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THE USE OF TIME INTERVALS BETWEEN SEISMIC PHENOMENA IN THE RISK ASSESSMENT OF MINING SHOCKS IN ROCK MASSES

1. Introduction

One of the main problems of mining seismology is the preparation for forecasting the threat of the occurrence of high-energy shocks. Currently, the interpretation of seismic emission is conducted on the basis of the energy analysis of phenomena. In the case of copper mines, it is possible to assess these phenomena whose energy at source exceeds the value of 1E3 J. Due to the stochastic nature of the emission, its interpretation should be conducted using statistical methods. First of all, the statistical distributions are specified, and their parameters should be determined using the proper estimators. In order to get effective evaluations, it is necessary to use the correct number of analyzed sets. It is known from practice that the number should be not smaller than 30 elements. To achieve the correct resolution of risk assessment, time windows in which the data is collected should not exceed 72 hours. Which means that emission activity of the phenomena of energies exceeding the value of 1E3 J is too low and does not qualify for the analysis.

The article presents a method based on the use of the phenomena, the energies of which are smaller than the value of 1E3 [J]. These phenomena, which are commonly referred to as "traces", have a high activity which enables us to conduct statistical analyses. Since these traces, have low energy and are registered on too few measuring positions, it is not possible to locate their sources. Consequently, it is not possible to assess their energy. This is why, the concept of replacing the phenomena energy with time intervals between the phenomena was adopted.

Contrary to the energy, time intervals between the phenomena are related to the localization of the phenomena sources only to a very small degree. This is why, their values can

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be determined with high accuracy. It is assumed that it is possible to assess the course of the development of tendencies of the phenomena energy on the basis of the analysis of the time intervals discussed above. This assumption is based on the statistical dependency which links the logarithms of the energy of phenomena with the time intervals of such phenomena. Thanks to this dependency, it is possible to assess the expected value of the energy of the phenomena.

It therefore follows that on the basis of the statistical analysis of time intervals between the trace of the phenomena there exists an intermediate possibility of estimating the course of tendencies of change in time of expected value of energy. Taking into consideration the geomechanical interpretation of this course, it can be used for assessing the hazard degree of high-energy shocks occurrence.

2. The estimation of expected value of 'trace' energy

Seismic trace phenomena are characturised by a scope of energy which is too low to measure due to the number of measuring positions being too few. Consequently, it is not possible to assess their energy source. This is why, it was decided to conduct the analysis of such phenomena on the basis of the time intervals of the phenomena. In this way, the expected value of the traces energy is estimated. The assessment obtained is proportional to the actual energy of the trace phenomena because it is determined in an indirect manner. Such proceedings are justified by the fact that in seismic emission there exists a linear statistical dependency which links the logarithms of phenomena energy with the time intervals between them, that is [4]:

$$u_k = \delta \cdot \log \frac{E_k}{E_0} + \sigma + \varepsilon_k \tag{1}$$

where:

u_k — time intervals between phenomena,
E_k — energy of phenomena,
E_0 — energy references,
ε_k — random values,
δ, σ — coefficients.

From dependency (1) it results that expected values of time intervals are proportional to logarithms of energy, that is [5]:

$$\bar{u} = \delta + \overline{\log \frac{E}{E_0}} + \sigma \tag{2}$$

where:

$\bar{u}$ — expected value of time intervals,
$\overline{\log(E/E_0)}$ — expected value of logarithm of trace phenomena energy.

It is known that to determine the parameter which represents the expected value of the time intervals it is essential to know their statistical distribution. It was assumed that their statistical distribution is described by the Weibull model in the following form [2, 5]:

$$F(u) = \begin{cases} 0 & \text{dla } u < u_0 \\ 1 - \exp[-\beta \cdot (u - u_0)^\gamma] & \text{dla } u \geq u_0 \end{cases} \tag{3}$$

where:

u_0 — the smallest value of time interval in the set of measurement data,

β, γ — parameters of the model of statistical distribution of intervals.

In accordance with this model, the expected value of intervals discussed above is described by:

$$\bar{u} = \gamma^{-1} \cdot \Gamma(\gamma^{-1}) \cdot \beta^{-\gamma^{-1}} \tag{4}$$

where: Γ is the Euler gamma function.

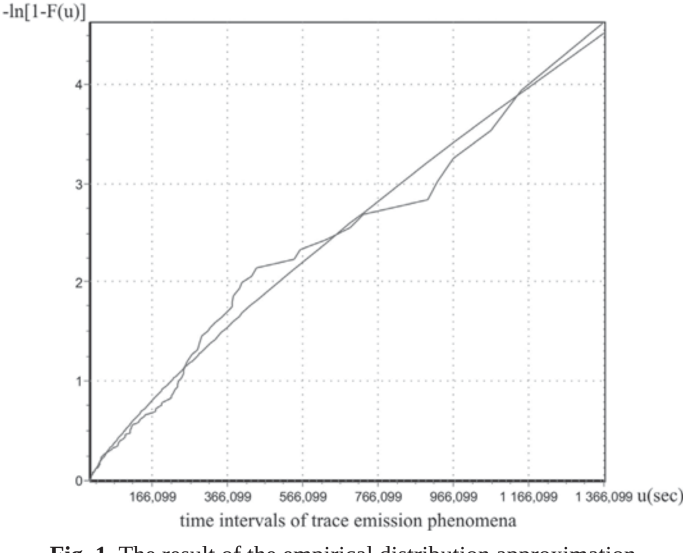

Fig. 1. The result of the empirical distribution approximation of the intervals of trace emission phenomena using model (3). Region of G-7/5 ZG “Rudna” branch

Figure 1 illustrates the result of the empirical distribution of the approximation of time intervals of the phenomena of trace emission with the use of model (3). The size of the time windows in which the measurement data was collected extended over 48 hours. The analysis conducted on the measurement data registered in the region of G-7/5 ZG. “Rudna” branch shows that the model of the statistical distribution of the time intervals of trace emission is correct.

