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SELECTED METHODS OF ROCK STRUCTURE DISINTEGRATION TO CONTROL MINING HAZARDS

WYBRANE METODY DEZINTEGRACJI STRUKTURY SKAŁ DLA ZWALCZANIA ZAGROŻEŃ GÓRNICZYCH

Natural hazards are inseparable element of underground mining, particularly of coal mining process. They are combated on a regular basis by many measures and effectiveness of these measures determines work safety in mines. Attempts to improve the effectiveness, presented in the paper is based on interference of seismic waves generated by blasting in a selected area of the rock mass and on modification of blasting technology. Preliminary results of detonating classical and new type of explosives in specific temperature and pressure conditions are analyzed. Theoretical and practical consideration of obtaining an interference effect of seismic waves is discussed. A device for making systems of starting notches and a construction of a chamber to test explosives are presented.

Keywords: mining hazards, rock structure disintegration, blasting technology

Nieodłącznym elementem podziemnego górnictwa, szczególnie węglowego, są zagrożenia naturalne. Ich zwalczanie jest codzienną praktyką, a jego skuteczność decydująco wpływa na bezpieczeństwo pracy. Przedstawione w artykule próby poprawy tej skuteczności obejmują badania efektu nakładania się w wybranym obszarze górotworu drgań generowanych robotami strzałowymi oraz informacje o próbach modyfikacji strzelniczych technik szczelinowania skał, a także wstępne wyniki badania charakterystyk eksplozji klasycznych i nowych materiałów wybuchowych w nietypowych warunkach temperatur i ciśnienia.

Omówiono między innymi teoretyczne i praktyczne warunki uzyskiwania efektu interferencji drgań oraz przedstawiono urządzenie do wykonywania systemów tzw. szczelin zarodnikowych i konstrukcję komory będącej elementem stanowiska do badania MW.

Słowa kluczowe: zagrożenia górnicze, dezintegracja struktury skał, technika strzelnicza

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1. Introduction

Occurrence of natural hazards is a specific feature of underground mining, especially coal mining. Natural hazard is a naturally occurring event that might have a negative effect on people or the environment (http://en.wikipedia.org/wiki/Natural_hazard). Independently on the definition of the concept, natural hazards are responsible for harmful effects on personnel's psychological and social comfort (Martyka & Lebecki, 2014) and impair effectiveness and efficiency of mining activities. In extreme situations these events lead to fatal accidents and partial or complete destruction of technical and technological infrastructure in mines.

There are many types of natural hazards and they are classified by different criteria (Dow's Fire..., 1994). Even in the above presented definition of natural hazard involves such a classification. Specific feature of the hazards occurring in underground mines is their origin associated mainly with ventilation of mine workings as well as geological and geomechanical properties of the rock mass (Bukowska, 2006, 2012; Kabiesz, 2002; Krause, 2005).

In the history of mining progress, accordingly to current state of mining science and technology, there were many methods to control mining hazards. The most effective are related to the origins of hazards, change properties of rocks, modify mining technology or change support systems of underground mine workings. The most common ways of combating mining hazards are methods based on different types of blasting technology. These methods employ effects of blasting materials to change properties of rocks (rock layers), distribution of stress in the rock mass (e.g. destress blasting) and stability of rock mass (e.g. inducing seismic tremors). Hydraulic fracturing is an alternative method (Konopko et al., 1997; Makówka & Drzewiecki, 2011; Makówka, 2014) with many more problems in practical application, which significantly limits its use.

The paper presents a concept and results of initial tests associated with development of blasting technology employed to improve effectiveness of seismic hazard control and methane drainage in coal seams.

2. Factors influencing seismic and gas hazard

The origin of seismic hazard and gas hazard (methane) is located in the rock mass surrounding a coal seam. Mining operations, influencing qualities and condition of rock layers, activate the sources.

Seismic hazard in underground mines occurs as a result of deformations and displacements of rocks in gravitational field, caused by mining (Bukowska, 2006; Bukowska et al., 2007; Drzewiecki, 2015). The deforming rocks accumulate large amounts of elastic strain energy, which can be violently released in a process of dynamic disintegration of their structures. The amount of energy and dynamics of the release depend, most of all, on strength parameters of rocks (Drzewiecki, 2004). As a result of displacements of rock layers, unstable areas of the rock mass with high values of strain energy may be formed. This energy can be transformed into kinetic energy when the stability is lost. In both cases the consequences of the scenarios are seismic tremors often of high seismic energy.

The origin of gas hazard is always gas (methane) trapped in the rocks, which, mainly as a result of changes in the rock structure, is released and gets into the mine workings along pores and cracks. Permeability of rocks for gas flow can be their original feature, e.g. in the areas of faults, yet it usually increases in destressed areas around mine workings (Kabiesz & Patyńska, 2009) and gob after mining operations.

The above mentioned elements of the rock mass state (structure of rocks significantly affects their strength parameters and permeability, stability of fragments of the rock mass) are the areas where blasting methods are employed to control rockbursts and methane hazards.

Blasting technology applied to control seismic hazard (rockburst) can be classified in three main groups:

- destress blasting, conducted in the deposit to change its mechanical and structural properties,
- torpedo blasting, conducted in the roof or/and floor of a deposit to disintegrate its structure and/or induce a seismic tremor,
- modified production blasting conducted in the deposit to mine the deposit and induce a seismic tremor.

