 1994; Trutwin, 1968, 1972) also provide numerical methods, including computer simulation methods, which can be used for the analysis of the discussed phenomena in such complex actual conditions, as those in the fan station and the mine ventilation systems. However, wider application of the simulation methods in mining practice has so far been limited by the lack of data necessary to verify them, as the data can only be obtained through experiments in a mine. Earlier observations of this type of transient states and their consequences in an actual mine ventilation system were impossible because of the lack of appropriate control and measurement equipment. Only the use of data recorded in mine monitoring systems (Wasilewski, 2005; Dziurzyński et al., 2011a, 2011b) and specialist equipment (Wasilewski, 1996) allowed for recording air parameters during such experiments on the scale of the entire mine.

Relatively simple transient states were registered while stopping and starting the main fan. In mine ventilation, such states are treated as an emergency and their effects, particularly in gassy mines, may cause serious hazards. This is why the most interesting thing about the observation of the stopping and starting of the main fan were the scope of the disturbances that occurred, as well as the reach and signals of their propagation in the underground workings. Thanks to the continual registration of air parameters, the effects of fan stoppage could be observed, in particular transient states of ventilation parameters in the mine's excavations, including absolute pressure, air flow velocity and the concentration of methane and carbon monoxide. The concentration of gases is particularly interesting because of the possibility of the direction of air flow changing in longwalls with wide goaf areas. Experiments consisting in stopping and re-starting the main fan are especially difficult in gassy mines and may only be conducted under close supervision of the mine services. As a fundamental mine facility, the functioning and operation of the main ventilation fan is regulated under special provisions of mining law. Therefore, the procedure for stopping a main fan is also regulated in detail, for example in the following sections of mining regulations:

***§ 151. 1.*** *A change of the operating parameters of a main fan or a stoppage thereof may take place solely with the consent and under conditions specified by the mine maintenance manager.*

…

***§ 152. 1.*** *In the event of a breakdown stoppage of a main fan lasting for at least 20 minutes:*

1) *all work shall be suspended;*
2) *equipment shall be switched off in methane fields with methane hazard levels II–IV;*
3) *staff shall be directed to downcast shafts or to the surface.*

***2.*** *The mine maintenance manager shall specify the procedure referred to in paragraph 1 above in the rescue scheme.*

The registration of air parameters during unstable fan operation, as well as an experiment consisting of stopping and re-starting a fan using specialised equipment were conducted (Wasilewski, 2005) in the closed mine Barbara-Chorzów and during the stoppage of a fan at ZG Bytom III while converting an upcast shaft into a downcast shaft (Wasilewski & Stradowski, 2002). Using the mine monitoring system, pressure in excavations and air flow velocity were registered. Another interesting main fan stoppage experiment took place in the mine Żory (Niezgoda, 2000). Its aim was to observe, using the mine's monitoring system and specialised equipment, the changes in air parameters such as pressure, air flow direction and methane concentration on the boundary between two mines.

The article discusses an instance of stopping and re-starting the main fan in shaft III at the mine Wujek – Śląsk as part of a controlled experiment. The observations of the experiment, from the monitoring system, provided a great deal of data for the verification and validation of the software tools **Ventgraf** and **VentZroby** (IMG-PAN Report, 2011) .

## 2. Fan stopping and restarting in the closed mine *Barbara-Chorzów*

The aim of the experiment was to register the air parameters while stopping and re-starting the main fan. One interesting finding was the scope and signals of air parameter changes in remote points of the network. The examination of transient states caused by stopping and re-starting the fan in the network showed differences in the distribution of parameters during the slowdown after the fan was switched off compared to the start-up after switching on. During start-up, the fan needs to move substantial masses of air in the network and therefore the duration of transient conditions in this case is much longer.

In the experiment, absolute pressure was recorded in the ventilation channel and several underground working network points at the level of 630 m. The measurement signals were saved in the data logger memory using a Campbell Scientific digital multi-channel data recorder (Wasilewski, 1996) at 1-second intervals.

In the fan channel at the upcast shaft *Zygmunt August II* on the surface, the equipment recorded the values of absolute pressure (B1) and air velocity (V1). Underground, at the level of 630 m on the bottom of the downcast shaft *Kolejowy*, i.e. the most remote accessible point of the mine, air pressure (B3) was recorded. The location of the measurement equipment is presented in Fig. 1.

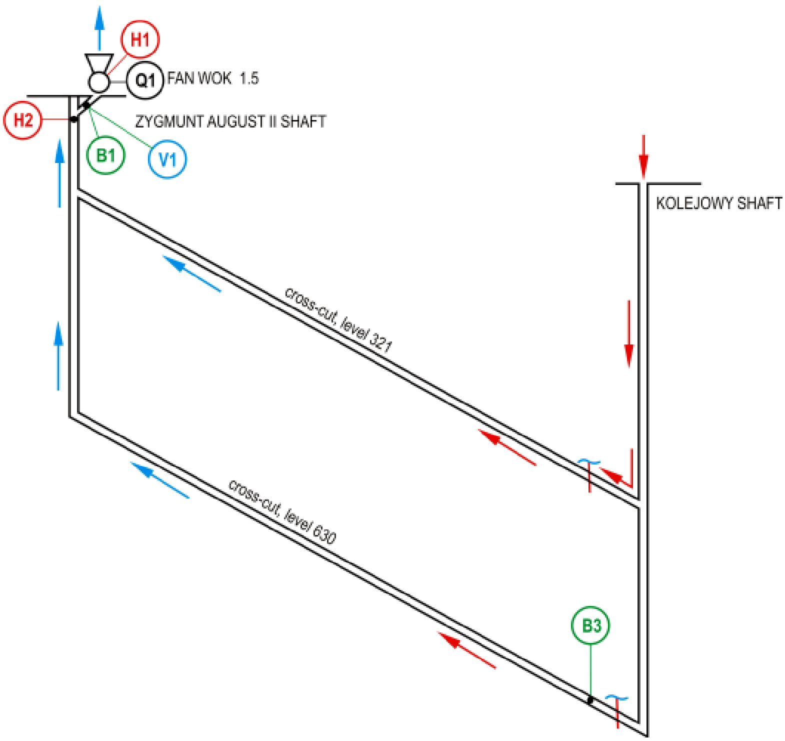


Fig. 1. Location of measurement points during the experiment

***The course of the experiment and its results***

The experiment consisted of the intentional stopping and re-starting of the main fan to observe the accompanying transient states of air pressure and velocity. The ordinary procedure for the start-up of a main fan is that its flaps are closed so that it is not under the load of the network. In this event, because of the small size of the network, the procedure was not observed and the fan was started under the load of the network. This meant that from the very start-up, the fan had to set the air in the underground workings in motion; once stopped, during its slow-down phase, it had to stop the air in the network. The mine's ventilation network was relatively small, therefore the transient states of air parameter had a relatively short duration and the specified ventilation conditions could be reached quickly.

The transient states while starting and stopping the fan showed (Fig. 2) that transient air pressure oscillation during fan start-up was slower than when it was stopped. This means that after stopping the fan, flow conditions stabilise more quickly than during start-up. The load of the network makes it more difficult for the fan to set the masses of air in the underground workings in motion than to stop them. For this reason, the time of start-up is shorter then the time of slowing down and stopping. Another observation was that transient states of air velocity are heavily disturbed. Also, changes in flow direction after stopping the main fan cannot be excluded.

