Researching acoustic radiation spectrum of the mining equipment used for controlling stress state of a face space

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Abstract. The procedure for estimating harmonic spectrum components of vibroacoustic disturbances produced by operating equipment and sounding acoustic signals which appear during the rock failure caused by operating body of a combined machine, drilling bit, plough-type machine, pneumatic coal pick, or impact effect of a special mechanism for realizing the method of continuous control of a face space stress state with the help of spectral acoustic method was worked out.

1. Introduction

The underground development of seam mineral deposits at the stages of development, preparation works and extraction are accompanied by dangerous geodynamic phenomena when the stresses grow to a critical value. These dangerous geodynamic phenomena are: coal, rock and gas outbursts, rock bumps, out-squeezing, rock bursts, roof caving, coal and rock rushes, rock tectonic bursts and shakes, water, clay and effluent breakouts from the drowned wastes and quick ground [1-3]. That is why a discreet, continuous control of a stress state is important to fulfill. Application of traditional unloading methods for measuring stresses is rather time and labour consuming; they are discreet in time and are characterized by poor accuracy of the measured values [4, 5].

There are less consuming geophysical methods such as: a method of acoustic emission or spectral-acoustic method. They are continuous methods and do not require drilling check bore-holes so they do not practically interfere with the mining process [6]. It allows controlling the stress state in the process of mining when the danger of gas-dynamic phenomena manifestation is the most probable one.

The method of the acoustic emission (AE) contains the data on fracture propagation intensity in a massif though there is no vivid functional connection of any acoustic emission parameters with the values of actual stresses. Apart from the abovementioned method spectral-acoustic method, as it will be demonstrated further, has such functional connection and that is the reason why it prevails over other methods for organizing continuous monitoring of a stress state. In this method, the estimation of a face space stress strain state is done by analyzing the parameters of acoustic radiation produced in the process of coal rock failure caused by an operating body of a combined machine or other mining equipment that influences on the face [7].

The cutting bodies of the tunneling machines, drilling rings and other mining equipment crash coal rocks during the operation. The crashed area emits elastic (acoustic) vibrations in a rather large frequency band. Assuming that the vibrations are a periodical $U$ function from time $t$ with the period $T$ then it can be introduced by Fourier trigonometric series. This is an infinite sum of simple trigonometric functions with adequately customized amplitude $A_k$ and initial phase $\phi_k$ in the form:

$$
U(t) = \sum_{k=-\infty}^{\infty} A_k \sin(\omega_k t + \phi_k)
$$
\[ U(t) = \frac{a_0}{2} + \sum_{k=1}^{\infty} A_k \cos(k \cdot 2\pi f_{1}t - \varphi_k), \]

(1)

where: \( a_0 \) is a constant component; \( k \) is a number of the harmonic; \( f_{1} = 1/T \) is the frequency of the main harmonic.

Amplitude harmonic of acoustic vibrations \( A_k \) with the distance from the source changes according to exponential law [9]:

\[ A_k = A_{k,0} \exp(-\alpha_k d), \]

(2)

where \( A_{k,0} \) is an amplitude of \( k \)-th source signal harmonic, B; \( \alpha_k \) – is an attenuation coefficient of \( k \)-th harmonic, m\(^{-1}\); \( d \) is a distance from the source of the signal to its receiver, m.

The attenuation coefficient depends on the signal frequency and a stress state. It is known that in a solid body \( \alpha \) is proportionate to signal harmonic frequency \( f \) and inversely proportionate to average stresses in a massif \( \sigma \). So, \( k \)-th harmonic attenuation coefficient can be expressed as [10]:

\[ \alpha_k = \alpha_0 \frac{f_k}{f_0} \beta \frac{\sigma_l}{\sigma_c}, \]

(3)

where \( \alpha_0 \), the attenuation at a certain frequency \( f_0 \), belongs to a working range; \( \sigma_l \) and \( \sigma_c \) – limit and current values of average stresses in a massif, respectively; \( \beta \) is a proportionality coefficient defined by a massif properties.

According to a spectral-acoustic prediction principle the coefficient of relative stresses \( K_{r.s.} \) is defined by the ratio of acoustic noise amplitudes formed by operating mining equipment measured at high and low frequencies [7]:

\[ K_{r.s.} = \frac{A_h}{A_l}, \]

(4)

where \( A_h \) and \( A_l \) are current amplitude values detected by amplitude detectors of high and low spectrum areas, respectively.

That is why the analysis of frequency content of “noses” formed by operating combined machines or other equipment allows estimating the stress state of a face space.

