Basic tasks for improving spectral-acoustic forecasting of
dynamic phenomena in coal mines

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Abstract. A number of tasks for improving the spectral-acoustic method for forecasting dynamic phenomena and controlling stress condition in coalmines is considered. They are: considering the influence of a gas factor on the danger indicator, dependence of a relative pressure coefficient on the distance between the source and the receiver of the probing acoustic signal, correct selection of operating frequencies, the importance of developing the techniques for defining the critical value of the outburst danger index. The influence of the rock mass stress condition ahead of the preliminary opening face on the relative pressure coefficient defined for installing the sound receiver in the wall of the opening behind the opening face is also justified in the article.

1. Introduction
Spectral-acoustic method for forecasting dynamic phenomena manifestation starts to be very popular with the coal mines operating on the former USSR territory. It is widely used in Donbass for forecasting high rock pressure zones where while entering, some rock bumps, sudden coal and gas outbursts and other similar phenomena can manifest themselves in case the danger mitigating measures are not performed. At present, the equipment supporting this method is used in nearly all coal mines of “SUEK-KUZBASS” JSC. However, the method itself has a number of drawbacks and the authors introduce several issues which being solved can improve the method and subsequently increase the adequacy of the forecast.

The work aim: to analyze basic drawbacks of a spectral-acoustic method for forecasting dynamic phenomena manifestation and to propose possible ways of their elimination.

About naming the method
The analyzed forecasting method carries different names. Historically, its first name was the forecasting method based on amplitude-frequency response characteristics of a seam. The name did not come into use, as it would seem to be too long. In various sources, one can find the reference to the acoustic method. This name also failed to be used as there were plenty of acoustic methods for controlling rock mass and the name did not bear its true nature. In current regulatory documents this method is referred as “…..based on the characteristics of artificial acoustic signal”. As we see it, this name is overly long and is not correct in revealing the nature of the forecasting method.

We offer to name it as a method of spectral-acoustic analysis as it fully reveals the idea of this forecasting method and we believe it will be widely used both in scientific literature and in regulatory documents. This supposition is based on the idea that the spectral-acoustic method for controlling rock
mass stress condition is in researching the frequency content of acoustic vibrations. The source of
the vibration is the operating mining machinery effecting on the rock mass by mining combine or plough-
cutting tools, drilling rig, a coal pick hummer etc. Any impact device that generates broadband
acoustic signal can be the source of the vibration. The acoustic vibrations should get through the
controlling rock mass area starting from the cutting unit of the operating mining machinery that
produced it to the receiver installed in the wall of the opening. (It is obvious that the source of the
signal is rather natural and the definition “artificial” is incorrect.)

2. The idea of the method

Primarily, this method was developed by S. Mirer’s researching team. It was applied for the
forecasting of coal and gas sudden outbursts [1]. This method was based on experimentally identified
regularity which revealed that as soon as the opening face approaches to the outburst danger zone the
amplitude of high frequency components of the noise spectrum of the operating mining machinery
grew stronger than the amplitude of low frequency components. So this relation was identified as an
outburst danger index. Therewith the authors of the method supposed that thus defined outburst index
took into account all basic outburst factors: rock mass pressure, inter-bedding gas pressure, coal
strength etc. and such outburst danger criteria based on the results obtained by analyzing the noise of
the mining machinery operation on several Donbass mines was true for all world coal-mining fields.

However, the case record of Kuznetsk, Vorkuta and Karaganda coal-mining fields proved that it
was not true. The analysis of acoustic wave propagation revealed that the growth of the relation of the
amplitude of high frequency components of the noise spectrum to low frequency components while
retaining the structure of a coal seam and the strength of its layers was caused by the increase of an
average stress around the controlling rock mass zone. It can be explained as in a solid body in a first
approximation the acoustic vibration decay coefficient \( \alpha \) is linearly proportional to vibration
frequency \( f \) and inversely proportional to the current average stress \( \sigma_c \)[2]:

\[
\alpha \sim \frac{f}{\sigma_c}.
\]

Herewith the non-associated gas pressure quantity in interstices, coal macro- and micro- cracks
does not influence on the acoustic vibration decay coefficient. Thus, the danger indicator for dynamic
phenomena manifestation in the form of the relation of high frequency and low frequency components
of the noise is also called relative stress coefficient.

3. The tasks that may help in improving spectral-acoustic forecast of dynamic phenomena
manifestation

Practical application of the spectral-acoustic method for forecasting gas-dynamic phenomena (GDP)
in Donbass mines proved to be of high integrity. As it seems, in Donbass, (with deep deposits of coal
seams and their low thickness) sudden outbursts start from the local rock burst and then transform into
a sudden outburst. Here the stress condition factor has a greater influence on the rock mass instability
than the gas factor [3]. Taking into consideration this peculiarity of a spectral acoustic method it
started to be successfully applied in Kuzbass mines for forecasting dynamic phenomena manifestation
and basically for rock bursts [4].