Blasting technology is less often used to control methane hazard, mainly in forms similar to torpedo blasting. There have been also attempts to take such actions in coal seams (Konopko & Makówka, 1998), however they are just isolated cases of little industrial scale. Current development of coal seam methane drainage techniques is aimed at drilling drainage holes, including the directed drilling (Szlązak, 2013).

Mining hazard control with blast works utilizes direct destructive effects of detonating explosives and the influence of generated seismic vibration. In typical blasting technology (Batko, 2004) parameters describing their effects are directly dependant on the size of detonated explosives. Most often many explosive charges are detonated simultaneously, destroying the structure of rock in the direct vicinity of blast holes and become sources of seismic vibrations. Detonating such charges without time synchronisation results in their unsatisfactory influence on the rock mass. Some parts of the rock mass can lose their unstable equilibrium when seismic vibrations deliver additional seismic energy to these areas. One can assume that to improve effectiveness of blasting, especially of the effect of seismic vibrations, it is necessary to consider the phenomenon of seismic wave interference.

3. Conditions of constructive interference of seismic wave packets generated by blasting

Blasting in the rock mass generates seismic wave packets and example of recorded digital seismograms from blasting are shown in Figure 1.

Seismic wave packets generated by blasting in mines propagate in rock medium in all directions. These wave packets are subjected to such phenomena as scattering, reflection and refraction. The phenomena depend on properties of the rock medium, and the waves are gene-rated in many locations where blasting is performed. Additionally blasting in different spatial locations occurs at different moment in time. Seismic wave packets generated by blasting propagating in the rock medium are subject to time and spatial changes and can interfere with each other. Basic condition of interference of elastic vibrations generated with blast works and propagating within the medium (rock mass) is their physical presence in a specific place at the same time. Assuming that many explosive charges are to be detonated, it is necessary to coordinate their detonation times. Many physical and technical factors determine whether the phenomenon occurs or not. It ought to be assumed that the most important physical and technical parameters, which in practice determine obtaining constructive interference of blast works induced vibrations, which can be determined are: *Similarity (coherence) of distribution of frequency of vibrations.*

The condition is not met in practice – Figure 2 shows results of Fourier analysis of vibrations recorded after production blasting in one of copper ore mines. Characteristics of vibration frequency distribution is much differentiated for given explosive charges.

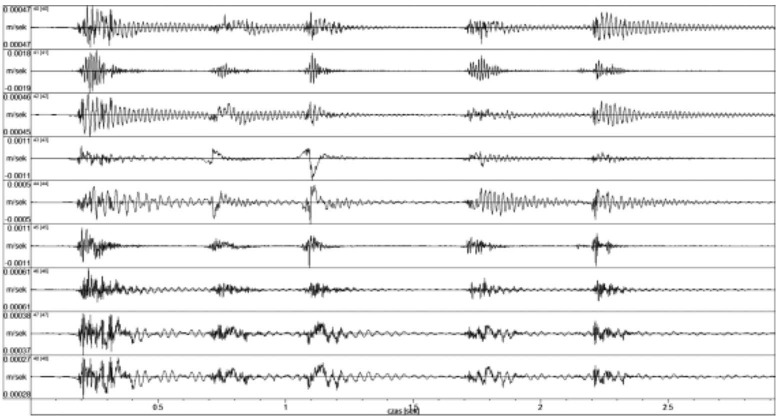


Fig. 1. Example of recorded seismic wave packets generated by production blasting in a copper ore mine

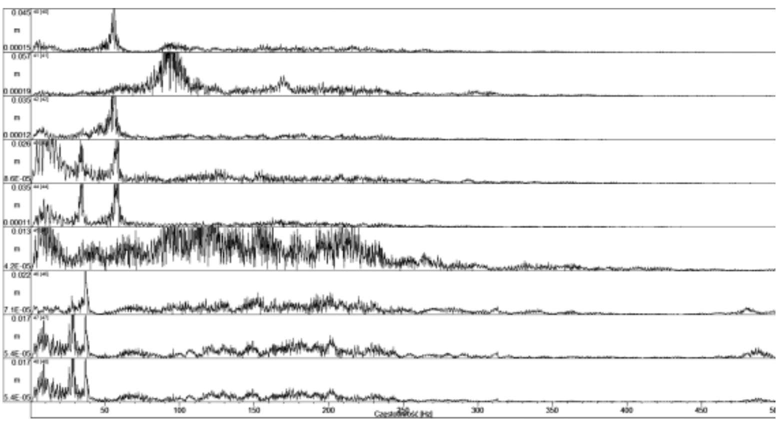


Fig. 2. FFT amplitude spectrum of seismograms shown in Figure 1

Coherence time determining how long vibration packet can interference

It specifies how long a given seismic signal can stack with itself. To determine it, it is necessary to check, among others, autocorrelation for each of the signals, determining Hilbert transform, envelope and auto-coherence time.