However, several mining machines: combine machine, drilling ring, conveyor, booster fan etc. operate in a controlled mine working and double entries simultaneously. Acoustic radiation formed while crashing coal rocks in the process of mining machine operation, mostly it is a combined machine, is the basic one for using spectral-acoustic method. We may call it sounding radiation. Thus, sounding radiation is a radiation sum that is formed while crashing coal rock and intrinsic radiation of an operating body that crashes rock mass when contacting with it. The radiation produced by other equipment appears to be acoustic disturbances for spectral-acoustic method. Due to this, the problem of estimating the disturbance influence on the controlling results arises.

The objective of the paper is to justify the procedures for researching the acoustic radiation spectrums, which are formed while crashing coal rocks by different types of mining equipment; this equipment may be used for sounding rock massif or it may be a source of acoustic disturbances.

2. Mining equipment for a development working (opening) that generates acoustic radiation

In accordance with normative acts, as a rule, spectral-acoustic method for controlling stress state in a face space is fulfilled from the development workings. Thus, firstly, we study the equipment applied in these workings, supposing that further, the research on studying the equipment emission spectrums
could be done in stopes. It is important as often, during dynamic phenomena prediction in long faces the initiator of sounding acoustic radiation formation could be a shearer.

Implementing modern schemes for preparing mining fields for extractions the scheme of double and triple entries excavation are applied [10].

Figure 1 demonstrates the scheme of double entry excavations simultaneously with two selective heading machines, indicating operating mining equipment which is the initiator of sounding acoustic radiation (in this case it is a tunneling machine in a belt entry) and the source of the disturbances (the rest mining machines and equipment).

![Figure 1. The scheme for controlling acoustic-signal while double entry excavation simultaneously with two selective heading machines: 1 – tunneling machine; 2 – drilling rig, 3 – belt conveyor, 4 – shuttle car; 5 – booster fan; 6 – belt elevator.](image)

According to the scheme of developing the workings the following mining machines and equipment are applied:

1. Tunneling machine P-110-01 – 2 pieces;
2. Drilling rig RAMBOR RTM 3/176 – 4 pieces;
3. Belt conveyor 2PT-120;
4. Shuttle car ВС-30;
5. Booster fan ВМ-6М;
6. Belt elevator PL-80.

To realize the method an acoustic vibration receiver – geophone is installed into a drilled in the wall of the working borehole with 1.5 m depths (see figure 1). The source elastic vibrations spread along the rock massif and reach the receiver. Spectral analysis of a “noise”, registered according to the given algorithm, by the receiver, for example, according to equation 4, allows estimating stress state of a face space [7, 11-12].

For receiving and processing acoustic radiation signal, corresponding equipment has been worked out by several companies. The most popular among Kuzbass mines is the System of rock massif acoustic control and dynamic phenomena manifestation SAKSM. As SAKSM designer asserts, the system, on the basis of acoustic signal sounding parameters, allow predicting the coal seam area dangerous on sudden outbursts, rock bumps, sudden coal outsqueezing, dynamic crash of bedrocks with intensive gas emission out of gas bearing layers; predicting worsening of a massif face area.
condition and negative manifestation of a rock pressure; predicting geological dislocations ahead of the face; controlling drilling safety and estimating the effectiveness of relief wells, hydro-ploughing of a coal seam; determining the parameters of rock massif stress strain state; controlling technological processes that take place in the face.

SAKSM system went through the probation at OAO “SUEK-Kuzbass” “Mine named after S.M. Kirov” in development workings and stops of coal seams Polenovskey and Boldyrevskey, which are dangerous on rock bumps [13]. At present, this system is installed in all the mine of this joint-stock company.

Common elements of processing acoustic signal in such systems are the following: receiving of a wide band sounding acoustic signal generated by operating equipment and its transformation into electric form by the acoustic converter (i.e. geophone), continuous automatic measuring of the amplitudes, analog-to-digital converting of a signal, forming test samples out of stream readings of analog-to-digital converter, fulfilling the procedures of fast Fourier transform and defining amplitude discreet series of spectral components (harmonics), their time averaging and further processing according to the accepted algorithm, for example the one that is introduced in this paper [14].

In the described scheme of developing the working one of the combined machines is a source of the acoustic radiation (useful in this case) which sounds the face space. The rest equipment, during the operation period, emits acoustic signals, which are referred to the disturbances. It is seen from the scheme that disturbance-forming equipment can be placed in different distances from the equipment that generates useful radiation. Depending on the distance between them the contribution of the disturbance into the processed signal can vary changing the relative stresses coefficient. That is why it is important to know the parameters of this radiation.