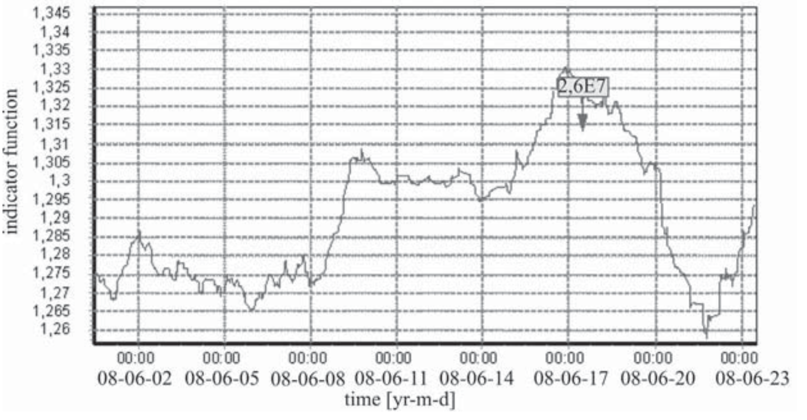

Fig. 2. The indicator function before the occurrence of shock of the energy 2.6 E7 J. Region of G-7/5 ZG "Rudna" branch

The identification of the statistical distribution of the time intervals of the trace phenomena involves the estimating of β and γ parameters in accordance with model (3). The estimation of the parameters is conducted on the basis of measurement data registered in the time windows of the specified value with the use of the highest reliability method [4]. On the basis of specified parameters the expected value of the time intervals described above is calculated. Then, using the dependency (2) the conclusion regarding the energy values of the trace phenomena is drawn.

3. Application for the risk assessment of shock occurrence

In the periods preceding the occurrence of shocks there is a tendency towards the increase in the size of fractures and consequently the rise in the phenomena energy [1, 6]. The trace emission is characterized by high activity of the phenomena, which allows for the correct estimation of a parameter which is proportional to the seismic energy.

This parameter's load time history facilitates the examination of the trend of the development of the phenomenas energy. It is known that this parameter, which is determined in the process of statistical analysis, may contain considerable deviations of the random. This is why, the load time history of this parameter should be properly and statistically analyzed in order to determine its trend. The carrying out of these operations and the obtaining good resolution of evaluations are conditioned by accurately high activity of emissions.

The values of the time windows from which the measurement data is collected should not be less than a period of 48 hours. The number of the phenomena, due to the requirements of statistical analysis, should not be fewer than 30 items.

The construction of the load time history is done in the following way. In the specified time window *T*, the statistical distribution of time intervals described by model (3) is identified. The identification involves the evaluation of the parameters of this model on the basis of measurement values taken from the window in question. The parameters are estimated using the highest reliability method [4]. On the basis of these parameters, the expected value of the time intervals is fixed. Next, the time window is shifted by a specified step Δ and all the calculations discussed above are repeated. The load time history of this parameter may contain considerable deviation of the random. This is why, it is necessary to carry on further statistical processing in order to polish the history (eliminate the deviations).

Load time history obtained in this way is referred to as an indicator function. It constitutes the basis for the risk assessment of shock occurrence. Picture (2) presents the indicator function before a strong shock of energy 2,6 E7 J. The value of window *T*, from which the measurement data was collected, was 48 hours with the step Δ = 2 hours. The case was described on the basis of the data registered in the region of G-7/5 ZG. "Rudna" branch.

4. Summary

One of the problems still unsolved in mining is the forecasting of the time of occurrence of high-energy shocks. Before the actual occurrence of shocks in the rock mass, the increase in the state of stress is created. It results in the rising tendency of energies of the registered seismic phenomena. It is impossible to determine this tendency on the basis of the seismic phenomena of energies exceeding the level of 1E3 J due to the random character of the emission and low activity of phenomena. The article presents a proposal of how to solve this problem using the seismic analysis of the trace emission. Since it is impossible to evaluate the phenomena energy for this emission, the emission analysis is conducted based on time intervals between the phenomena. The expected value of the time intervals is assessed, next the expected value of the energy is predicted taking into consideration dependency (2). On the basis of the expected values described above, the 'indicator function' is evaluated. It constitutes the basis of the risk assessment of shock occurrence. Before the occurrence of shocks, the rising trend in this function can be seen. Figure 2 presents the 'indicator function' before the occurrence of the shock of the energy 2,6 E7 J. This case was analyzed using the measurement data registered in region of G-7/5 ZG. "Rudna" branch.

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