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Acoustic Emission and Electromagnetic Effects in Loaded Rocks

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1. Introduction

At the turn of the XX century, the progress of science and technology has pointed out a new possible way to approach the problem of reducing the hazard of strong earthquakes. This unexpected way is related to powerful physical fields which may influence the structures in terrestrial crust to induce unloading of tectonic overstress and, thus, to reduce seismic hazard. Initially, the effects allowing to control deformation processes in seismogenerating zones manifested themselves as induced seismicity, which resulted from underground nuclear explosions, fluid industrial waste injection to borehole located in seismic area, variation of water level in large water storage, or from mining operations etc. Thereafter it was revealed that dynamical actions may redistribute the seismicity in the following manner. They are to decrease the number of major events due to growth of energy released by week earthquakes. There are some ways which are the most acceptable from geoenvironmental consideration for man-caused relaxation of tectonic stress in terrestrial crust. One of them is electromagnetic actions by electric current flashing. Pioneer results of the effect of power electromagnetic pulses produced by magnetohydrodynamic (MHD) generators to test the seismic activity in regions of Bishkek and Garm testing fields were obtained in Russia and Kyrgyzstan (UIPE, OIVTRAN) (Tarasov & Tarasova, 2004). It is very important that such external impacts have always triggered the seismic events of minor magnitude (M<5). Such power actions are adequate for civil and scientific purposes only. At the present time the results of Tarasov have been confirmed by other works which involve a new approach to the experiment with the MHD generator (Chelidze et al, 2006) as well as the fresh data on powerful electromagnetic soundings (Bogomolov et al., 2005; Sychev et al, 2008). It is evident that the similar effect must occur in loaded rock specimens when the pulses of electromagnetic fields act on them in addition to the main mechanical load. The method of acoustic emission (AE) measurements which has recommended itself as a good tool for geophysical applications (Vinogradov, 1989; Paparo et al., 2002; Sobolev & Ponomarev, 2003) allows to get information about the aforementioned effect during laboratory experiments. This work is devoted to the simulation of phenomenon of weak seismicity triggering by actions of impulsive physical fields (so-called energy influence, EI). Concerning terminology it should be noted that the signatures of electromagnetic influence on defects accumulation in loaded geological medium are described as seismic, seismic-acoustic or acoustic emission response (AE), depending on the scale. In our previous experiments (Bogomolov et al., 2004, 2004a; Zakupin et al., 2006, 2009; Bogomolov & Zakupin, 2008) we have revealed the effect of AE activity increment stimulated by external electromagnetic fields, which indicates the effect of medium's factors on crack formation. The AE activity has proved to be a rather informative parameter reflecting both the process of structure defects accumulation in load-carrying medium and the variations of its rate under the effect of external fields. But not only easy building and visualization of activity's temporal plot during AE data processing have made it the main object of investigations in the above mentioned publications. The similarity between AE response to the physical fields effect and induced seismicity initiated with electromagnetic pulses of natural and man-made origin has been revealed just by activity variations, and this circumstance is working. The responses to the actions of nonstationary physical fields, detected on various scales: from the laboratory length of 1-10 cm, to the natural one of kilometers-length (Tarasov & Tarasova, 2004; Sychev et al, 2008; Zakupin, 2010), to be complement each other. At the same time, the problem of mechanism (or mechanisms) of generation of acoustic emission signals' responses (destructure indicators) to electromagnetic effect has not been fully ascertained yet. A theoretical complicacy is related mostly to the fact that a very wide range of effects, realizing on the various structural-scaled levels, are able to stimulation of AE activity, for example: inverse seismic-electric effect and piezoelectric effect occurred in the separate impurities, relaxation of electrical polarization, electroplastic and magnetoplastic, effects of spreading electro-magnetoelastic waves etc. The main problem is connected with a significant (by many orders of magnitude) difference between typical wavelength of external perturbations and defects' sizes. Nevertheless, it has been supposed that currently the understanding of electromagnetic effect on the base of physical model is possible in a case of tested specimens rather than natural, full-scale phenomena during the crust straining. Previously all relevant experiments to study electromagnetic influence on a specimen have been conducted in the conditions of quasi-static compressive loading. In addition, in such experiments tensometric measurements either have not conducted, or they have been too coarse (only AE). In this work we have tried, as far as possible, to expand the ideas about responses to EI by the arrangement of experiment in new conditions. Measuring of tensometric parameters, such as compressing load, longitudinal and lateral deformations, is an integral part of laboratory experiments, since specified parameters characterize deflected mode of a test specimen. Note that the system of AE data gathering has passed upgrade both by quality of record signals, and by registration speed (several hundreds of acts per second) and sensitivity of system. Using the new system of loading (lever press) and material (marble versus granitoids has apparent semibrittle properties) is a logical development of the experiments we have conducted earlier. The experiments have been held at Bishkek Geodynamic Research Center - RS RAS.