Hilbert transform can be defined in the following way. With given Fourier transform $F(\omega)$ of signal $f(t)$ we zero complex-valued function $F(\omega)$ for $\omega < 0$, introducing $\overline{F}(\omega) = F(\omega)$ for $\omega \geq 0$ and $\overline{F}(\omega) = 0$ for $\omega < 0$. Then inverse Fourier transform of new function $\overline{F}(\omega)$ defines complex-valued function in time $z(t)$:

$$z(t) = \int_{-\infty}^{\infty} \overline{F}(\omega)\, e^{-i\omega t}\, d\omega \tag{1}$$

by definition called a complex analytical signal in reference to output signal $f(t)$. Function $z(t)$ assumes the form:

$$z(t) = \frac{1}{2}\left[f(t) + ig(t)\right] \tag{2}$$

where: $f(t)$ and $g(t)$ are associated with each other with:

$$\begin{aligned} f(t) &= \frac{1}{\pi}\int_{-\infty}^{\infty} \frac{g(t')}{t'-t}\, dt' \\ g(t) &= -\frac{1}{\pi}\int_{-\infty}^{\infty} \frac{f(t')}{t'-t}\, dt' \end{aligned} \tag{3}$$

The two above relations form Hilbert transform of signals $f(t)$ and $g(t)$. Having a given actual signal $f(t)$ we can calculate its Hilbert transform, i.e. signal $g(t)$ and complex analytical signal $z(t)$. Basing on signal $z(t)$, it is easy to define envelope $A(t)$ as:

$$A(t) = \sqrt{f(t)^2 + g(t)^2} \tag{4}$$

The last important step to calculate the coherence time of seismic signals is determining auto-coherence function. Assuming that we know parameter $f(t)$ of the seismic signal, we create its analytical signal $z(t)$. Then auto-coherence function $\Gamma(\tau)$ is defined as autocorrelation of complex analytical signal $z(t)$:

$$\Gamma(\tau) = \int_{-\infty}^{\infty} z(t+\tau)\overline{z}(t)\, dt \tag{5}$$

where: – $\overline{z}(t)$ is complex conjugate $z(t)$.

TABLE 1

Coherence time for seismograms in Figure 1

Coherence time, s
1.012
0.789
0.976
0.468
0.839
0.736
0.870
0.730
0.727

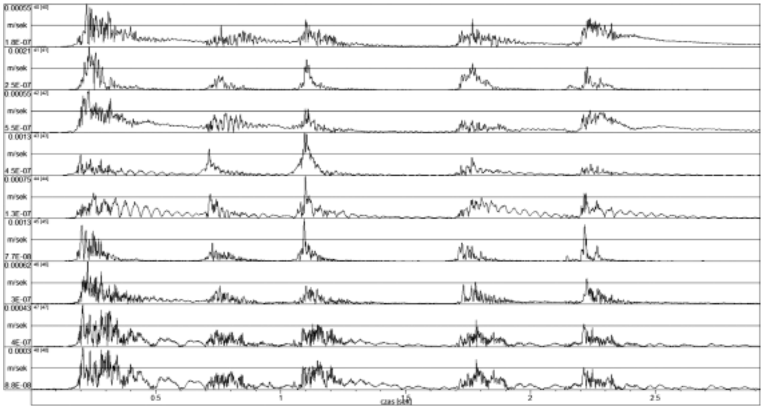


Fig. 3. Hilbert envelope of seismograms of vibrations of Figure 1

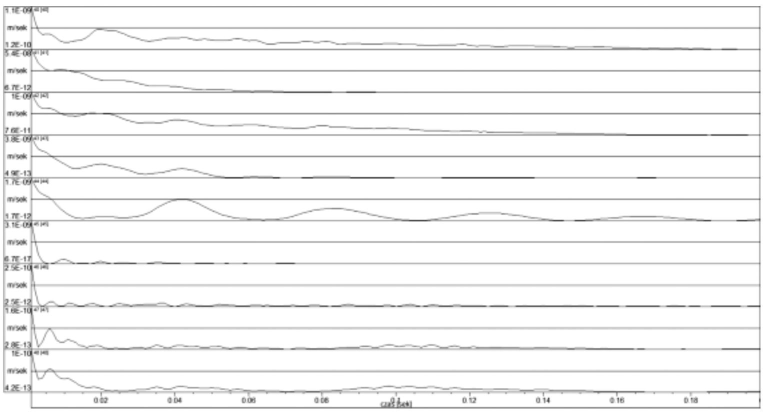


Fig. 4. Auto-coherence function of seismograms in Figure 1

Basing on the function of coherence it is possible to calculate a key parameter which determines coherence time, i.e. how long a given signal can undergo constructive superposition:

$$(\Delta\tau)^2 = \frac{\int_{-\infty}^{\infty} \tau^2 \Gamma(\tau)^2 \, d\tau}{\int_{-\infty}^{\infty} \Gamma(\tau)^2 z \, d\tau} \tag{6}$$

Wave propagation velocity in heterogeneous medium

Propagation velocity of seismic waves in a medium (rock mass) depends on its physical properties, structure of rocks, stress state, and kind and frequency of waves (Dubiński, Mutke, 1996). Practically always, in natural conditions, the medium is a heterogeneous body. The result is heterogeneity of distribution of values of velocity of seismic waves. The most reliable method of measuring values of vibration propagation velocity in the rock mass is measuring time of their passage between selected points, and if it is not possible, to determine it in velocity field in curvilinear seismic ray seismic tomography examination (Fig. 5). Due to a special method of determining proper phases of vibrations for a series of blast works at the mining face, a modern algorithm of tracing rays ought to meet the following requirements (Lurka, 2009):

- tracing has to occur in 3-D space,
- for the sake of accuracy, assumption of straight-linear propagation of rays ought to be avoided,
- tracing ought to determine passage time in such areas as seismic shadow zones,
- algorithm convergence of seismic ray tracing, due to the time necessary for calculations, ought not to exceed a few iterations,
- algorithm of seismic ray tracing ought to be precise, and the relative error of determining time of passage of seismic wave ought to be of 10^{-4}.

