The active method to control cracks formed in a solid sample

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Abstract. This paper proposes a method to control microcracks in fragile samples of solid bodies. Rock samples were tested and analyzed to prove high performance and time efficiency as well as high sensitivity of the method. Key words: spectrum, ultrasonic testing, spectral densities, zero enveloping function.

1 Introduction

Currently, the problem of controlling changes in the physical properties of various loaded solid samples draws much attention [1 — 4] and makes researches look for new improved methods and techniques able to identify prognostic parameters. Active method is the main tool to work with fragile solid samples as it allows sample ultrasonic testing by different signals, depending on its internal structure [5]. Due to its specific structure not all known methods are applicable to research rock samples. In this regard, spectral method [6] should be considered as the most efficient in majority of cases, yet it requires vast computer resources since spectrum calculations imply certain limitations to be set on a computer (sampling frequency, equipment cut off frequency, etc.), so the more limited factors are implied the less accurate will be the outcome. So ideally field experiments should apply a tool able to control fracture changes in rock samples in real time yet able to be sensitive enough.

2 Model description and numeric modelling

The solution for the problem can be found by searching for new approaches. There has been proposed a method to control changes in rock fractures [8] that rests upon the idea of selecting special emitting signal for ultrasonic testing and its detailed examination. The essence of the method is to perform an ultrasonic testing of a sample by series of individual rectangular shape acoustic impulses, which will alter when going through the sample and these altered signals will be recorded. Then the sample will be set on load applied perpendicular to the control line (emitting device - receiver). At this point the sample is

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expected to change its physical properties as there will microcracks or fractures (depending on the load rate) appear that are good to be identified by the known methods [7]. In this case the receiver will register a signal that has come though the sample but the important thing is that it will be able to register the difference of these impulse parameters from the ones of the sample prior to the load. There are various technical devices that can register the difference but its accuracy will depend mostly on how well the incoming signal is processed. Eventually, the target is to select prognostic parameters contributing to prevention of sample destruction.

The goal is to know about sample destruction as early as possible.

Sample is ultrasonic tested by individual rectangular impulses. Each impulse can be expanded in a Fourier integral

$$u_{inp}(t) = \int_{-\infty}^{\infty} S_{inp}(\omega)\exp(-i\omega t)\frac{d\omega}{2\pi}$$

to get the spectrum

$$S_{inp}(\omega) = \int_{-\infty}^{\infty} u_{inp}(t)\exp(i\omega t)dt = u_0\frac{1}{i\omega}\{\exp(i\omega\tau)-1\} \quad (1)$$

and to get the spectral density of each impulse

$$\left|S_{inp}(\omega)\right| = \frac{u_0}{\omega}\left|\exp(i\omega\tau)-1\right| = 2\frac{u_0}{\omega}\sin\left(\frac{\omega\tau}{2}\right) \quad (2)$$

where u_0 is the amplitude of signal; τ is the length.

The signal (video impulse) will change as it goes through the sample. Specifically, such parameters as length, slope of fronts k, α, amplitude u_0 are expected to alter. Subsequently, the spectral density will also change and can be determined by the following formula:

$$\left|S_{out}(\omega)\right| = \frac{u_0}{k\tau\omega^2}\left|\exp(i\omega k\tau)-1\right|\left|1-\exp(i\omega\tau)\right| = 4\frac{u_0}{k\tau\omega^2}\sin\left(\frac{\omega k\tau}{2}\right)\sin\left(\frac{\omega\tau}{2}\right) \quad (3)$$

where k is a slope of α fronts of the signal, undergone through the testing sample.

Function $S_{out}(\omega)$ if $\omega = 0$ equals

$$\begin{gathered}\left|S_{out}(0)\right| = \lim_{\omega\to 0}\left\{4u_0\left[\left\{\sin\left(\omega k\tau/2\right)\sin\left(\omega\tau/2\right)\right\}/\,\mathrm{k}\,\tau\omega^2\right]\right\} = \\ = \left(\omega\tau/2 = x, \omega k\tau/2 = y\right) = u_0\tau\lim_{y\to 0}\left\{\sin y/y\right\}\lim_{x\to 0}\left\{\sin x/x\right\} = u_0\tau\end{gathered} \quad (4)$$