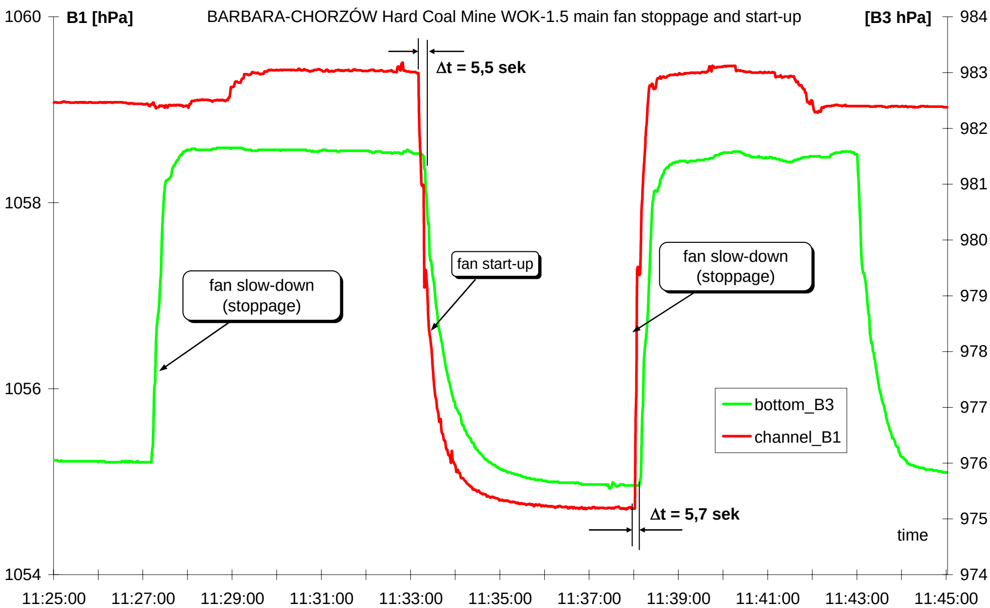


Fig. 2. Transient states of air pressure recorded during main fan stoppage and re-start at the closed mine Barbara-Chorzów (Wasilewski, 2005)

Fig. 3 is a comparison of pressure changes in the fan channel (B1) and pressure changes recorded underground (B3). There are clear differences between the curves representing start-up and stoppage conditions. Fan start-up, with pressure changes recorded in the channel and

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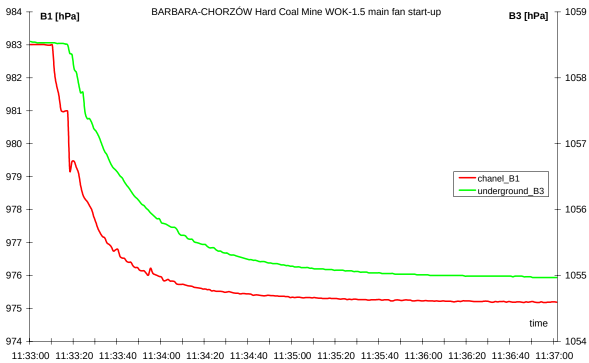


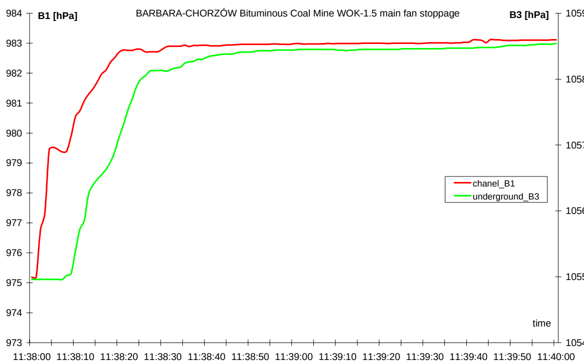

b)



Fig. 3. Transient states of air pressure recorded while starting (a) and stopping (b) the main fan

the workings (air masses in the working network), is much slower (it lasts for approximately one minute), while pressure stabilisation after the fan stops is quicker and only lasts for several dozen seconds.

A comparison of the transient states for the pressure recorded in the fan channel (B1) and underground (B3) during the start-up and the stoppage of the fan shows a clear delay of the recorded pressure signals. The delay time for the start-up in the graph is $\Delta t = 5.6$ s, with pressure drop in the shaft equal to $\Delta p_4 = 715$ Pa and underground – $\Delta p_1 = 390$ Pa. The analogous values for the time after the fan stopped are as follows: delay $\Delta t = 5.5$ s; pressure increase in the shaft: $\Delta p_4 = 770$ Pa; pressure increase underground: $\Delta p_1 = 345$ Pa. This means that the delay in each case is the same while the stabilisation times (time constant) for start-up and stoppage are different.

## 3. Transient states of air parameter after fan stoppage at the mine *Bytom III*

The restructuring of the Polish mining sector have lead, amongst other things, to the simplification of network structures and the exclusion of a part of underground workings from the ventilation systems. In some cases, this has lead to switching main fans off and the liquidation of shafts or the conversion of upcast shafts into downcast shafts. Such change was implemented at the mine Bytom III, where the function of the shaft Jan was reversed. This conversion, as well as the resulting changes in air distribution in the ventilation network improved the climatic conditions in the area of functioning longwalls.

Thanks to the recording of air parameters, the effects of fan stoppage could be observed, particularly transient ventilation conditions in the mine's workings, including absolute pressure, air velocity, methane and carbon monoxide concentration, etc. The latter was interesting because of the transformation of the ventilation system and the flow direction in a longwall with wide goaf areas.

***Transient states of air parameters after the conversion of the Jan shaft***

On 24 November 2001, a major change was introduced in the ventilation system of the mine Bytom III by switching off the fan station # JAN and changing the function of the shaft. After converting the upcast shaft Jan into a downcast shaft, the main ventilation fan parameters and the air discharge direction in the other shafts changed (Fig. 4). The ventilation conditions of the area of longwall 21 bed 510 and other areas in the close of the shaft improved significantly, particularly in terms of climatic conditions.

In consequence of the stoppage of the main fan of the Jan shaft, a transient state of air parameters occurred in the ventilation network of Bytom III mine. The transient states of air parameter were recorded using the sensors of the mine's ventilation monitoring systems. The locations of the sensors are shown in Fig. 4.

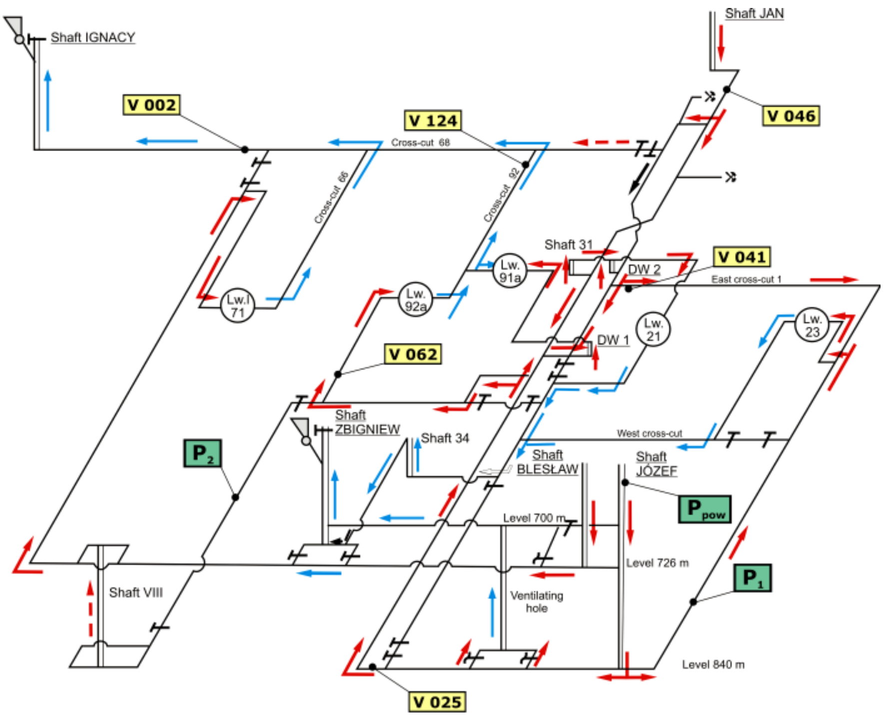



Fig. 4. Location of sensors in the mine Bytom III (after switching off the fan # JAN)

The recording of air pressure

Barometric pressure is of major importance for deep-mine ventilation conditions. Changes in pressure, as practice shows, are an important factor affecting air distribution and gas emission.