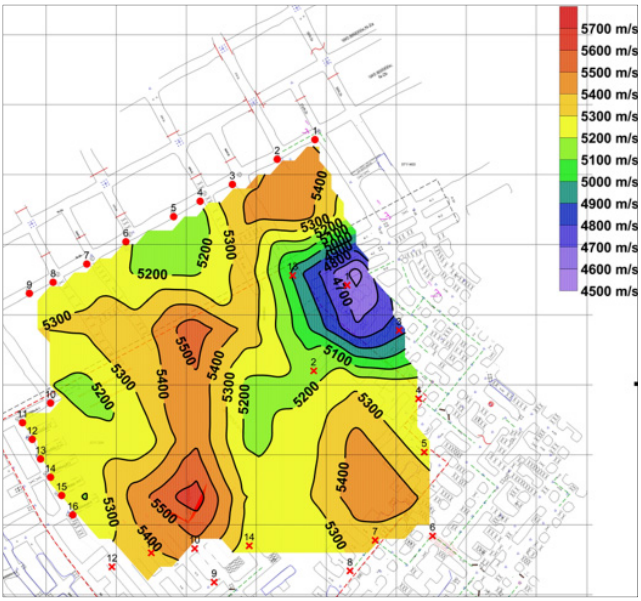


Fig. 5. Velocity field of wave P (ms^{-1}) obtained in tomography examination

With a two-point method of seismic ray tracing and describing curves (of a tracing ray) with so-called B-splines, and applying conjugate gradient method and trapezoidal rule integration, it is possible to determine the time of wave passage in the following way (Lurka, 2009):

$$T(\gamma) = \sum_{s=1}^{n}\sum_{j=1}^{m}\frac{1}{2}\left[\frac{1}{V_{sj}}+\frac{1}{V_{sj-1}}\right]\sqrt{\begin{array}{l}(K_{sx}(u_j)-K_{sx}(u_{j-1}))^2+(K_{sy}(u_j)\\ -K_{sy}(u_{j-1}))^2+(K_{sz}(u_j)-K_{sz}(u_{j-1}))^2\end{array}} \tag{7}$$

where:

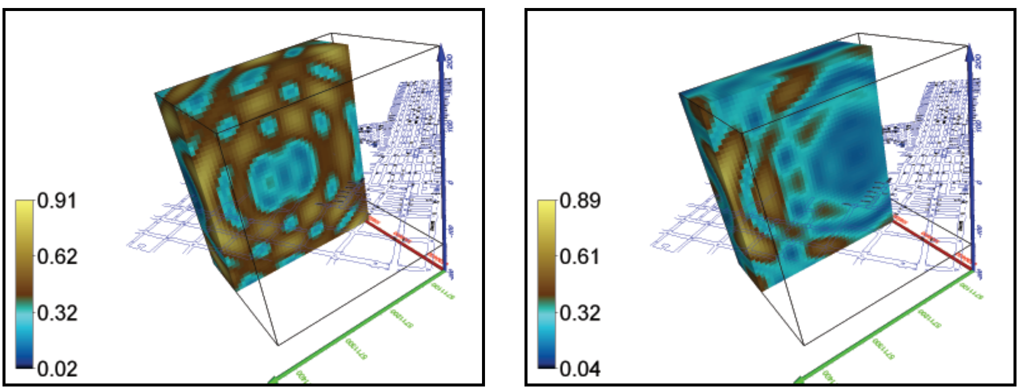
γ	—	curve (seismic ray), of minimum time of wave passage,
$K_{sx}(u)$, $K_{sy}(u)$, $K_{sz}(u)$	—	components of respectively x, y, z of B-spline position vector of index s,
n	—	number of divisions of a seismic ray into curves $K_s(u)$,
m	—	number of sections of parameter u from range (0, 1) making up curve $K_s(u)$,
V_{sj}	—	wave velocity.

Area of potential interference of vibrations

Interference of vibrations ought to, first of all, occur in a previously specified place in the rock mass. It is a multiaspect issue, yet, focusing on realization of blasting technology, "internal" ability of vibrations to interfere in the area and selection of optimum configuration of places where the explosives will be detonated ought to be mentioned.

Coherence time and wave passage velocity are input information for calculating dimensions of the area where interference of vibrations may occur (having met other conditions as well). A place where the waves will interfere must be selected within the area. The hitherto practical applications (Kabiesz & Lurka, 2014) show, that it is contained, ignoring anisotropy of the medium, within circles of radius between approximately 360 m and 13,100 m. It is obvious that the critical element determining the range of interference area will be components of the smallest dimensions.

Spatial distribution of explosives detonated in mining conditions is in most cases determined with possible location and actual need to conduct blast works. Nevertheless, there is an effect of directed interference which means that with an increase in the number of sources the interference occurs in specific directions. Number and location of faces where blast works are conducted, enable controlling the effect. In Figure 6 there are results of numerical modelling of areas where 40 Hz waves interfere in heterogeneous medium characterised with Figure 5. The frequency was chosen basing on research into dominant frequencies in blast works induced vibrations in one of copper ore mines.



a) b)

Fig. 6. Distribution of longitudinal wave P seismic vibration interference intensity for: a) two seismic sources, b) four seismic sources. Dominant frequency of vibrations 40Hz

Increase in the number of seismic sources clearly changes distribution and dimensions of zones where waves interfere with one another at different levels of intensity. In the figures, areas of constructive interference are marked brown and yellow, and of its lack with green and blue. A greater number of sources generating waves enables locating the area of interference more precisely. In reality for vibrations induced with blast works it is impossible to obtain the classical phenomenon of constructive interference mainly because of lack of monochromaticity of the vibrations. Nevertheless the determined locations of interference zones, as it is shown in Figure 6, show areas where they overlap for the assumed dominant frequency.