The sources of the acoustic vibrations (noise, vibrations) are the dynamic forces that act in machines of different origin: mechanical, electro-magnetic, aerodynamic and hydrodynamic [15]. The source of the acoustic emission of the mechanic nature is moving mining equipment structure units. Amplitude-frequency characteristic of this emission depends on the presence and on the fault type in these elements [15, 16].

As an example of the emitting source, figure 2 presents kinematic diagram of the combine machine operating body driving mechanism II 110-01 with two axial cutting heads with 45 cutters per each.

![Kinematic diagram of a combined machine executive body drive gear P 110-01](image)

**Figure 2.** Kinematic diagram of a combined machine executive body drive gear P 110-01: EE – electric engine; EB – executive body; I, II, III, IV, V, VI, VII, VIII – reducing gear axles; 1, 2, 3, 31, 4, 41, 51, 61, 7, 8, 9, 10, 11, 12, 13, 14 – reducing gear toothed wheels.
Each of the indicated elements rotates with its own frequency and depending on its mass, rotation speed, quality of the lube and the degree of the faults (out of balance conditions, misalignments, mechanical weakening, bearings and gear faults etc.) it generates acoustic radiation that differs by amplitudes and radiation frequency of other elements [15]. During the operation, radiation frequency ranges of some elements stay permanent, however, signal amplitudes at corresponding frequencies will grow as far as wearing-outs and faults continue. The radiation signals from some elements superimpose on one another forming a complex amplitude-frequency-modulated polyharmonic vibrations.

3. Mining equipment acoustic radiation (vibrations) researching technique, which is applied for sounding face space under the condition of acoustic disturbances

For the purpose of generating sounding radiation (vibrations) only the equipment that influences on a mine rock such as tunneling machine, shearer and drilling unit, plough-type machine, pick-hammer is used in spectral-acoustic method of controlling stress state of a face space. Sometimes acoustic radiation is created by a specially designed percussion hammer mechanism or a heavy hammer.

The sources of acoustic disturbances are all the above-mentioned types of equipment that generate sounding radiation (vibrations) but operating in neighbouring workings and not influencing directly on a mine rock but producing acoustic radiation (vibrations). They are drilling rings, conveyors, shuttle cars, RMS, belt elevators etc.

Sounding the rock massif radiation (vibrations) consists of: vibrations of the rotating elements of mining equipment and fluctuations produced by picks of a combined machines executive body or drilling rings that destroy the rock mass.

The receiving converter (e.g. geophone) catches acoustic vibrations radiated by all types of operating equipment but weakened due to the attenuation at the area between the source of a signal and its receiver. Together with this radiation geophone also catches acoustic emission pulses, formed in the process of fracture propagation in roofs and coal seams as a result of rock pressure and gas in-situ pressure influence. The given type of emission apart from vibroacoustic disturbances and sounding signal of a cutting body of the equipment carries short-term impulse character.

In order to consider the influence of the acoustic disturbances on the estimating results of a stress state controlled rock massif area it is important to know amplitude frequency and time-response characteristics of the radiating sources and harmonic attenuation coefficient at their frequency. For doing this it is necessary to define:

- Spectral content of internal “noises” (vibrations) of an operating mining equipment;
- Spectral content of acoustic radiation produced while destroying rock mass by cutting element;
- Sounding signal and disturbance spectral components (harmonics) attenuation coefficient.

To achieve it a vibration analyzer is necessary to apply following the instructional manual.

There are two schemes for installing the vibration analyzer transducer towards the sounding source. According to the first scheme amplitude-frequency characteristics of internal vibroacoustic signals (vibrations) of the given equipment are studied. This is the reason of installing the transducer on the operating equipment.

According to the second scheme the acoustic radiation attenuation of sounding and disturbance forming sources in a rock massif is studied. For this purpose several boreholes are drilled in the wall of the working at a certain distance. And metallic cores of cylindrical form are installed inside. To provide reliable acoustic contact of the cores with the massif their diameter must be close to the diameter of the borehole and the time for their squeezing is to be taken into account. The vibration analyzer transducer is installed on the side surface of the cores. The attenuation coefficient of \( i \)-th radiation harmonics \( \alpha_i \) are defined according to the equation:
\[ \alpha_i = \frac{A_{i,1} - A_{i,2}}{r}, \]  

where \( A_{i,1} \) and \( A_{i,2} \) are the \( i \)-th harmonic amplitudes measured on the first, that is close to the source of the emission, and the second cores, respectively; \( r \) the distance between the cores. The distance \( r \) must be characteristic for spectral-acoustic method, i.e. within the range of 5-30 m from the source.

As a signal attenuation by exponential law of type (2) is done only in a far zone of an emitter (in the distance of 3-5 wave length [17]), the distance between the cores should be increased discreetly from the minimal 1 meter to the maximal 30 meters with the step for example 3 meter.

