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METHOD OF PREDICTING THE FRACTURE OF ROCKS USING THE FEATURES OF THE SPECTRAL-TIME CHARACTERISTICS OF SIGNALS OF ELECTROMAGNETIC RADIATION*

G. I. Kulakov and G. E. Yakovitskaya

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At this Institute of Mining, Siberian Section of the Russian Academy of Sciences, we have investigated the formation of cracks and the fracture of rocks when they are loaded, by recording the signals of electromagnetic radiation, and we have also investigated its spectral-time characteristics [1, 2]. The results obtained in [3, 4] were used, in which the idea of a concentration criterion was introduced for the characteristic of the fracture process, while the process itself was regarded as consisting of several stages. It was shown in [1] that the uncorrelated buildup of cracks corresponds to fracture stage I (the buildup of microcracks), the formation of a main crack zone corresponds to stage II (macrofracture), whole the splitting of the rock into parts corresponds to stage III (post fracture).

This paper is a continuation of [5], where an experiment on the loading of rock specimens, its method and the results obtained, represented in the form of spectral-time matrices o[illegible]ectromagnetic signals, were described in some detail. Below we consider the predictive characteristics of the fractu[illegible] 721 [illegible]tained by analyzing the spectral characteristics of the electromagnetic signals recorded during an experiment at different stages of the loading corresponding to stages II and III of the fracture process.

Table 1 shows the results of an experiment for a specimen of fine-grained syenite (from the Tashtagol'skii deposit), where the arrow on the left denotes the direction in which the time increases from the beginning of loading and the load itself, respectively, the arrow above the Table 1 indicates the increase in the spectral frequencies, while the isolated printed numbers in each row of the spectral-time matrix, together with the arrow in the Table 1, demonstrate the change in the maximum spectral amplitudes A as the load increases at stages II and III of the fracture process. The results of an analysis of these tables (the spectral-time matrices) were presented in [6, 7].

We will further consider the maximum spectral amplitude A corresponding to its spectral frequency f, the increment of the maximum spectral amplitude ΔA as a function of the time t (Fig. 1), and the derivatives $\Delta A/\Delta t$, $\Delta A/\Delta f$ as a function of the time t (Fig. 2) and the frequency f (Fig. 3) (here and below we use reduced notation for the derivatives).

It can be seen from Fig. 1 that A and f reach maximum values at the same instant of time, in this case when $t \cong 22$ msec (see Table 1), and the parts of the curves on the left of these maxima correspond to stage II of the fracture, while the parts to the right correspond to stage III. As the loading time increases the increment of the maximum spectral amplitudes A falls and reaches a zero value, intersecting the abscissa axis at the instant of time $t \cong 22$ msec. Note that the graphs in Fig. 1, up to the instant of time $t \cong$ msec, correspond exclusively to the electromagnetic signal obtained as a result of the fracture of the rock itself. The continuation of the graph (stage III of the fracture) contains, in addition to the useful signal, considerable experimental interference and is ignored in this analysis. The approach of the values of the functions A and f to the maximum values and the simultaneous transition of ΔA through zero can serve as predictive indicators for determining the instant when the loaded rock begins to separate into parts.

We will consider the features of the derivatives of the maximum spectral amplitude with respect to time and with respect to frequency.

