Study of interrelation between electromagnetic radiation and rock strength

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Abstract. The paper presents the study of the electromagnetic radiation of real rock samples under acoustic impact. The test samples are made of kerns from the iron ore mine with different petrophysical features and strength. The study has shown that the electromagnetic radiation parameters are related to the sample strength. However, this dependence is not observed for samples with magnetite that can be due to individual structural-textural features and quartz inclusions.

1. Introduction

The basic mechanism of mechanoelectric transformations (MET) in rocks is to be revealed to work out a method based on measuring electromagnetic radiation (EMR) to monitor the change in the rock stress-stained state (SST) and its strength and to forecast geodynamic events. To obtain MET patterns, we used the method of physical modeling in vitro.

When rocks crack, electrons, positive ions, photons and radio waves are emitted. In the study, we consider the EMR in the frequency range up to 1 MHz.

Stepanov was the first to observe the electric charge on the NaCl crystal surface as a result of flowage in the absence of an external electric field in 1933 [1]. He attributed this phenomenon to crystal slayers rubbing against internal inhomogeneity and microcrack originating.

Further investigations on this phenomenon were conducted by Fishbach and Novikov (1955) [2]. They studied increase in the electric charge on the NaCl crystal surface under pressure and attributed it to charged dislocation. Urusovskaya (1958), Martyshev (1965) and Kornfel'd (1971) continued the study [3–5]. A number of investigations were performed for piezo- and nonpiezoelectric, crystalline and amorphous, metallic and dielectric materials and rocks under different effects [6–11].

After that, interest in EMR was of applied relevance and focused on the earthquake forecast [12–14], forecast of rock destruction in underground mines [15–17], study of explosion [18–19], nondestructive testing of defect structure and strength.

It should be noted that a significant part of the research into this problem belongs to a research group under the guidance of Vorob'ev A.A. (1970), Tomsk Polytechnic University.

He coined the term "mechanoelectric transformation" related to EMR. Vorob'ev noted that transformation of mechanic energy into electromagnetic one depends on the properties of interacting systems which possess energy. He pointed out that all types of energy can transform into mechanic energy which in the interior of the Earth can transforms into electric energy [20]. Transformation of free charges or charged particles occurs under the influence of an electric field. Thereby, EMR is caused by increase or change in the charge on the dielectric surface.

Over recent years, great attention has been paid to studying electromagnetic signal (EMS) parameters, induced by acoustic impact [21–24] to find out the mechanism of EMR processes. The majority of the researchers consider an electric dipole occurring on the opposite sides of the crack to be the source of EMS [25–27]. The electric dipole is also formed by double electric layers (DEL) in interaction of different materials through pores in materials. The change in the dipole moment causes EMS.

Theoretical underpinning of the EME method for testing dielectrics quality is provided in the research by B.B. Lasukov [28]. It shows that stimulating mechanic vibration by a single normed stroke causes the bias current that is a function of the dipole moment and of the speed of change in the volume density of elementary sources. The quantity of charge, its volume structure and amplitude depend on physicochemical properties of the sample inner regions.

Therefore, the paper aims to study the change in the EMR parameters under acoustic impact for rock samples with different physicochemical properties, granules and micro-cracks. Charged particles with higher probability concentrate in inhomogeneities, produce an electric field and, as consequence, mechanic energy transforms into electromagnetic energy. In addition, the study of EMR emitted from the rocks is of practical interest as a key to developing the method of monitoring and forecasting geodynamic events in rock massifs.

2. Test object

The test objects are rock samples from Tashtagol ore mine (Kemerovo region). These are skarn samples with different petrographic composition without magnetite and magnetite ore samples with different content of magnetite. Cylindrically-shaped samples with a diameter of 42±1 mm and a height of 80±2 mm were cut out of the core. Before testing, the sides of the samples were polished until flatness with the discrepancy no more than 0.5±0.1 ^{o}. The angle between the sample sides and its axis was 90±1 ^{o}. The image of the samples is shown in Figure 1.

Figure 1. Samples image: left is skarn sample, right is ore sample.

3. Study technique

Acoustic impact was performed by a little steel ball launched from a spring pistol. It is a dynamic method of impact. The block diagram of the dynamic method is shown in Figure 2.