vanishing points can be determined by:

$$\begin{gathered}\left|S_{out}(\omega)\right| = 0 \to \begin{cases}\sin(\omega\tau/2) = 0 \to \omega\tau/2 = \pi n \to \omega_n^{(1)} = \omega_0 n, \\ \sin(\omega k\tau/2) = 0 \to \omega k\tau/2 = \pi n \to \omega_n^{(2)} = \omega_0(n/k)\end{cases}, \\ \omega_0 = \frac{2\pi}{\tau}, (n = 1,2,...); \\ \left\{\alpha \in (0,\pi/4) \to k = \tan\alpha \in (0,1) \to k\tau \le \tau \to 2\pi/\tau \le 2\pi/k\tau\right\}.\end{gathered} \quad (5)$$

When calculating $\omega_n^{(2)}$ for the first zero function of the envelope of the signal spectrum density at the outlet the receiving transducer, one can check whether physical properties have changed in relation to the previous ultrasonic testing.

Above analytical formulas were used for numeric modeling (Table 1). Slope fronts angle of a rectangular impulse was set, first floating zero for $\omega_0^{(2)}$ function of the envelope of the signal spectral density of the signal and Δ-shift were calculated with respect to the previous data. These data indicate that theoretically the change for the slope fronts angels can be defined from a split second to a degree. Evidently, it also can be well applied for the small size solids with a minor fading but the sensibility will be utterly dependent on a capability of the technical equipment to enhance a desired signal from various types of noise.

Table 1. The dependence of a frequency on fronts slope level

α	Seconds				Minutes				Grades			
	5	20	35	50	5	20	35	50	5	20	35	50
$\omega_0^{(2)}$, (MHz)	82,51	20,63	11,79	8,25	1,38	0,34	0,20	0,14	0,022	0,006	0,003	0,002
Δ (MHz)		61,88	8,84	3,54		1,04	0,14	0,06		0,016	0,003	0,001

3 Experimental research

Described below is the experiment done to determine changes in the spectral density of impulses depending upon fractures in rock samples. The rock sample was tested by video signal close by the shape to the rectangular, then spectral density of the received signal was analyzed. At the first stage of the experiment the intact sample was ultrasonic scanned, at the second stage there was a sample with a 2 mm diameter hole in it.

As signal extracting and receiving transducers there were used capacitance transducer suitable for the preset frequency band. The transducers were well studied and recommended for use to control rock samples [9 —11].

One of the capacitance transducers electrodes is 10 mm diameter aluminum, where the dielectric layer was applied by exposing the electrode to anodic oxidation. The other electrode is s a layer of a thin foil placed on the anodized surface.

Anodic oxide coating being flexible, durable, mechanically and electrically wearproof apply tightly to aluminum electrode creating an integral piece. The coating is easy and cost effective to manufacture [12].

The experiment used a 63.3 mm diameter and 55.4 mm high sample of hybrid garnetiferous rock with the geological composition varying from quartzdiorite to gabbroidiorite being dark grey in color and spotty. The sample is solid with a taxitic, crystalline and grainy structure.

The embodiment of the suggested method is presented by a flowchart in Figure 1.

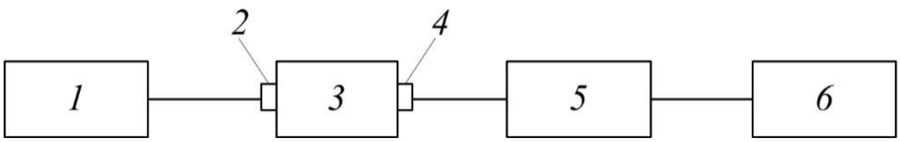

Fig. 1. Overall flowchart of a device for the experiment:
1 — impulse generating module; *2* — capacitance transducer;
3 — rock sample; *4* — capacitance transducer;
5 — broad-band amplifier; *6* — oscillograph LeCroy WaveSurfer 422.

Capacitance transducers 2 and 4 are installed on parallel-sided horizontal surfaces on the top and on the bottom. Video impulse parameters were selected according to geometric dimensions and acoustic properties of the sample. From impulse generating module *1* video signal is fed to the capacitance transducer *2*. Signal length is 400 nanosecond, amplitude is 30 V with a high duty ratio. On the output of the capacitance transducer *4* the signal gets recorded by digital oscillograph LeCroy WaveSurfer 422 through broad-band amplifier *5*.