The stoppage of fan station # JAN and the change of function were registered by a system of pressure sensors (p1 and p2) whose underground locations are shown in Fig. 3. The switching off of the main fan caused a transient pressure state, registered at both measurement points, although the changes were different in nature. The pressure changes recorded on the bottom of the downcast shaft JÓZEF (p2) oscillated much more than (p1) recorded a long way from the downcast shaft, approximately 4 km closer to the switched off fan. The transient states of pressure and differences in the nature of pressure changes are shown in Fig. 5 and Fig. 6.

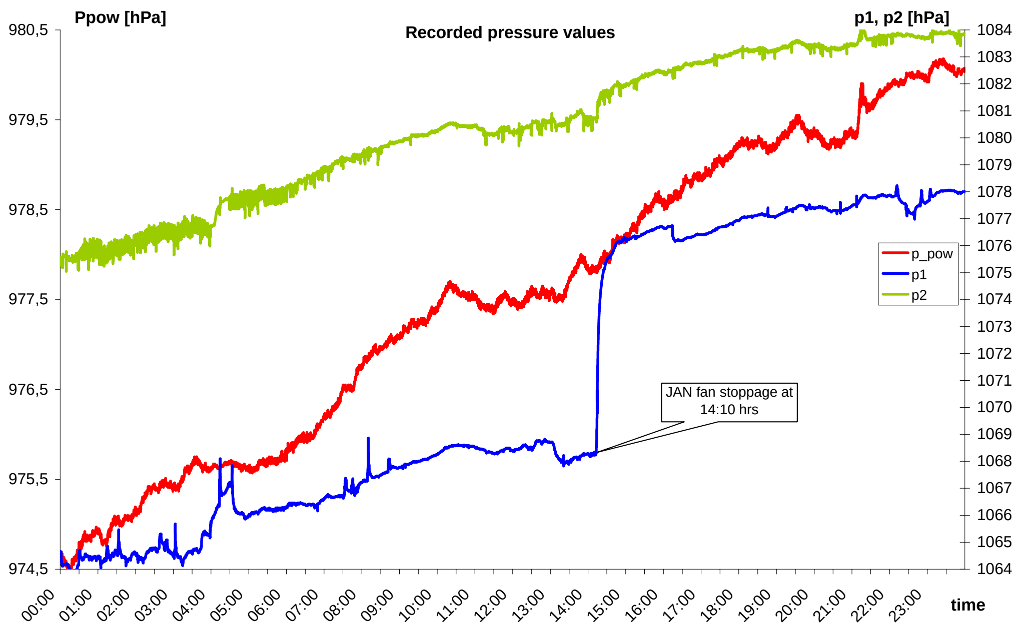



Fig. 5. Pressure values recorded during Jan shaft fan stoppage

Changes in flow direction and air velocity

The switching off of the main fan at the shaft Jan and the conversion of this upcast shaft into a downcast one lead to changes in air flow direction (Fig. 7) and air velocity in the mine's workings. This applies in particular to the shaft Jan (anemometer V046) and eastern cross-cut I (anemometer V041). At the same time, the direction of air flow changed in the area of longwall 21 and a marked slow-down in longwall 92 occurred, a development registered by anemometers V062 and V124.

Such significant changes in ventilation conditions, particularly in gassy mines, may lead to serious hazards, especially in the area of longwalls with wide goaf areas. For this reason, both in actual operation and as part of research experiments, they need to be induced subject to special

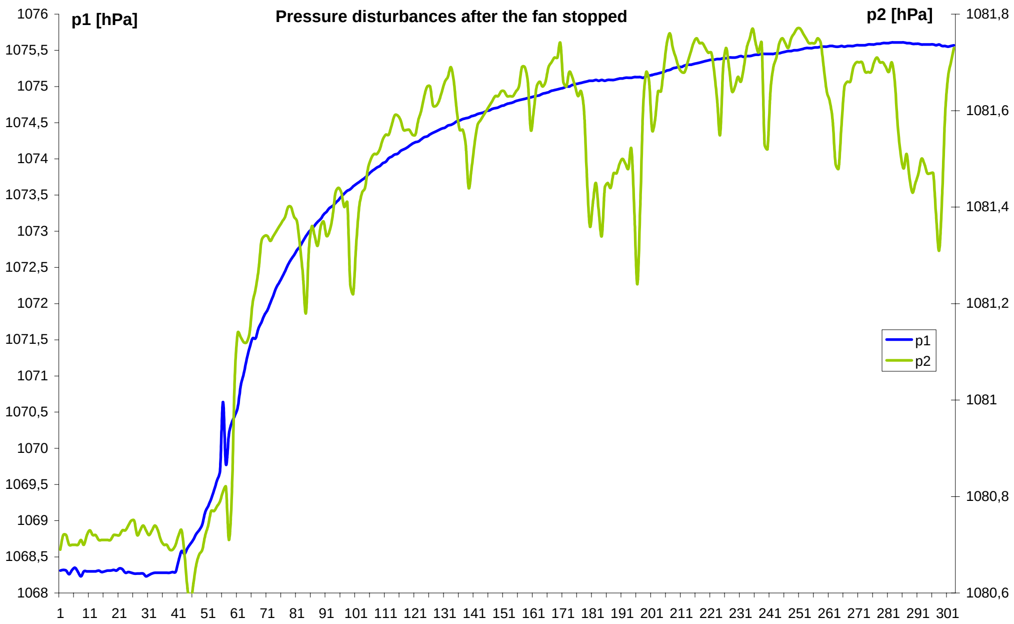



Fig. 6. Transient states of pressure after shaft Jan fan stopped

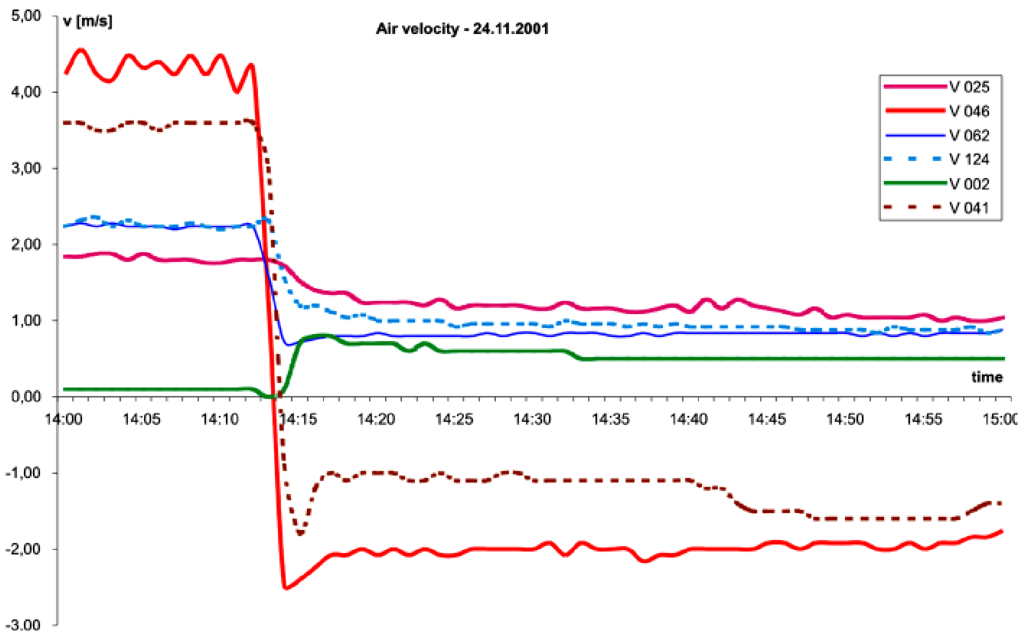



Fig. 7. Transient states of air velocity after shaft Jan fan stopped

safety conditions. Ventilation parameter changes during the stopping of a main fan must be continually monitored and controlled to prevent hazards involved in the changes of flow direction in excavation areas and in air parameter transient states.