Time delay and sequence of detonating explosive charges

A crucial element of synchronising blast works is sequence and relative time of detonating explosive charges in given mining faces. Detonation time (so-called time delay) is associated with the distance, which given vibration packets have to cover between the mining face and the interference zone. Sequence of detonations has to ensure that waves reach the interference zone simultaneously, preferably synchronised.

Time T_1, T_2, T_3,..., T_n of detonating explosive charges in mining faces 1, 2, 3, … n is calculated basing on either direct measurements of time (velocity) of waves passing or is selected basing on a model of velocity field, obtained with curvilinear seismic tomography, with the following formulas:

$$\left.\begin{aligned} T_1 &= \int\limits_{III_1} \frac{ds}{v(x,y,z)} \\ T_2 &= \int\limits_{III_2} \frac{ds}{v(x,y,z)} \\ &\vdots \\ T_n &= \int\limits_{III_n} \frac{ds}{v(x,y,z)} \end{aligned}\right\} \tag{8}$$

where:

ds — element of way along a seismic ray,

$v(z,y,z)$ — function of spatial variables x, y, z describing the model of velocity field of seismic wave propagation.

Wave vibration packets propagating along seismic rays described with curves III_1..., III_n in medium I ought to reach the selected point of zone IV simultaneously. To obtain the effect it is necessary to determine the longest time T_i among the values of T_1, T_2, T_3,..., T_n. Then time delays, which ought to be applied with time T_1, T_2, T_3,..., T_n of detonating explosive charges 1, 2, 3,..., n, are as follows:

$$\left.\begin{aligned} \Delta T_1 &= T_1 - T_i \\ \Delta T_2 &= T_2 - T_i \\ &\vdots \\ \Delta T_n &= T_n - T_i \end{aligned}\right\} \tag{9}$$

Sequence of values of time delay is a schedule of detonating given mining faces.

Measuring the effect of overlapping blast induced vibrations

Classical phenomenon of wave interference is possible only if the condition of their full coherence is met. Vibrations induced with blast works do not meet the condition. In reality they are short packets of elastic vibrations with a specified amount of energy. In the areas where they interfere there may occur an increase in the stream of energy j. Its value can be determined with the dependence:

$$\left.\begin{aligned} \varphi &= \text{const} * \int_{t1}^{t2} v(t)^2 \, dt \\ v(t) &= \sqrt{v_x(t)^2 + v_y(t)^2 + v_z(t)^2} \end{aligned}\right\} \tag{10}$$

where:

const	—	constant, for simplicity assumed to be equal 1,
$v(t)$	—	absolute value of vibration particle velocity vector,
$v_x(t)$	—	component X of particle velocity vector,
$v_y(t)$	—	component Y of particle velocity vector,
$v_z(t)$	—	component Z of particle velocity vector,
t_1	—	initial time of seismic packet,
t_2	—	final time of seismic packet.

For example, for the conducted *in situ* tests (Kabiesz & Lurka, 2014) average values of the stream of energy from single (out of phase) detonations of explosives were $7.01 \cdot 10^{-11}$ J/m^2, while for two synchronized explosions $12.77 \cdot 10^{-11}$ J/m^2, i.e. 55% increase. Hence it is an apparent indicator that there has occurred constructive interference of two tested seismic signals.

Possibility of synchronizing blast works in practice

Meeting the condition of simultaneous presence of vibrations in a selected area of the rock mass requires very precise synchronising of detonation times of the planted explosives.

It is a technical issue, yet it is crucial if the effect of overlapping vibrations is to be obtained. Due to high velocity of their propagation in the rock mass (up to approximately 6000 ms^{-1} in homogeneous hard rock e.g. anhydrites) minimum values of time delay ought to be as low as possible. Contemporary electronic systems of detonating explosives, consisting of electronic detonators (Fig. 7), programming and detonating systems, provide minimum time delay of 1 ms, and their accuracy is ±0.05 ms (Batko & Wizner, 2008). In practice, it means that for the above mentioned velocity a seismic wave covers a distance of 6 m in 1 ms and determines the minimum distance between explosive charges for which time delay ought to be determined.

Synchronised blasting procedure

The elements of assessing possibility to obtain the effect of blast work induced vibrations overlapping presented above can be basic stages of a procedure specifying the right course of action. Figure 8 presents them in the chronological order of realization. The procedure contains actions of analytical nature, as well as of organizational and practical one. Its critical stage is precise determination of the time delay and the schedule of detonating given explosive charges. For its realisation it is necessary to apply an electronic detonating system, which guarantees following the determined time delay.

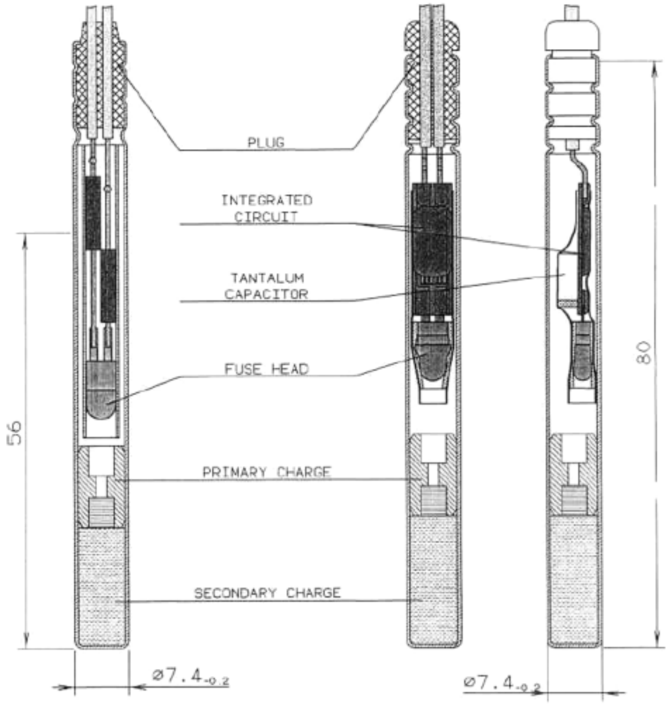


Fig. 7. Electronic detonator DYNAenergetics (LRI et al. 2009)