Despite the positive experience of applying the spectral-acoustic method for controlling the rock
mass stress condition there are several tasks which are meant to be solved for increasing the integrity. They are:

Correcting the danger criteria of gas-dynamic phenomena manifestation defined by the application
of a spectral-acoustic method. The idea is in taking into account the influence of other danger factors
beyond the rock pressure such as inner-bedding gas pressure and coal strength in particular.

Considering the dependence of the danger criteria of gas-dynamic phenomena manifestation
(relative stress coefficient) on the distance between the source and the receiver of the acoustic
vibration.
Defining the sensitivity zone of the method while controlling the stress condition of the rock mass ahead of the preliminary opening when the receiver of the acoustic vibrations is installed in a borehole of the wall of the opening in a certain distance from the face.

Justifying the operating frequencies for implementing the method.

Updating the hardware-software complex for spectral-acoustic forecasting of gas-dynamic phenomena manifestation.

Working out the techniques for defining the critical value of the outburst danger index for a current state of the opening face.

The setting of the first task is vivid as the gas factor: coal gas content and non-associated gas pressure in cracks and interstices causing the development of sudden coal and gas outbursts and similar types of GDP influence greatly on the danger of gas-dynamic phenomena manifestation. The danger of GDP development also depends considerably on the coal strength and its humidity.

The setting of the second task is conditioned by the fact that the current relative stress coefficient value $K_c$ defined as a relation of high frequency $A_h$ and low-frequency $A_l$ amplitude components of acoustic vibration spectrum decreases exponentially as far as the “noise” source distances from its receiver according to the expression (2):

$$K_c = \frac{A_h}{A_l} = e^{-\frac{\sigma_l-x}{\sigma_c}},$$

where $\sigma_l$ and $\sigma_c$ – respectively, the average limit and the average current values of stress in adjoining the working face zone of the rock mass, where the outburst danger situation is formed; $x$ is the distance between the source and the receiver of the sound.

In this expression $C$ parameter defines the sensitivity of the method and is equal to (2):

$$C = \frac{\alpha_o \beta (f_h - f_l)}{f_0},$$

where $f_h$ and $f_l$ – the characteristic frequencies of upper and lower zones of the “noise” source, $\alpha_o$ – decay coefficient at a frequency $f_0$; $\beta$ - proportionality factor determined by the rock mass property.

Thus, the critical value of the index is not only a constant quantity for the mines of a certain coal basin or for a singular mining seam but it varies as far as the face distances from the installed acoustic vibration receiver.

One of the possible solutions is studied in the paper [2]. However, it stipulates the adjustment of the transmitting coefficients in accordance with the frequencies (application of equalizer) as far as the opening face advances further and technically, it is rather difficult to do. It may be better to work out a convenient technical solution.

The third task is conditioned by the fact that while controlling the stress condition ahead of the preliminary opening face the source and the receiver of acoustic vibrations are placed behind the rock mass zone (see figure 1). However, even in this case the received acoustic signal bears the information about a stress condition of a rock mass ahead of the opening. It can be explained as follows:

Firstly, the acoustic wave while moving cannot be focused on the volume of space the cross-sectional effective radius of which is smaller than a half of the wavelength [5]. Therefore, a coal seam can be subjected to the radiation generated by the cutting unit of an operating mining equipment to at least this minimal depth.

We can estimate this value for spectral-acoustic method, which is realized by the equipment set (such as AK-1V) where the receivers of the sound are the geophones of CB-20 or CB-30 type. Their operating area is in the limits of 30-1500 Hz [6]. This range covers frequency content of wideband acoustic vibrations produced by a cutting unit of a mining combine. If the compressional wave (P-wave) velocity in the coal equals about 1600 meters per second then the operating wave length is
within the interval $\lambda \approx 1.1-50$ m. Therefore, if spherical sound waves propagated in straight lines from the wideband transmitter to the receiver then, depending on the frequency, the coal mass in the limits of the formed tube with the diameter over 0.55-25 m near the transmitter would influence on their decaying. The probing of the rock mass ahead of the preliminary opening face would go to that very depth. In reality, there appear a superposition of shear waves (S-waves) and compressional wave (P-waves) in the geophone operating area but it does not influence sufficiently both on the danger indicator of the dynamic phenomena manifestation and on the depth of the method’s sensitivity zone ahead of the opening face.

However, for the scheme of the sound propagation, depicted in figure 1, the receiver is positioned in a specific acoustic shadow area. That is why the diffraction of sound in the point of changing the direction of propagation will effect on the resultant acoustic field of a receiver. A qualitative evaluation of the sound diffraction effect can be obtained through application of Huygen's principle [7].

The principle states that any wave of any shape can be considered consisting of a large number of spherical waves of similar frequency (so called elementary wave). Each of such waves is propagated from its own starting point and possesses its own initial phase and amplitude. Thereby any wave front can be considered as an envelope of all these elementary waves with their starting points in the former wave front [7]. Consequently, the scheme of a single sound harmonic propagation from the transmitter to the receiver is viewed as follows (figure 2)

Figure 1. Scheme of the sound propagation starting from the source of the sound $S$ (for example, tunneling machine) to the receiver of the signal $R$ while forecasting outburst danger in the preliminary opening.