Pilot electrical signal on the input of the capacitance transducer is shown in Figure 2.

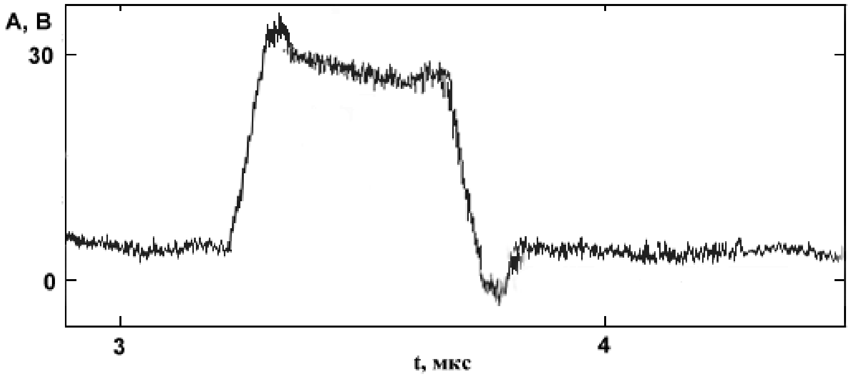

Fig. 2. Oscillogram of the emitted signal.

Significant differences in signal oscillograms received by capacitance transducer *4* were recorded from the experiment with the intact rock sample and from the experiment with the sample with the hole in it (see Figure 3).

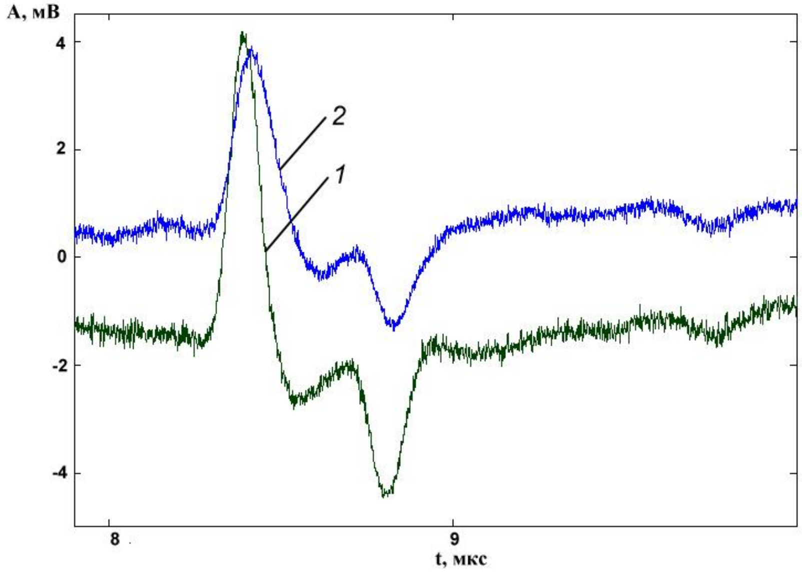

Fig. 3. Signal at outlet of the capacitance transducer after going though the intact sample (*1*) and a sample with a hole (*2*).

For calculation purpose the signals were standardized, smoothed and approximated.

According to the analytical formulas for the floating zero frequency calculation listed above impulse spectral density for the intact sample and the holed sample was calculated. Besides, there were calculated frequency shift of floating zero function of envelope spectral density power of the received signals. Specific values for the characteristic under control that is shift of floating zero function of envelope spectral density power of the signal for the intact sample were obtained. The difference in the received values constitute 2 MHz. This is a significant offset of the zero function of envelope spectral density power of the signal, being fed through the holed sample. It emphasizes the ability to control the cracks or fractures of different sizes. The smaller the transverse size of the cracks, through which the signal passes, the smaller the zero offset of the envelope function.

4 Discussion

To compare the proposed method with other known ones, specific values of controlled parameters with same initial data were determined. The results of the calculation is shown in Table 2.