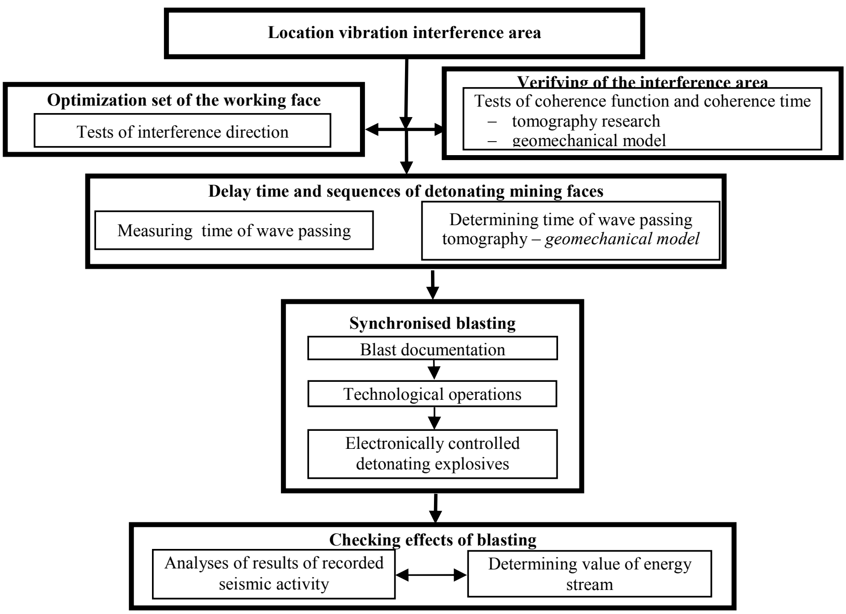
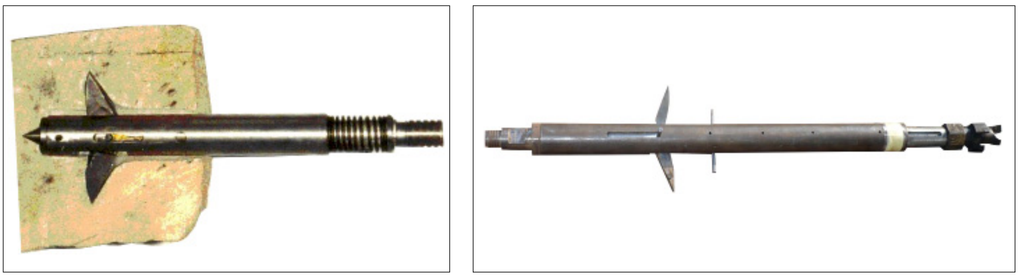


Fig. 8. The most important elements of procedure to synchronize blast works

4. Improving intensity of rock destruction

The fundamental aim of blast works, applied as a preventive measure against seismic and methane hazard, is to disintegrate the structure of rocks. Increasing intensity and range of fracture zones results in decreasing amount of elastic strain energy accumulated there (Bukowska et al., 2007; Drzewiecki, 2004, 2015) and creating conditions for a better desorption and migration of methane (Drzewiecki, 2004a; Konopko & Makówka, 1998; Krause, 2005; Makówka & Drzewiecki, 2011). The range of detonation effect zone in strong rocks is at most 3¸4 metres measuring from the axis of the blast hole (Przeczek et al., 2005; Batko, 2002; Hanukajew, 1974; Siskind et al., 1973), hence effective application of the preventive measure requires drilling a dense grid of holes. The unfavourable situation inspired attempts of improving efficiency of fracturing rocks undertaken at the Central Mining Institute. The result was devising directed rock fracturing: UHS and USS (Konopko et al., 1993; Konopko et al., 1996, 1996a; Konopko & Kabiesz, 1997) together with the right equipment – Figure 9a. The works aimed at perfecting the method through redesigning a tool to cut so-called starting notches (Fig. 9b) and modifying blasting technology were started. They will enable employing the effect of directed fracturing initiated in the starting notch, and then a deep penetration of post-blast gases in the rock environment – Figure 10.



a) b)

Fig. 9. Device to cut starting notches in bore holes: a) near the bottom, b) anywhere along a borehole

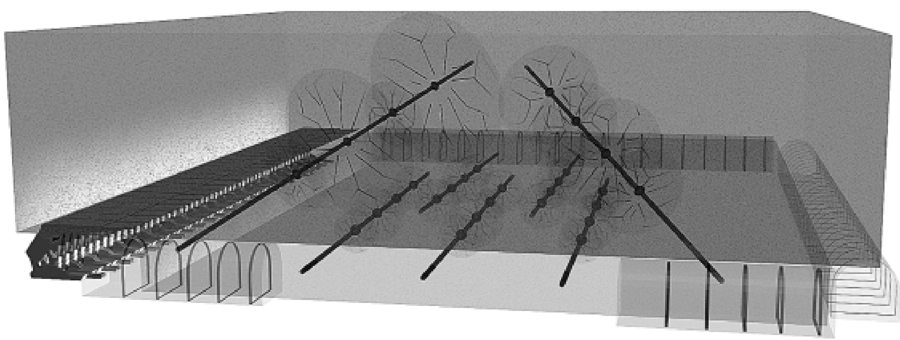


Fig. 10. Sketch of planned intensive fracturing of a coal seam and the overlying rock mass with boreholes with starting notches