## 4. Main fan stoppage at the mine *Wujek – Slask:* an experiment

In mining practice, both in Poland and elsewhere, software tools and computer modelling methods are used to try and reproduce the conditions prior to and during disasters based on the existing network model (Dziurzyński et al., 2010) and monitoring system data. Another important issue is the application of these tools to simulating ventilation options for the elimination of methane and fire hazards after a disaster. The observation of parameters during the regular course of the process (a *passive* experiment) only allows the researchers to find out its current state. A much richer and fuller material can be obtained during an *active* experiment, i.e. during the observation of parameter changes caused by an intentional and controlled disturbance of the process. This is the method applied in the research conducted after a disaster in the mine *Śląsk-Wujek* that took place in September 2009. Data registered in the mine's monitoring system during the stoppage of the main ventilation fan were used for the verification and validation of the software tools used for the purposes of reproducing the events and disasters that had happened developed on the basis of the **Ventgraf** and ***VentZroby*** systems (IMG-PAN Report, 2011).

The stoppage of the fan on shaft III of the mine *Wujek – Slask* took place on Sunday, 18 October 2009, one month after a methane ignition and explosion disaster in longwall 5 bed 409 on 18 September 2009. The experiment was conducted with the consent of the mine's Maintenance Manager and pursuant to all safety requirements, in the absence of miners in the underground workings and under a regime of strict control of air parameters using the mine's monitoring system. The research involved recording air velocity, methane concentration and pressure differences at stoppings as well as methane concentration in the goaf degasification pipeline registered during the experiment in the logs of the mine's monitoring system.

The adopted configuration of the mine monitoring system (*Report of the Commission...*, 2010), as far as security control of methanometric sensors are concerned, was based on a digital station registering methane concentration at 2-second intervals. Anemometers encased in the mine's workings were included in the monitoring system through analogue station allowing for measuring and recording signals at 4-minute intervals. Differential pressure sensors at stoppings were included in the monitoring system and recorded signals every 4 minutes (CRC) and the MRC sensors at 2-second intervals.

Equipment operation sensors (controlling i.a. the on/off status of main fans and air duct fans and the opening and closing of ventilation there) were included in the monitoring system, and their status was recorded at 1-second intervals.

The effects of the stopping and re-starting of the main fan were recorded using the sensors of the mine's monitoring system encased in the workings (Fig. 8), including 10 anemometers (V), 14 methanometers (M), 1 methanometer in the degasification pipeline and three differential pressure sensors at stoppings (CRC, MRC). The operation status of the main fan, including the moment of it being switched off and on again was controlled using a current sensor (W).

TABLE 1

Hard Coal Mine Wujek - Slask sensors parameters of the monitoring system

| No. | Sensor No. | Type | Location |
|---|---|---|---|
| 1 | V102 | SAS-2 | Cross-cut to bed 409 – 50 m to the north of the testing and ventilation heading |
| 2 | V103 | SAS-2 | Haulage plane 417K – up to 50 m from cut-through 2/502J |
| 3 | V104 | SAS5 | Western cross-cut 1050, air inlet to the battery room repair workshop |
| 4 | V105 | SAS-2 | Testing rise gallery 3/409, up to 10 m south of cut-through 2/409 |
| 5 | V108 | SAT-1F | Ventilation incline 417K up to approx. 30 m north of siding 2 |
| 6 | V113 | SAS-2 | Western cross-cut, level 765 m, up to 30 m west of the ventilation cross-cut from chambers |
| 7 | V114 | SAT-1F | Monkey drift 502J up to 30 m north of the subsidiary road |
| 8 | V116 | SAS-2 | North-western cross-cut 1050 up to 100 m from the southern cross-cut 1050 m |
| 9 | V118 | SAS-2 | Cut-through 3/409 – up to 20 m west of the central rise gallery |
| 10 | V119 | SAS-2 | Testing gallery 5/409 up to 50 m west of testing rise gallery 1/409 |
| 11 | M209 | MM-2 | Conveyor belt plane 417K 10-15 m south of testing rise gallery 1 |
| 12 | M227 | MM-2PW | Conveyor belt plane 417K, next to switchgear RE-11 |
| 13 | M275 | MM-2PW | Longwall 4/409, above conveyor belt drive box – 2 m from the excavation |
| 14 | M290 | MM-2P | Ventilation incline 10-15 m east of the cross-cut |
| 15 | M291 | MM-2P | Cut-through 3/409 – 5 m from the degasification station mixer |
| 16 | M317 | MM-2PW | Testing rise gallery 1/409 – 10 m south of cut-through 1 |
| 17 | M318 | MM-2PW | Longwall 5/409 – above face conveyor drive box |
| 18 | M319 | MM-2PW | Secondary testing gallery 3a 409, 10-15 m west of the rise gallery |
| 19 | M320 | MM-2P | Testing rise gallery 1/409 – 10 m south of cut-through 1 |
| 20 | M360 | MM-4 | Western cross-cut, level 765 m, 10-15 m west of the ventilation cross-cut |
| 21 | M287 | MM-4 | Testing gallery 5/409 – 10 to 15 m from the testing rise gallery |
| 22 | M292 | MM-4 | Testing rise gallery 1/409 – 10 to 15 m north of cut-through 3 |
| 23 | M295 | MM-4 | Cut-through 5 – up to5 m from southern dip-heading 1050 |
| 24 | M300 | MM-4 | Cut-through 5 – 5 m from the degasification station mixer outlet |
| 25 | M294 | MM-2A | Cross-cut 3/409 – degasification pipeline of the degasification station |
| 26 | CRC035 | CRC-6/1 | Cut-through 1/409 by SW-2, between testing rise gallery 1 and the central rise gallery |
| 27 | MRC429 | MRC1250 | West cross-cut, level 765 m |
| 28 | MRC430 | MRC1250 | Cross-cut to bed 409, 10-15 m from the ventilation incline |
| 29 | W025 | CPP-1 | Fan 1#3 |

The experiment consisting of switching of the main fan at shaft III of the mine *Wujek – Slask* started at approximately 08:00 hrs on 18 October 2009. The fan operation sensor recorded a change in the operation status (switching off) at 08:06:53 hrs, which indicated the stoppage of the main fan. Because of the existing configuration of the mine's system, the event was recorded by the sensors of the monitoring system.