Based on the fulfilled researches it is planned to create three databases:

- Spectra database of internal acoustic radiation of the operating mining equipment which is used in underground mine workings;
- Radiation spectra of mining equipment cutting bodies during their work on coal massif;
- Acoustic radiation attenuation coefficients of different harmonics with the operating range of the frequencies (20-150 Hz) and operating distance between geophone and the emitting source (5-30 m) of spectral-acoustic method.

At present, to calculate harmonic components of the vibroacoustic signals formed by the driving gears and executive bodies of the mining equipment frequency response analysis is applied (see [15] as an example). According to this method spectrum harmonic components of several mining machines are set. As an example, table 1 presents rotating frequencies of a tunneling machine executive body elements P110-01, and table 2 presents relevant for the most energy carrying faults (chopping and impeller frequencies, misbalances, disalignments) frequencies of vibroacoustic signals of some mining equipment for drifting faces here the generation of vibroacoustic disturbances could take place [15].

### Table 1. Rotating element frequencies of a tunneling machine executive body elements P110-01.

| No. | Executive body elements | Number of teeth of a tooth wheel | Rotating frequency rpm | Rotating frequency, Hz | Rotating frequency rpm | Rotating frequency, Hz |
|-----|-------------------------|---------------------------------|------------------------|------------------------|------------------------|------------------------|
| 1   | Electric engine 2ЭДКОФВ250LB4 |                                | 1500                   | 25                     | 1500                   | 25                     |
| 2   | Axle I                 |                                  | 1500                   | 25                     | 1500                   | 25                     |
| 3,a | Axle II                | 18/39                            | 692                    | 11.5                   |                        |                        |
|     | Axle II                | 1 speed                          |                        |                        |                        |                        |
| 3,b | Axle II                | 29/37                            |                        |                        | 1176                   | 19.6                   |
|     | Axle II                | 2 speed                          |                        |                        |                        |                        |
| 4   | Axle III               | 19/48                            | 274                    | 4.6                    | 594                    | 9.9                    |
| 5   | Axle IV                | 17/35                            | 133                    | 2.2                    | 288                    | 4.8                    |
| 6   | Axle V                 | 17/37                            | 61                     | 1                      | 132                    | 2.2                    |
| 7   | Axle VI                | 16/35                            | 28                     | 0.5                    | 60                     | 1                      |
| 8   | Axle VII               | 35/33                            | 30                     | 0.5                    | 64                     | 1.1                    |
| 9   | Axle VIII              | 33/32                            | 30                     | 0.5                    | 65                     | 1.1                    |
| 10  | Executive body         |                                  | 30                     | 0.5                    | 65                     | 1.1                    |

As it is seen from the table, the introduced types of the equipment generate low-frequency vibroacoustic disturbances. In case such equipment is installed into the sensible zone of the geophone which belongs to the device for spectral-acoustic control of a face space working, than the signals, which it produces can influence on the defining of the relative stress coefficient. The closer the source to the geophone the stronger its influence is.
### Table 2. Vibroacoustic signal characteristic frequencies of mining equipment in a drifting face.

| No | Type of equipment                      | Characteristic frequencies , Hz |
|----|---------------------------------------|--------------------------------|
|    |                                       | driving gear  | working body |
| 1  | Tunneling machine P-110-01             | 25            | 45/99         |
| 2  | Drilling ring RAMBOR RTM 3/176        | -             | 20            |
| 3  | Belt conveyor 2PT-120                 | 24.75         | 1             |
| 4  | Shuttle car BC-30:                    |               |               |
|    | driving gear                          | 25/17/8       |               |
|    | conveyor driving gear and oil pump gear | 25/12.5       |               |
| 5  | Booster fan BM-6M                     | 50            | 350           |
| 6  | Belt elevator PL-80                   | 25            | 1.25          |

#### 4. Conclusion

1. Spectral-acoustic method of controlling stress state of a face space workings is affected by the influence of the vibroacoustic disturbances generated by the equipment placed in the controlled and neighbouring workings in case it is in the distance of geophone sensitivity.

2. To take into account the noise disturbances influence the technique for researching internal acoustic radiation (vibration) spectra of mining equipment which is applied for sounding face space and the emission produced by rock failure under the condition of the acoustic disturbances from other mining machines has been worked out.

3. The researches fulfilled in accordance to the Technique will allow creating three data bases: internal acoustic radiation spectra of the mining equipment operating in workings; radiation spectra of mining equipment cutting bodies which develop the rock massif; acoustic radiation attenuation coefficient of different harmonics within the operating range of frequencies.

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