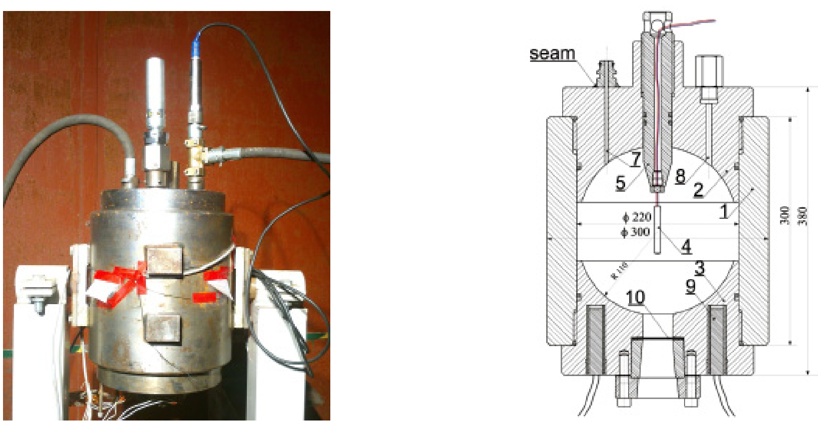
Device for cutting starting notches

To disintegrate the structure of rocks means either to create new fractures (cracks) in them or to increase width and propagation of the existing ones. It is the result of the influence of the pressure of post-blast gases or hydraulic medium. It is also possible to increase efficiency of such a process by using so-called starting notches. They are wedge-shaped notches artificially made (mechanically, hydraulically) in a bore hole. The notches contribute to concentrating stresses which facilitate cracking in the deformed material.

The undertaken works are aimed at manufacturing a mechanical device cooperating with a drill rig, which makes at the same time a bore hole and a system of starting notches perpendicular to the axis. The solutions which have been applied so far (Konopko et al., 1996a) enable making such a notch only close to the bottom of a borehole. A starting notch can radically increase the range of destructive fracturing effect in the rock mass by several times.

Tests of characteristics of explosives

Effectiveness of rock fracturing with blasting technology depends on many factors, including values of pressure of the post-blast gases on the walls of existing fractures (including starting notches) and the time of their action. That is why, taking into account specific conditions of conducting blast works (e.g. high initial values of pressure in blast holes) research has been initiated at GIG. It is aimed at determining the desired characteristics of mining explosives, including new formulas of explosives. It was assumed that such explosives should have sufficiently long burn time, maintaining dynamics of the process, which will form a dense grid of fractures around a starting notch and limiting effect of destroying rocks/coal in direct vicinity of an explosive charge. To conduct such research it was necessary to design and build a site to test dynamics of combusting materials in complex conditions of pressure and temperature (Drzewiecki & Myszkowski, 2015). The main element of the site is a tests chamber (Fig. 11), where explosive charges are detonated, together with a hydraulic pump and high-frequency measuring set which records results of tests in digital form.



a) view of test chamber b) cross-section

Fig. 11. Chamber for tests of explosives

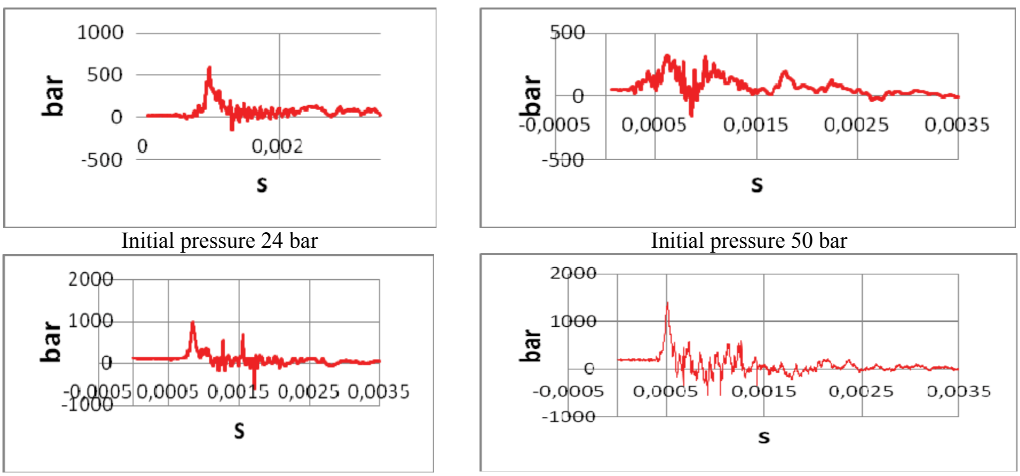
Body 1 of the tests chamber (Fig. 11b) is a thick-walled high performance steel cylinder, which is connected with two steel elements with internal surfaces shaped into concave hemispheres (upper element 2 and lower element 3). In the spherical void a sample of tested explosive with detonator 4 is placed. To obtain given values of pressure and ambient temperature the chamber is filled with water. Pressure within the chamber is obtained with a hydraulic pump, and the temperature by heating the water with four heaters 9. To provide safety during tests in the lower element of the chamber there is a safety hole covered with steel plate 10. The steel plate is the weakest element of the tests chamber and during detonation it is destroyed. Another safety measure is the fast relief valve with pressure regulation.