After the fan had been switched off, a change in the conditions in the workings ventilation system was first recorded by differential pressure sensors at stoppings: after 8 seconds (8:07:01)

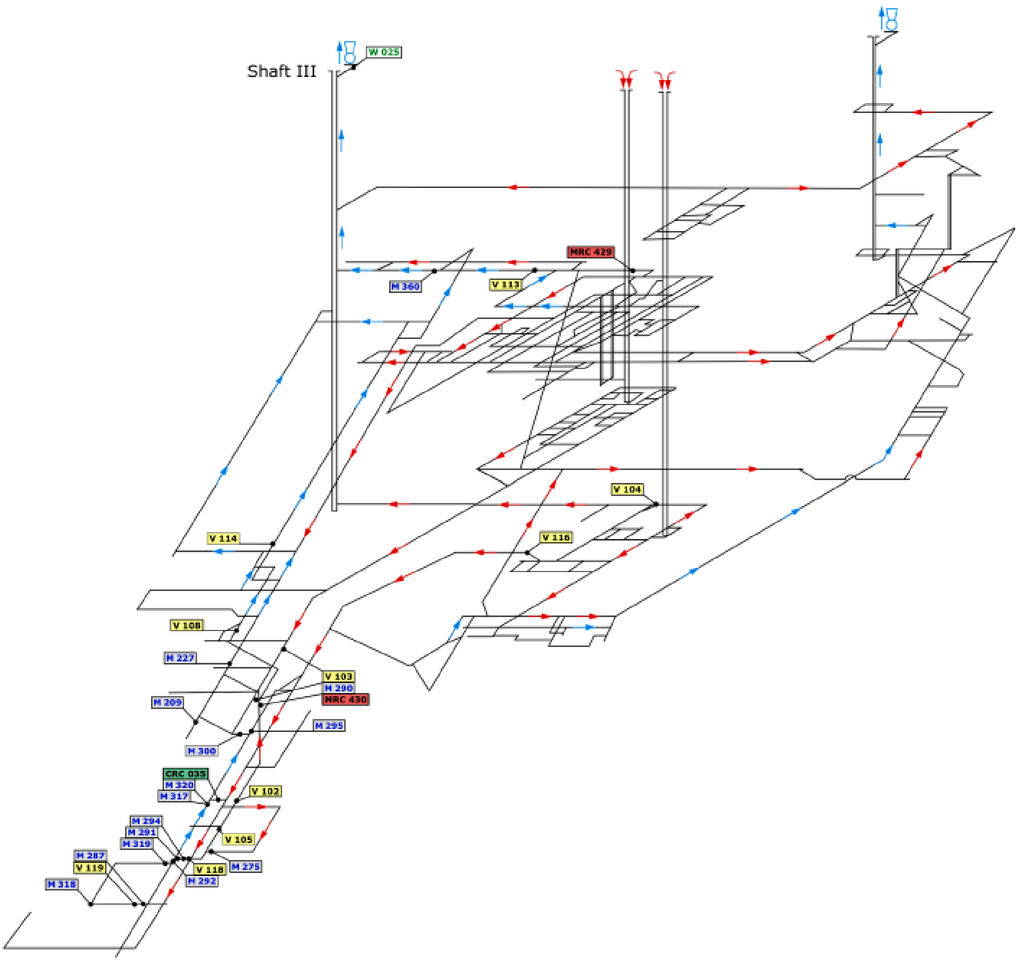



Fig. 8. Locations of selected sensors of monitoring system in the workings of the mine

by a sensor (MRC429) encased at a stopping in the western cross-cut, level 760 m and then at 8:07:18, after 17 seconds, by sensors (MRC430) at the stopping in the cross-cut to bed 409. A differential pressure sensor (CRC035) encased in cut-through 1/409 between testing rise gallery 1 and the central raise recorded a change in the monitoring system, as late as at 8:10:30 hrs, 3 minutes 37 seconds after the fan had been switched off. A delay of this duration is a consequence of the sensor (CRC) being connected to the monitoring system by a switchboard whose sampling cycle was 4 minutes.

Similarly, the signals of air velocity changes after the switching off of the fan cannot be interpreted based on anemometer readings, as these sensors were also connected to the system through a station with a 4-minute cycle. Under these circumstances, no attempts at specifying the order and time of changes in air flow parameters after the fan had been switched off can refer to actual moment of time. Anemometer data can only be considered in terms of the steady states.

Much more information concerning the signals of the process and the scope of parameter changes can be obtained from the readings of methane concentration sensors, connected to the mine's monitoring system with a 2-second sampling cycle. Here, the readings show that already after 43 seconds from the switching off of the fan, at 08:07:36 hrs, a drop in methane concentration was recorded by a sensor (M311) encased in secondary testing heading 3a. Ten seconds later, at 08:07:46 hrs, a systematic increase in methane concentration was recorded by a sensor (M291) encased in cut-through 3/409; at the same hour, a drop in methane concentration was recorded by a sensor (M321) encased in testing rise gallery 4/409.

The re-start of the fan on shaft IV was recorded by its operating status sensor at 11:08:15 hrs.

The start of the fan was recorded almost at the same moment by differential pressure sensors (MRC 430 and MRC429) on stoppings, while another sensor (CRC) recorded this event only 2 minutes 17 seconds later (at 11:10:32 hrs), which again was a consequence of the mine's monitoring system to which the sensor belonged having a 4-minute sampling cycle. An analysis of the signals of air velocity changes is impossible for similar reasons.

The first changes in methane concentration after the fan had started were observed by the mine's monitoring system (sensor M291) in cut-through 3/409,8 m from the outlet of the degasification station at 11:08:26 hrs, 11 minutes after the event. Interesting changes, with clear over-regulation, were recorded by three methanometers ((M290, M317 and M320).

As regards the observation of transient states of air parameters, it may be stated that because of the different data recording methods used in the mine monitoring system during the experiment involving the stopping and re-starting the main fan, it would be more appropriate to refer to steady states recorded by air parameter sensors before and during stoppage and after the re-start of the fan, which took place after 3 hours of stoppage.

It should be emphasised that because of the parameter monitoring system configuration at the mine *Wujek – Slask*, the researchers abandoned attempts at a detailed analysis of the air parameter change signals based on the recorded transient states during the stoppage and re-start of the fan. However, the data recorded during the experiment by the monitoring system can be used for the verification and validation of software tools for the modelling of ventilation conditions based on the **Ventgraf** and **VentZroby** systems. Steady states of air parameters recorded before and after the event were used for this purpose.

***Air parameters recorded during the experiment by the monitoring system***

The conditions involved in the stoppage and re-start of the main fan on shaft III at the mine *Wujek – Slask* were recorded in the mine monitoring and supervision system by air velocity, methane concentration and differential pressure sensors and the methane concentration sensor in the degasification pipeline.

The parameter change signals recorded in the monitoring system database are shown in Fig. 9-12. The graphs of the air parameters are always shown against the backdrop of the change of the fan operation mode illustrated by vertical lines: the one at approximately 08:07 hrs indicates the stopping and the one at 11:08 hrs indicates the re-start of the fan.

The records of air velocity in the workings of the mine *Wujek – Slask* after the stoppage and re-start of the main ventilation fan show (in Fig. 9) a marked change in the level of signals, with significant variability of momentary values. Changes in air velocity were significant, particularly in south-western cross-cut 1050 (V116), in monkey drift 502J (V114) and ventilation

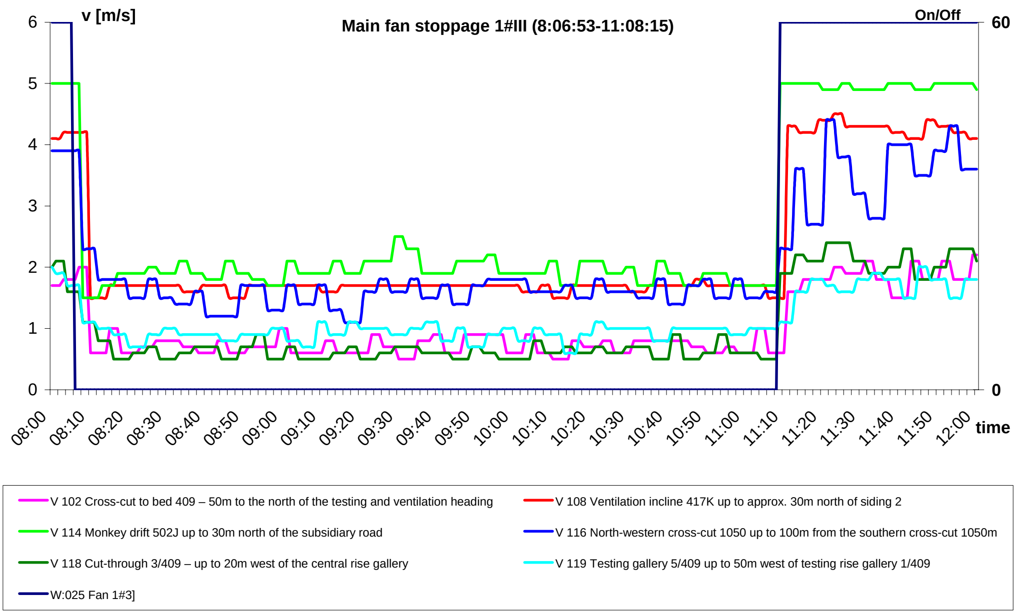



Fig. 9. Air velocity values recorded in workings during main fan stoppage and re-start at the mine Wujek – Slask