2. Measuring equipment

While forming the experimental complex, the significant role is played by the choice of a press with technological characteristics which provide a solution of methodical tasks. Primarily this is the securing of automated loading mode with ability of continuous monitoring of load changes and absence of instrumental noise – the false acoustic signals. At the present time, the tests in the RS RAS are conducted with lever press PLT-L. This press has been created in RS RAS based on the spring rheological plant for long-term tests (PLT) with maximal press tonnage of 100 tons (Stavrogin & Protosenja, 1979). PLT-L provided a load up to 35 tons and noiseless conditions of experiment carrying out, including experimental sessions with constant uniaxial compressive loading and with loading, increasing by addition of weight on the long lever arm. The photos of the press and the specimen are shown on the fig.1.

Fig. 1. Specimen with sensors and the lever press: a specimen with AE sensor, LVDT sensors of axial and lateral strain and electrode (the left frame); general view (the right frame)

This testing method (uniaxial compression) has been chosen in connection with the fact that the stressed state, initiated during the process, in a specimen with prevalence of compression stresses in the single direction is similar, in a certain extent, to a mountain mass, where tectonic stresses prevail over a lithostatic one (Kropotkin et al, 1987; Heidbach et al, 2008). From the viewpoint of continuum mechanics, the uniaxial compression is considered as elementary, and all the investigations of rocks always begin with it. Moreover, this method of tests is technically easy realized. Specimen material is more compliant then a material the pressing thrust journals are made of; therefore a specimen compression may be believed to occur between absolutely firm, rigid planes. Side face of a specimen is stress-free. And on its bearing faces (butts) through which pressure has been propagated to a specimen, conditions are determined with available or absence of a grease on contacting surfaces of a specimen and press. In our case when grease is absent, direct contact of a specimen bearing surfaces and press platters is realized. On these surfaces the strong bearing friction appears; the possibility of couple sliding of contacting surfaces' elementary parts is practically ruled out. In a specimen aggregate (heterogeneous) the stress state is created. Specimen volume elements located near the center of butts are in condition close to hydrostatic compression. On butts' ends the zone of stresses concentration with maximal difference of normal compressive stresses along different directions is formed. Therefore the maximal tangential shearing stresses developed here and the cleavage cracks are possible. In average horizontal cross-section of a specimen close to its center we observe irregular uniform compression with prevalence of vertical component that brings stretching deformations in horizontal direction to a specimen. It should bring to both cleavage and tensile cracks initiation. During the research of rock for uniaxial compression, the main methodical troubles appear by deformation in the area which is above ultimate strength. These troubles are connected with rather high brittleness of rocks under condition of uniaxial compression. That is why in the new series of experiments marble has been chosen rather than granite. In the work (Gzovsky, 1975) it is shown that it is impossible to fulfill all the similarity conditions when modeling the seismic process simultaneously in a single trial, even if all the process parameters and properties of a material at a depth, as well deformations and stresses were known. The work presents (Vinogradov, 1989) different similarity factors for deformation processes in the Earth crust and modeling specimens, derived by using various models of deformation. We use the method of acoustic emission in experiments, and this is the best way for investigation of different rocks of magmatic and sedimentary types with strongly expressed acoustic-emissive properties. Choosing solid materials of these rocks, we do not provide similarity by coefficient of viscosity but perform similarity by compressional speed and Poisson ratio, which allows talking about deflected mode similarity. In the