Figure 2. Scheme of a single sound harmonic propagation from the transmitter $S$ to the receiver $R$ according to Huygen's principle: 1- elementary spherical waves; 2- resultant wave front; 3 – half wave propagation trajectory from the transmitter to the receiver.

Figure 3 explains the case of the reflection caused by disjunctive dislocation. The front of the reflected radiation is obtained according to geometrical acoustics principle. Regulating the line thickness it demonstrates that the farther the distance from the radiation source $S$ the less the wave

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Figure 2 presents a vivid idea that the farther the receiving geophone is installed into the wall of the opening and the closer to the opposite side of the wall of the opening the cutting unit of a mining combine is then the wider the zone ahead of the opening face that acoustic wave radiation covers before reaching the geophone. Thus, the width of the zone can reach 2-3 half-waves i.e. critical probing depth ahead of the opening face for this model is around 1.5 m. It is obvious that the depth of such zone for a harmonic with bigger wavelength will be even larger.

It is known that gas-dynamic phenomena as sudden coal and gas outbursts and other similar ones manifest themselves near the dislocated zones. In this case to the sound that floated from the transmitter to the receiver according to the scheme depicted in figure 2, radiation that reflected from the dislocated area of a seam is added.

Figure 3 explains the case of the reflection caused by disjunctive dislocation. The front of the reflected radiation is obtained according to geometrical acoustics principle. Regulating the line thickness it demonstrates that the farther the distance from the radiation source $S$ the less the wave
amplitude. The closer the face to the dislocation the higher the amplitude of the radiation reflected from it. This radiation component goes through the face area twice before reaching the receiver (geophone) \( R \) installed into the borehole drilled into the wall of the opening.

Figure 4 demonstrates the scheme of formation the acoustic field around the geophone in case there is a plicative dislocation ahead of the opening.

The difference from the abovementioned case is that the reflection comes from the advanced zone of a seam in dislocated area but not from the plane interface of two structures. This peculiarity leads to broadening of the reflected signal in time.

Superposition of the waves propagated according to the schemes depicted in figure 2 (“direct” wave), figure 3 or in figure 4 (the wave reflected from the dislocation) takes place in a geophone zone installation. Frequency content of the resultant signal informs about stress condition of a face area.

*The importance of the forth task* is in the following. On the one hand, as it is seen from the relations (2) and (3) the greater the difference \((f_h-f_l)\) the higher the sensitivity of the method towards stress condition changes. On the other hand: the increase of the frequency \(f_h\) brings about the decrease of the sensitivity zone ahead of the preliminary opening face as the wavelength shortens in inverse proportion to the frequency (see task 3). It is necessary to keep in view that frequency content of the radiation from the cutting unit of an operating equipment depends both on the type of the equipment and on the thickness of the rock mass layers of a seam and adjacent strata. The latter is conditioned by a waveguide property, which every rock mass layer possesses. It provides minimal decaying on the frequencies with the wavelength commensurable to the layers thickness or divisible by it [8]. Frequency content interference in the measuring tract, if there any, also influences on the choice of the operating frequency band.

At present, there is no absolute answer as what operating frequency to choose. It can be explained by the fact that the known sets of stationary equipment for spectral-acoustic forecasting of dynamic phenomena manifestation AK-1M and CAKCM are produced by different companies with different principles of low and high frequency spectral range definition [4, 6].

*The fifth task* is set as the presently applied hardware- software complexes for forecasting dynamic and gas-dynamic phenomena by spectral-acoustic method commit a significant error in evaluating outburst danger, as first two abovementioned tasks have not been solved yet.
Another reason for errors in evaluating danger by this method is in discrepancy between basic parameters of digital signal processing (sampling frequency and, basically, sample length) and target values in some samples of the equipment meant for spectral acoustic forecasting [9].

The setting of the sixth task resulted from the acting “Instruction on forecasting dynamic phenomena”. This instruction states that the critical value of the outburst danger index for spectral-acoustic method should be initially defined according to the “noise” parameters of the operating equipment in the areas of mine opening which is evaluated as “not dangerous” by other suitable methods [10]. However, the Instruction dose not say anything about the quantitative evaluation of a danger level and states that the critical value of the outburst danger index (the derivation of which is not known) should be approved by the technical director (chief engineer) of the mining company. In other words, every mine is offered to work out its own techniques for defining the critical value of the outburst danger index.

The situation with arranging the forecasting of outburst danger using this method results from the lack of scientific background justification in particular, from the failure to take into account all basic outburst danger factors and rock mass parameters. The solution is in the development of the technique which can help to set a geophysical danger parameter for a certain opening face according to the instrumental criterion which is based on measuring the parameters that define the danger of GDP manifestation while test borehole drilling [11].

4. Conclusion
At present automated method for spectral-acoustic forecasting of dynamic phenomena manifestation, for sudden gas and coal outbursts in particular, does not have any valid scientific background justification and cannot compete with the instrumental method of current forecasting outburst danger based on the initial gas emission velocity and drill fines outlet during test borehole drilling. The solving of the abovementioned tasks will heighten the validity of the forecasting made by the automated method to the value that the instrumental method provides.

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