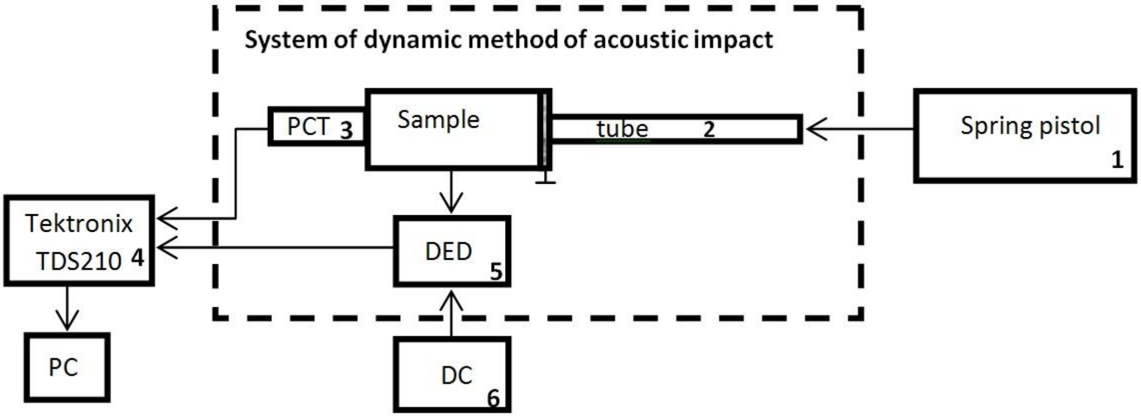

Figure 2. Block diagram of the dynamic method of acoustic impact

The ball is launched by pistol (1), passes through tube (2) and strikes a metal grounded plate that is connected to the sample by means of mineral oil. The acoustic pulse passes through the sample and is recorded by piezoceramic transducer (PCT) (3). A signal from PCT (3) initiates recording by the scope Tektronix TDS2024B (4). The EMS generated by the acoustic wave is received by differential electric detector (DED) (5) measuring only the electric part of the EMS. DED connected to the scope differentiates and amplifies the signal. The signals from the scope are transferred to a PC for the analysis. To change the duration and amplitude of the acoustic signal, we used balls with different mass of $0.25\cdot10^{-3}$ and $0.86\cdot10^{-3}$ kg that corresponds to the acoustic signal front of $10\cdot10^{-6}$ and $14\cdot10^{-6}$ s.

4. Experimental results

To determine an ultimate strength of the investigated samples, they were subjected to uniaxial compression with a press.

The task for iron ore samples was to estimate the relation of the quantity of the magnetite content in the samples to their ultimate strength and the maximum EMS amplitude. Table 1 summarizes the data on the magnetite content in the iron ore samples, their ultimate strength and the maximum EMS amplitude.

Table 1. Data on the magnetite content in the iron ore samples, their ultimate strength and the maximum EMS amplitude.

Sample	Mass (g)	density (g/cm^3)	volume (cm^3)	Magnetite in sample (g)	Magnetite in sample (%)	Ultimate strength (kN)	max EMS (mV)
1	360	3.21	112	57	16	158.6	350
2	380	3.45	110	118	31	279.8	20
3	393	3.60	109	157	40	196.5	800

The magnetite mass in the sample is calculated by the formula:

$$M_m = \rho_m \cdot V_o \cdot \left(1 - \frac{\rho_0 - \rho_m}{\rho_{vm} - \rho_m}\right),$$

where M_m is magnetite mass, g; ρ_m is magnetite density, g/cm^3; V_o is sample volume, cm^3; ρ_o is sample density, g/cm^3; ρ_{vm} is density of the enclosing rock, g/cm^3.

As can be seen in Table 1, the ultimate strength of the samples does not correlate with the magnetite content. The EMS amplitude does not correlate to the ultimate strength as well. However, this does not mean that there is no dependence between the parameters. Structurally-textural features of the samples and the quartz content may considerably affect the parameters. This is proved by the study which shows ten-fold increase in the EMS amplitude in the sample containing quartz in comparison with the sample containing no quartz under acoustic impact [29]. Analogous results were obtained by other researchers [30–31]. In particular, in [31], in the experiment on dynamic compression of rocks, it was found that the EMS amplitude for a gabbro sample with 2 % of quartz was six times less than that for a granite sample with 36 % of quartz. Quartz inclusions are randomly arranged by volume in magnetite ores samples, and this can explain significant difference in the EMS amplitude in the samples in our experiments.

The task for enclosing rock samples was to estimate the relations between the ultimate strength and the parameters of the recorded EMS. For this purpose, the analysis of analogue electromagnetic signals was carried out. Each sample was subjected to dynamic impact for 2 times. As the EMS amplitude oscillations varied from 4 to 10 %, their values were averaged. The average EMS amplitude, average duration of the signal and the mean value of the EMS amplitudes were calculated. Table 2 shows the data of the analysis.

Table 2. EMS parameters of skarn samples under acoustic impact.

Sample	Strike	EMS peak-to-peak (V)	Averaged peak-to-peak (V)	Signal duration (ms)	Averaged signal duration (ms)	Amplitude EMS (V)	Averaged amplitude EMS (V)	Ultimate strength (kN)
4	1	0.0296	0.0284	11.5	13.05	0.018	0.0164	222.8
4	2	0.0272		14.6		0.0148		
5	1	0.0428	0.045	37.5	37.15	0.0232	0.0264	127.6
5	2	0.0472		36.8		0.0296		
6	1	0.0948	0.1002	22.9	30.1	0.0432	0.0388	125.2
6	2	0.1056		37.3		0.0344		
7	1	0.0736	0.072	21.8	22.8	0.0324	0.0314	110.6
7	2	0.0704		23.8		0.0304		

The analysis of the data presented in Table 2 shows that the averaged EMS amplitude and its duration decrease as the ultimate strength increases under acoustic impact on skarn samples by the dynamic method.

5. Conclusions

Real samples of the iron ore deposit have been tested. These were skarns as an enclosing rock and ore samples with magnetite. The iron ore deposit is useful because of ore extraction is performed through blasting. All works in mine are accompanied by various acoustic effects, and acoustic waves passing through inhomogeneities produce EMS. Samples with different ultimate strength were tested to reveal the dependence of EMS parameters on rock properties. This is an integral characteristic that depends on petrographical features. The dynamic method of acoustic impact has shown that as the ultimate strength of enclosing rocks increases, the average EMS amplitude and its duration decrease. However, this dependence is not characteristic of samples containing magnetite that can be attributed to its complicated structurally-textural features and quartz inclusions present in the volume.

Acknowledgements

Work is performed with financial support of a grant of the Russian Federal Property Fund No. 14-08-00395 and within the state task of the Ministry of Education and Science of the Russian Federation.

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