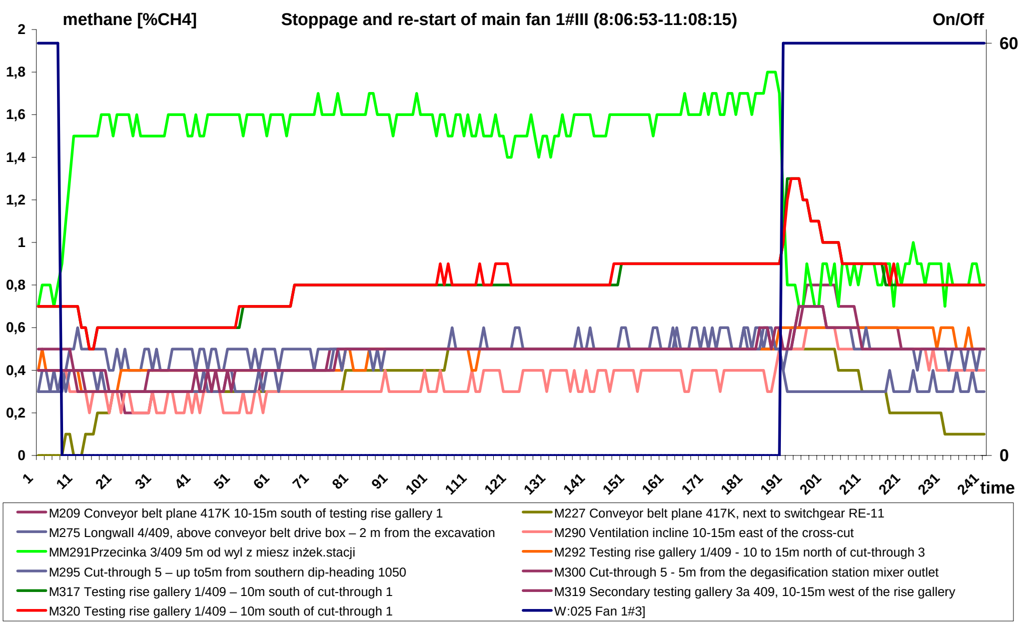



Fig. 10. Methane concentration values recorded in workings during main fan stoppage and re-start at the mine Wujek – Slask

incline 417K (V108). Another important finding was a significant increase in the fluctuation of momentary values recorded by anemometer V116 in south-western cross-cut 1050 after the re-start of the fan, i.e. after 11:08 hrs.

Records of methane concentration in the workings of the mine *Wujek – Slask* after the stoppage and re-start of the main ventilation fan clearly show (in Fig. 10) how different the changes of this parameter are in different points of the mine. Methanometer M311 encased in secondary testing gallery 3a recorded a quick slump in methane concentration from 1.0%$CH_4$ to 0.2% $CH_4$ after the fan stopped and a much slower increase in methane concentration to 1.4% $CH_4$ after it was restarted. Methane concentration in cut-through 3/409 (M291) increased from 0.8% $CH_4$ to 1.6% $CH_4$ after the fan stopped, to return to the level of 0.8% $CH_4$ after the re-start of the fan. Interesting transient states of methane concentration with clear over-regulation were registered by methanometers (Fig. 10) encased respectively in testing rise gallery 1/409 (M320), the ventilation incline east of cross-cut M290 and in testing raise 1/409 south of cut-through 1 (M317), both right after the switching off and the re-start of the fan.

The recorded signals of pressure changes at stoppings (Fig. 11) have shown significant pressure changes at the moment of the main fan being switched off and the restoration of the original conditions after the restart of shaft III fan.

An interesting pattern of methane concentration in the degasification pipeline (M294) was recorded (Fig. 11), in the monitoring system after the stoppage and re-start of the shaft III fan. Note that in this case, clear transient states of methane concentration are visible, lasting up to a dozen or so minutes.

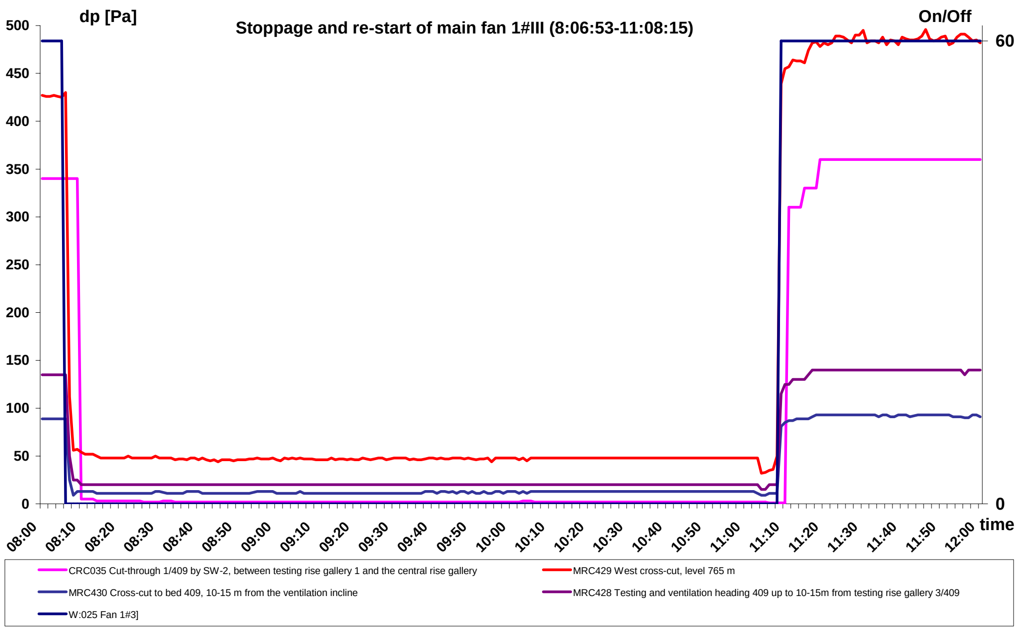



Fig. 11. Pressure differences at stoppings recorded in workings during main fan stoppage and re-start at the mine Wujek – Slask