The results of initial tests showed that the measuring and recording set, as well as safety measures work properly. Sample results of the first tests are presented in Table 2 and Figures 12-13.

TABLE 2

Results of tests of electric detonators and samples of explosives

No.	Explosive	Initial pressure, bar	Tempe-rature, °C	Maximum value of pressure, first impulse, bar	Length, first impulse, µs	Average value of pressure, first impulse, bar
1	detonator ERGODET 0.45 A 9.8 MPa 70°C	24	5	583.3	242	334.7
2		50	5	317.5	–	
3		100	5	990.8	223	447.0
4		200	5	1412.2	273	625.3
5	emulsion SK/SN	200	5	1091.5	141	543.7
6		200	5	959,8	182	514.7
7	metanit E7H	200	5	842.2	162	516.8
8		25	61.7	502.5	212	276.9



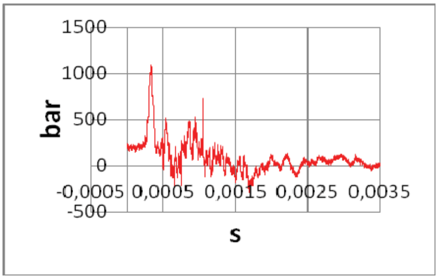
Initial pressure 24 bar

Initial pressure 50 bar

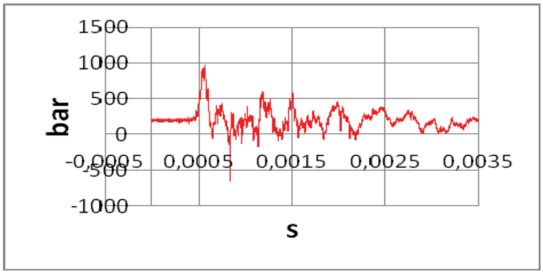
Initial pressure 100 bar

Initial pressure 200 bar

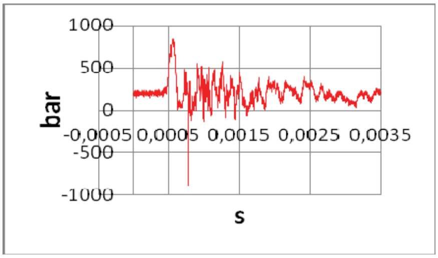
Fig. 12. Recorded changes in pressure after detonating electric detonators ERGODET 0.45 A 9.8 MPa 70°C



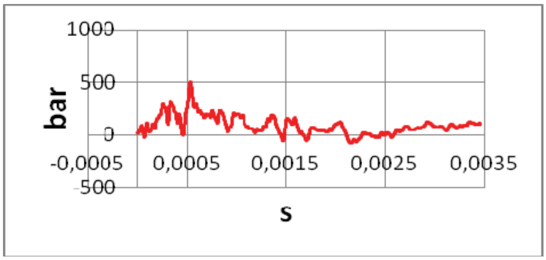
Initial pressure 200 bar
emulsion SK/SN



Initial pressure 200 bar
emulsion SK/SN



Initial pressure 200 bar
metanit specjalny E7H



Initial pressure 25 bar
metanit specjalny E7H

Fig. 13. Recorded changes in pressure after detonating samples of explosives

It is expected that the device will be used to test characteristics of new types of explosives, including the slow burning ones, under changing conditions of pressure and temperature. It has to be emphasized that materials of prolonged burn time and the new design of the device to make starting notches are a contribution in improving effectiveness of rockburst and methane hazard prevention.

5. Summary

Natural hazards in underground mines require actions aimed at preventing their occurrence and limiting their intensity. One of the most common techniques preventing these hazards is destress blasting conducted usually in form of classical long- and short-hole blasting. To increase the quality in controlling mining hazards and improve conditions of mining process require modification of the used the measures. The scope of the paper presents such attempts undertaken at the Central Mining Institute. Conditions to obtain the interference phenomenon of seismic waves generated by blasting in a selected location in the rock mass, actions aimed at improving efficiency of rock fracturing with blasting through making systems of so-called starting notches and testing characteristics of explosion of both non- and classical explosives under unusual temperature and pressure conditions are discussed.

During the investigation of seismic waves interference generated by blasting in a selected fragment of the rock mass it was shown that:

- seismic wave packets generated by blasting are not coherent,
- the interference effect of seismic wave packets depends on their coherence time and seismic velocity field in a heterogeneous medium,
- it is possible to indicate location of the areas of seismic interference,
- to obtain interference of seismic waves generated by blasting it is necessary to determine time delays of these blasting,
- accurate time delays of blasting can be obtained only utilising electronic detonation systems,
- values of seismic energy flux integrated in time for several seismic wave pockets can be used as an indicator of seismic interference,

The research on improving fracturing efficiency and tests of characteristics of explosives (classical and new types) are in preliminary stage. The following conclusions can be formulated:

- a device to make multiple starting notches in a borehole has been designed and manufactured,
- a stand for tests of explosives under increased pressure and temperature conditions has been designed and manufactured,
- tests of the stand and initial tests of electric detonators and samples of explosives have been conducted.

We hope that presented analysis and tests will contribute to improve effectiveness and efficiency of blasting methods in preventing mining hazards. They will hopefully improve work safety in mines and contribute to improve profitability of mining .

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