Table 2. Comparison of methods

The name of the controlled characteristic in the spectral method	Source	Entire sample	Holed sample	Difference in values
Power spectral density area	[7]	0,020041	0,02039	0,0003
Spectrum area in the frequency range $2\pi/\tau$	[6]	0,0167	0,01683	0,0001
The ratio of the parts of the spectrum (in the frequency range $10\pi/\tau$)	[1, 2]	9,889619	9,481726	0,4080
Floating zero frequency	[8]	0,090957	0,079011	0,0120

All signals were first digitized to enable further digital processing and direct calculations. It is evident, that methods are very different from each other in sensitivity. The first two [6, 7] have very weak sensitivity and probably they (being the main ones) show in principle the probability of obtaining the necessary information. Two suggested methods (one of them was proposed earlier [2]) have much higher sensibility compared to others and therefore deserve special attention. The previously proposed method in relation to parts of the spectrum [1, 2] is particularly sensitive (more than 3 orders) and it is most applicable for calculating statistical tasks not requiring a result in a relatively short time frame. Under cyclic loading of the samples this method is most preferred.

As for the method that is based on analytical calculation of a floating zero function of envelope spectral density of the tested signal, it has a two orders as higher sensitivity as the base methods. Since this method doesn't imply calculating infinite integrals, which would require complex computer tools, it turned out to be the most efficient. Therefore, there are no special practical restrictions on it.

5 Conclusions

This paper was targeted at researching the possibility of detecting microcracks in fragile solid samples using a method that calculates a "floating" zero function of envelope spectral power of a signal that goes through the sample. Particularly, this research was focused on a rectangular impulse or the series of individual rectangular impulses as emitted signals.

This research implied both experiment and numerical modeling to prove the efficiency of the proposed method and to compare it with other known methods. These results demonstrate a significant advantage over other known techniques. The method can be considered by researchers working with various samples in dynamic mode in order to produce a higher-quality result.

References

1. I. A. Krivosheev, A. I. Shamurina, Sensitive control method of fracture changes in the rock mass, Russian Journal of Nondestructive Testing, 2, 62 (2013). [In Russian].
2. I. A. Krivosheev, A. I. Shamurina, Patent of the Russian Federation 2498353, Method to control discontinuity changes in the rock mass. Submitted on June 7th, 2012; published on November 10th, 2013, Newsletter 31.
3. Y. Tomikawa, H. Ishigaki, J. Masuda, K. Honiyo, H. Yamada, Consideration of nondestructive inspection using frequency analysis method of ultrasonic pulse signals H Jap., J. Appl. Phys., 26-2, 162 (1987).
4. A. L. Uglov, Acoustic control equipment in the constriction and operation, (Moskow, Nauka, 2009) 280 pp. [In Russian].
5. A. V. Shadrin, V. A. Konovalenko, V. A. Rudakov, S. E. Trusov, E. A. Plotnikov, V. M. Ryichkovskii, The use of spectral – acoustic prediction of outburst hazards at the Kuzbas mines, Vestnik of KuzGTU, 2, 31 (2002). [In Russian].
6. S. D. Vinogradov, P. A. Troitskiy, M. S. Solovyova, The influence of crack changes and environment stress on the parameters of propagating elastic waves, Fizika Zemli, 4, 42 (1989) . [In Russian].
7. V. V. Rzhevskiy, V. S. Yamshikov, Acoustic methods for the rock mass study and control, (Moscow, Nauka, 1973) 244 pp. [In Russian].
8. I. A. Krivosheev, Patent of the Russian Federation 2480792, Method of control of fracture changes in the rock mass. Submitted on July 8th, 2010; published on April 27th, 2013, Newsletter 2. [In Russian].
9. I. A. Krivosheev, Capacitance transducer for the rock mass. – Transducers of acoustic emissions to the rock pressure monitoring systems, (Moscow, IPKON USSR Academy of Science, 1990) 82 pp. [In Russian].
10. F. M. Boler, H. A. Spetzler, I. C. Getting, Capacitance transducer with a point-like probe for receiving acoustic emissions, Review of Scientific Instruments, 55-8, 1293 (1984).
11. T. Ohira, T. Kishi, Acoustic emission source characterization and its application to the study of dynamic micro-cracking. — Tetsu To Hagone, 16, 2188 (1984).
12. A. I. Golubev, Anodic oxidation of aluminum alloys, (Moscow, USSR Academy of Science, 1961), 192 pp.