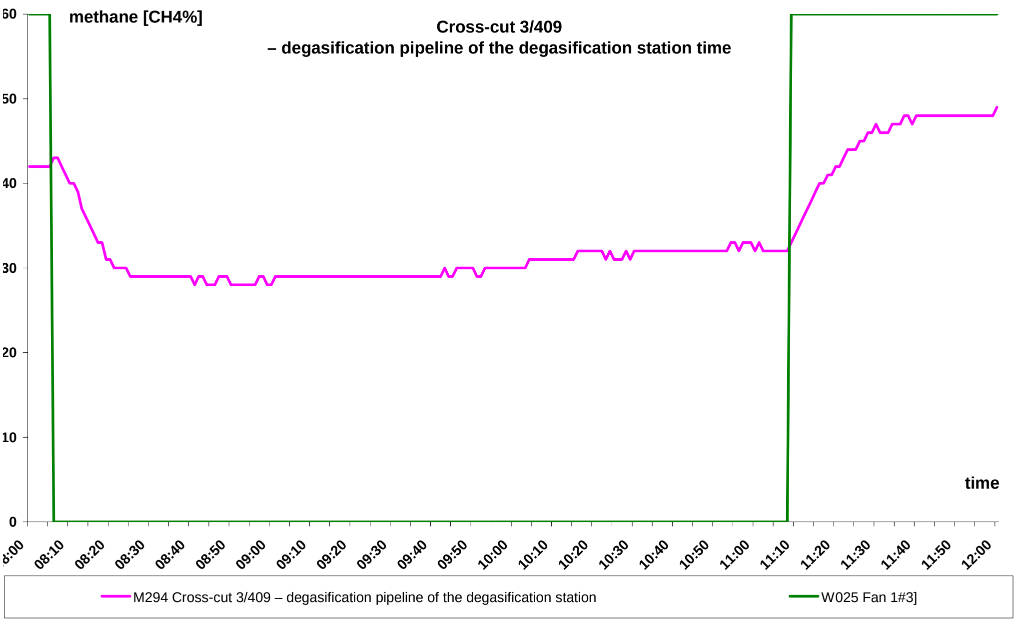



Fig. 12. Methane concentration in the degasification pipeline recorded during main fan stoppage and re-start at the mine Wujek – Slask

## 5. Filtration of data from monitoring system for the simulation

Data from sensors encased in the mine's workings and registered in the monitoring system both during regular operation and during experiments, are much disturbed and subject to major fluctuations. This is also shown by air parameters records from experiments involving the stoppage and re-start of a mine's main fan described in the article. To use the data recorded in the monitoring system for the verification and validation of software tools based on the **Ventgraf** and **VentZroby** system, designed to simulate processes occurring in deep-mine ventilation systems, it is necessary to smooth the original data and separate irrelevant disturbances (fluctuations) to signals.

Thanks to research conducted in gas hazard monitoring and monitoring systems, we were able to get to know the structure of air parameter disturbances in mine ventilation processes. Studies of the nature and signals of these disturbances (Wasilewski, 1984) show that they have an additive character and that they can be classified into the following three types, depending on their duration:

- quick-changing disturbances, lasting for minutes, caused by the turbulent flow of the air-gas mixture and random events in the system, e.g. the movement of trains, cages, shooting, opening and closing of stoppings, etc, which cause only momentary and local fluctuations of air parameters,
- quasi-deterministic disturbances, lasting for hours and cyclical in nature and caused by technological operations related to exploitation in longwalls, mainly to the operation of mining machines,

- slow-changing disturbances, lasting for days and weeks and caused by changes in the structure and geometric parameters of workings, atmospheric conditions and gas source output; disturbances of this type bring about lasting changes to the ventilation process.

At the same time, observations in the examined mines showed that air velocity and methane concentration oscillation occurring in workings and caused by disturbances involved in exploitation are of a local and temporary nature. They are extinguished as air masses move towards the upcast shaft. On these base, the ventilation process can be considered slow-changing. It is subject to many disturbances, a fact used in the further analysis of measurement signals recorded in the monitoring system. This also substantiates the elimination of random parameter disturbances recorded by monitoring system sensors through filtration of measurement signals before using them for modelling studies (Trutwin & Wasilewski, 1994).

The analysis of momentary disturbance signals to be eliminated is done using digital low-pass filters, which help to remove measurement noise and quick-changing signal disturbances. The simplest low-pass filter is the so-called moving average, consisting in the averaging of several momentary values. A similar measurement signal filtration effect can be achieved using the first-order low-pass Brown filter (Wasilewski, 1984), defined also by the following recurrent equation:

$$y'_i = \alpha\, y'_{i-1} + (1-\alpha) y_i\,, \qquad \mathrm{i} = 1.2, \ldots, \qquad y'_o = y_1$$

with the filtration coefficient $\alpha$ being a real number from the range (0,1).

The air velocity signals in the workings of the mine Wujek – Slask recorded during the switching off and restarting of the main ventilation fan as part of the experiment (Fig. 13 and 14) are characterised by large fluctuation of momentary values, so it was necessary to smooth air velocity signals before using the data for the verification and validation of software tools more and more frequently used by mining practitioners for re-creating events and disasters, based on the **Ventgraf** and **VentZroby** system (IMG-PAN Report, 2011).

Smaller fluctuations affected the signals recorded by methane concentration sensors in the workings of Wujek – Slask during the experiment of the stoppage and re-start the main fan in shaft III. Momentary methane concentration signal value fluctuations were also smoothed (see Fig. 15 and 16).

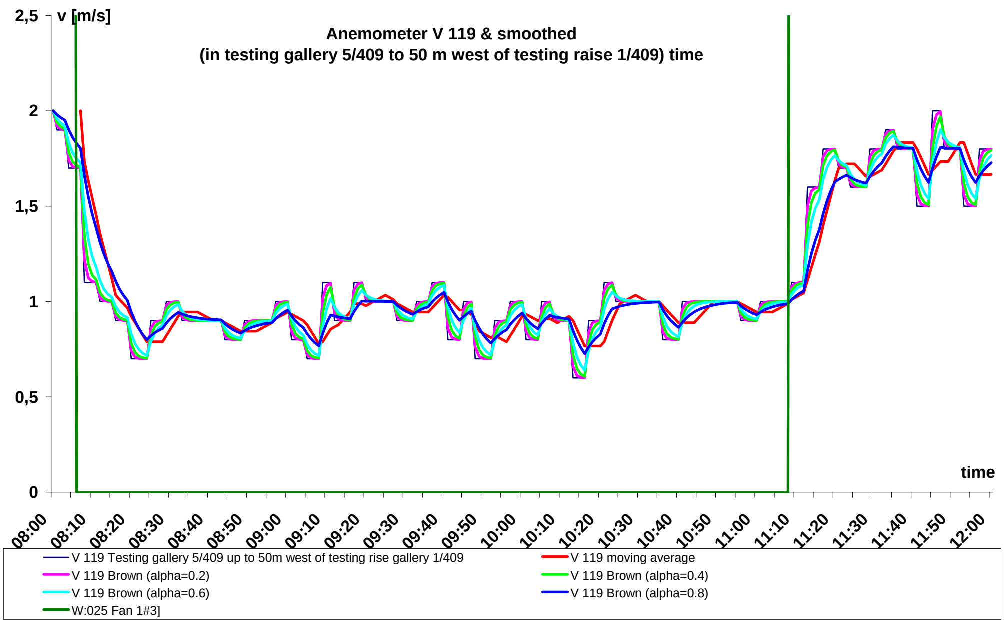



Fig. 13. The recorded original and smoothed air velocity signals for testing gallery 5/409 during main fan stoppage and re-start at the mine Wujek – Slask