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TABLE 1

f, kHz

t, msec	0,25	0,29	0,33	0,38	0,43	0,50	0,57	0,65	0,74	0,85	0,98	1,12	1,28	1,47	1,68	1,92	2,20	2,52
15,87				714	740	764	721	688										
16,03				718	747	761	732	702										
16,19				723	753	769	742	716										
16,37				727	760	775	752	729										
16,51				732	766	782	761	742										
16,64				736	772	789	771	754										
16,83				740	778	795	700	766										
16,98				744	784	801	789	778										
17,14				748	789	807	797	789										
17,30				751	795	815	806	808										
17,46				755	800	819	814	810										
17,61				759	805	824	821	820										
17,78				762	803	830	829	830	816	763								
17,94						835	836	839	822	779								
18,10						840	843	848	834	796								
18,25						844	849	856	846	811								
18,41						849	856	864	857	826								
18,57						853	862	872	867	841								
18,73						857	868	879	877	854								
18,80						861	873	886	886	868	839							
19,05						865	878	892	895	880	855							
19,19							883	899	904	892	878							
19,37							888	904	912	903	885							
19,53							892	910	920	914	890							
19,68							896	915	927	924	911							
19,83							900	920	933	935	923	909						
20,00								924	939	942	933	922						
20,15								928	945	950	949	934						
20,32								932	950	957	953	945						
20,49								935	955	964	961	955						
20,63								938	959	970	969	964						
20,78								941	963	976	975	972						
20,95								943	966	981	981	978	972					
21,11									969	985	986	984	979					
21,27									972	989	991	988	985					
21,43									974	992	994	992	989					
21,59									975	994	997	994	992					
21,75									976	996	998	996	993	998	993	980		
21,90											999	997	993	1000	995	982		
22,06									977	998	999	995	991	999	995	982		
22,22									977	998	999	993	989					
22,38									976	997	997	991	984					
22,54								946	987	996	995	987						
22,70								944	973	994	991	982						
22,86								942	972	991	987	976						
23,01								940	968	988	983	968						
23,17								934	965	985	977	960						
25,08							869	877	892	893	846	771						
25,24							865	870	892	882	838							
25,48							859	862	874	870	813							
25,56							853	854	864	857	796							
25,71							847	846	853	844	778							
25,87					826	836	840	837	842	831	759							
26,03					822	831	833	828	830									
26,19				772	818	826	826	819	818									
26,35				769	814	820	810	800										
26,51				766	809	814	811	799										
26,67				763	805	808	803	789										
26,83				759	800	801	794	778										
26,98			711	756	799	799	786	767										
27,13			700	753	798	790	777											
27,30			700	749	785	781	768											

II

III

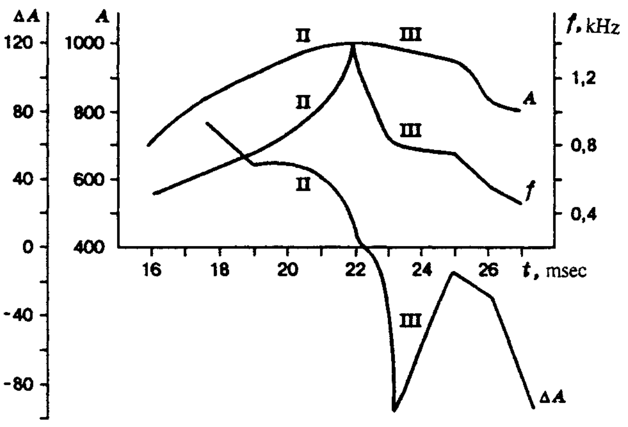

Fig. 1

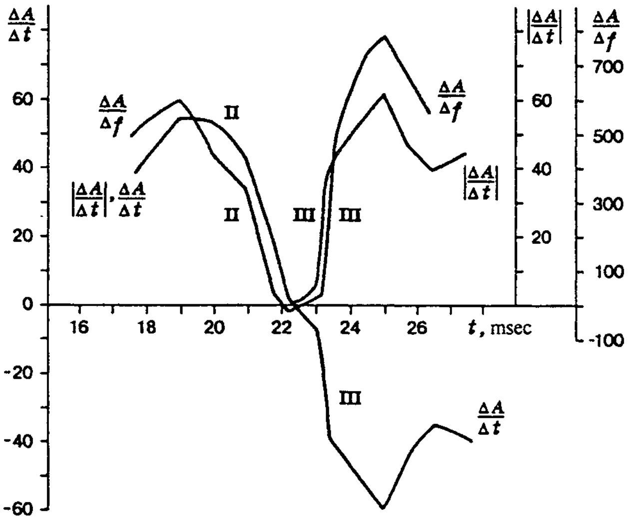

Fig. 2

In Fig. 2 we show graphs of the derivative ΔA/Δt and its modulus |ΔA/Δt|, and also of the derivative ΔA/Δf with respect to the spectral frequency f as a function of the time t. The graph of |ΔA/Δt| and ΔA/Δf have extrema (minima) in the region of the instant of time t ≅ 22 msec, while the graph of ΔA/Δt, in the region of the same point, passes through zero. These features of these quantities can be used as a predictive indicator that the rock is about to fracture.