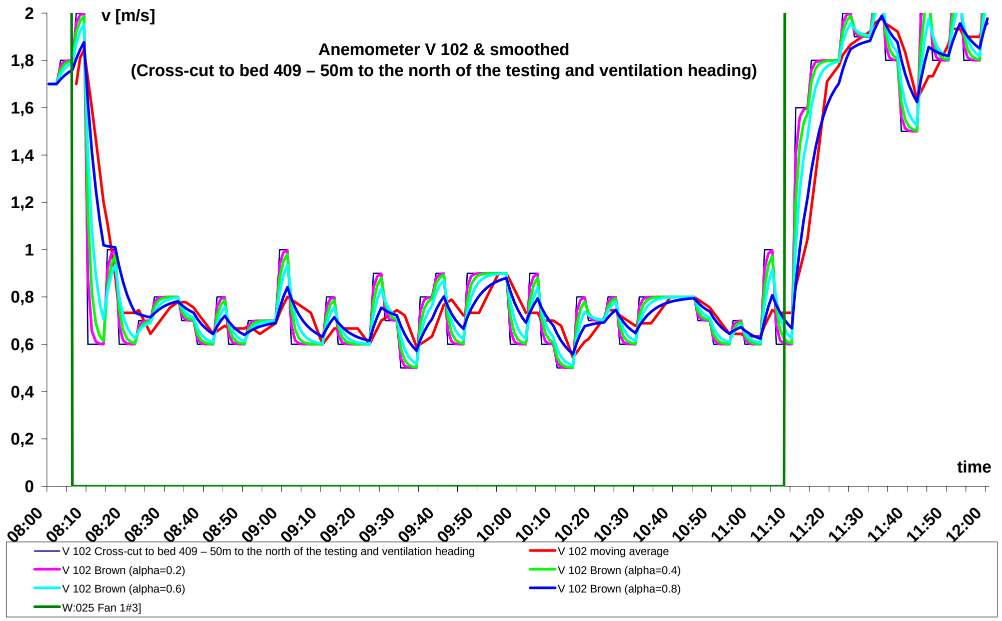



Fig. 14. The recorded original and smoothed air velocity signals for the cross-cut to bed 409 during main fan stoppage and re-start at the mine Wujek – Slask

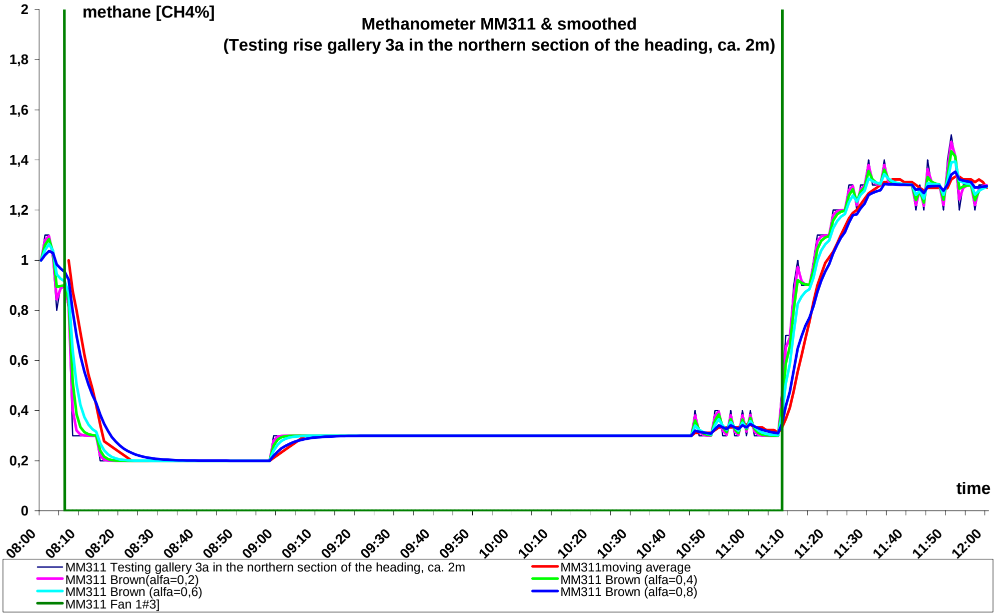



Fig. 15. The recorded original and smoothed methane concentration signals for testing gallery 3a during main fan stoppage and re-start at the mine Wujek – Slask

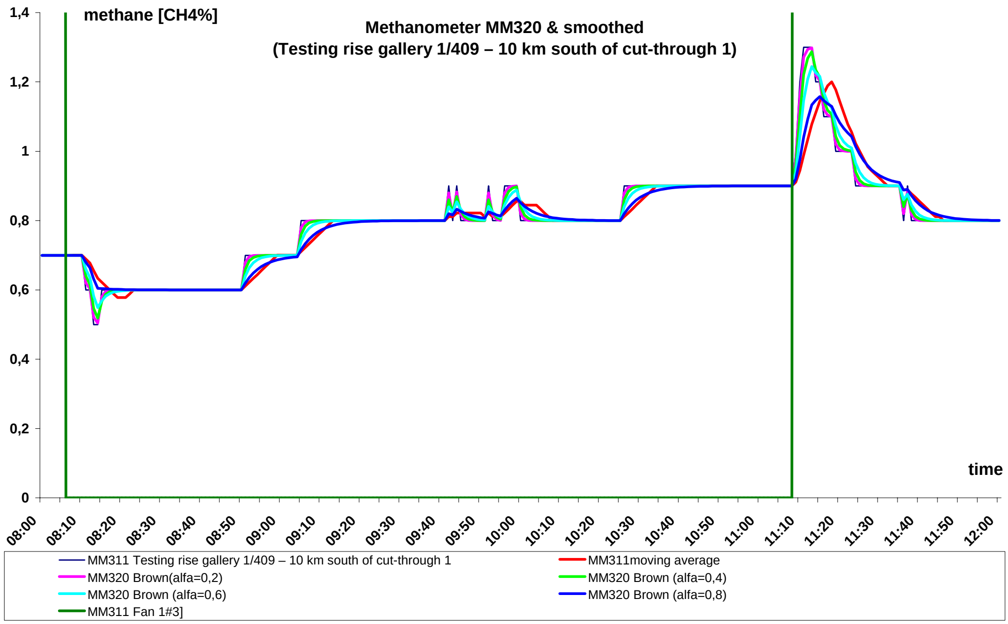



Fig. 16. The recorded original and smoothed methane concentration signals for testing raise 1/409 during main fan stoppage and re-start at the mine Wujek – Slask

## 6. Conclusions

- The stoppage of the main ventilation fan of the examined deep-mine, effected for the purposes of shaft revision and as a research experiment, was a major disturbance to the ventilation conditions in the mine's workings, including pressure distribution, air and gas flow directions or methane concentration. Disturbances caused by fan stoppage in the underground workings of a mine, particularly a gassy mine, may have serious consequences and bring about serious hazards. Therefore, under mining law, detailed principles for switching off main ventilation fans are regulated in rescue schemes subject to the approval of the mine maintenance manager.
- The discussed research, consisting in main fan stoppage and re-start at shaft III of the mine *Wujek – Slask*, based on a controlled experiment, provided a lot of data for the verification and validation of the software tools **Ventgraf** and **VentZroby**.
- Computer simulation methods are more and more commonly used, both in Poland and elsewhere, when attempting at reproduce the conditions prior to and during disasters. This kind of study can be conducted only on the basis of the current network model and monitoring system data. Another important issue is the application of the tools for the simulation of ventilation options to combat and eliminate methane and fire hazards occurring after an event. Such applications of the **Ventgraf** and **VentZroby** systems were addressed as part of the charter activities of the Strata Mechanics Research Institute of the Polish Academy of Sciences
- The configuration of the mine monitoring system, particularly the signal sampling cycles, admittedly did not provide data sufficient for the evaluation of air velocity and methane concentration signals, but this does not limited the validity of the recorded data for the verification and validation of the software tools. For these purposes, the researchers used steady states of air parameters before and after the fan was switched off and before and after it was switched on again.
- Air parameters recorded during the stoppage and restart of the main fan at shaft III of the mine *Wujek – Slask* showed large fluctuation of momentary values. For this reason, measurement signals had to be smoothed before being used for the verification and validation of the **Ventgraf** and **VentZroby** programs.

The research was conducted as part of activities provided for in the charter of the Strata Mechanics Research Institute of the Polish Academy of Sciences.

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