In Fig. 3 we show graphs of the spectral amplitude A and its derivatives ΔA/Δt and ΔA/Δf as a function of the spectral frequency f. Here the quantities are functions of two variables t and f and their graphs are different. It follows from Fig. 3 that at stage II of the fracture the amplitude A increases gradually as f increases, and after the load reaches a critical value, corresponding to the occurrence of the highest maximum spectral amplitude and its corresponding frequency (f = 1.47 kHz), its graph turns in the opposite direction and moves in the direction in which A decreases, at stage II the parameters A and f increase, while at stage III they decrease.

This transition from a simultaneous increase to a simultaneous decrease in both parameters was suggested in [8] to be an indication of the beginning of the fracture of the loaded rock into parts. It can be seen from Fig. 3 that the graphs of ΔA/Δt and ΔA/Δf as a function of f at stage II of the fracture decrease, reaching their minimum values at a frequency f = 1.47 kHz, and then, increasing in modulus, transfer to the lower-frequency region (stage III). All three functions considered have a single common feature, which is that, after reaching the maximum frequency, all the functions transfer once more into the lower-frequency region. Consequently, the transition from the high-frequency region (stage II) to the lower-frequency region (stage II) can serve as a predictive characteristic that the rock is transferring to the stage of splitting into parts.

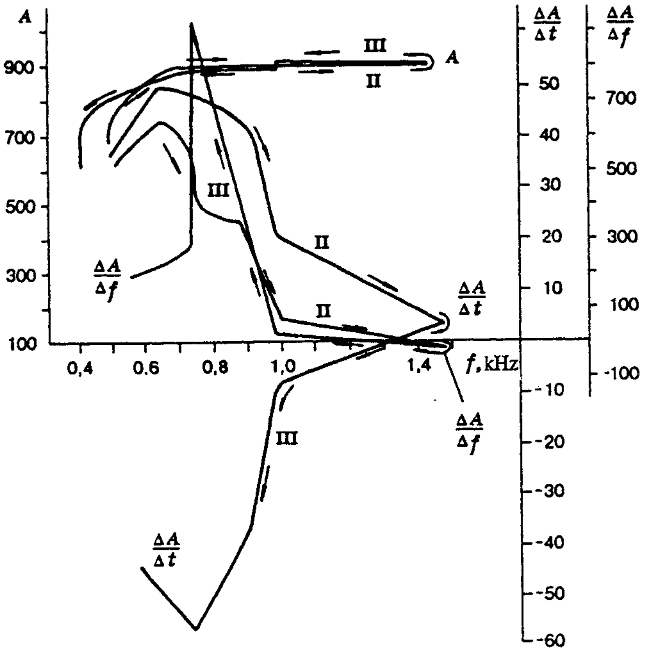

Fig. 3

Hence, the features of the spectral composition of the signals of the electromagnetic radiation and the behavior of the functions considered enable us to recommend a number of methods of predicting the fracture of rocks. These are as follows.

The simultaneous increase in the maximum spectral amplitude A and the corresponding frequency f as the load increases and their subsequent reduction indicate that the instant when the continuous rock breaks into parts is approaching.

The transition through zero of the quantity ΔA as the load increases (and the time t, correspondingly) can also serve as a predictive indicator that the instant of fracture is approaching.

A simultaneous reduction in the rate of variation (the derivative) of the maximum spectral amplitude and its modulus while the load is increasing and of the derivative of the maximum spectral amplitude with respect to frequency as a function of the time to values close to zero, and also their subsequent increase in modulus, serve as a predictive characteristic of the approach of fracture.

A reduction in the derivatives of the maximum spectral amplitude with respect to time and frequency as a function of the change in the spectral frequency to a minimum value at the maximum frequency for both quantities and their subsequent increase in modulus confirm that fracture of the rock is about to begin.

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