experiments, AE signals have been registered with piezosensors in the frequency range from 80 kHz to 2 MHz. According to the experiment tasks and the methodology of acoustic emission measurements the hardware and software complex for wideband AE measurements has been worked out and used in the RS RAS (Bogomolov et at., 2004 a). The hardware of the complex allows to record signals coming from the AE sensor located on the tested object (rock specimen) and converted them to electrical signals. The specially designed program for data acquisition with the USB3000 modulus allows to fulfill signal processing and calculation of the parameters pointing out the changes of tested specimen deflected mode. It should be noted that due to calibration of used SE2MEG sensors (DECI, 2009) the output signal from AE measuring channel is proportional to the oscillating pressure on sensor-to-specimen contacting surface. The data registration and processing programs are developed on the C++ programming language in WINDOWS environment. For preprocessing of the gathered information, the software including viewers and correcting of received information programs is used. To calculate the activity of acoustic emission, we use the program of batch processing and forming of single time series of activity over all the data series received from one specimen. In the program, the algorithms of numerical differentiation and smoothing with Laplace running window are used. The equipment has worked in a standby mode, the launch has been executed by the set threshold value exceeding of a signal on the output of measuring AE channel. Signals have been digitized by a high-performance eight-channel unit of ADC USB 3000 (capacity is 14 bit, maximal frequency is 3MHz) and written onto the hard disk of a personal computer in automatic mode. As sensors for deformation (longitudinal and lateral) and load registration, we use the linear-variable differential transformers LVDT designed for linear displacements measurements. Operation of these sensors is based on the electromagnetic induction phenomena. Their output voltage is in proportion to position of a moving magnetic core. Primary coil is excited with a source of alternating voltage inducing in secondary coils voltages, which change with shift of a magnetic core within a set. Secondary coils are opposite winded, and when a core is in the center, voltages on coils are equal in value and opposite in sign, and output resulting voltage is zero. When core shifts from the center, voltage in secondary coil (in side of which core shifts) increased. As a result, output differential voltage lineary changes depending on a core's position. Usually a core has thread within to ease fastening of non-magnetic rod, which in his turn is fixed to an object, whose displacement will be measured. These sensors have high accuracy, linearity, sensitivity and definition, and also provide work without friction with high rigidity. In the

RS RAS the two types of LVDT sensors of Lucas Schaewitz company are used: MHR 010 and MHR 050, they have the following ranges of registered linear displacements: ±0,01''≈ ± 0,254 mm and ±0,05''≈ ± 1,27 mm respectively (Pallas-Areny & Webster, 1991). Load value is evaluated by circumstantial way with use of special construction, located in the bottom bearing of the test unit. Its principle of operation is based on measurement of the rigid membrane deflection which appears under action of applied mechanical force. Experimental specimen is placed between the dynamometer membrane and the top bearing. Inductance coil of the sensor is located in the bottom bearing of the test construction. Sensor core is rigidly tied to the membrane. When the membrane deflects under the action of loading, the core position is changed within sensor. Accordingly, the differential electrical voltage from secondary coils of the sensor inductive transformer is changed as well. Deformation is defined immediately by the value of core shift within a sensor. To measure longitudinal deformation, the sensor is located between the bottom and top plates of the test unit together with a specimen. For lateral deformations measurement, the special surrounding case has been made, so the shift of specimen surface gives the deformation in respect to case with sensors. The unit of conversion and gaining is a part of the system of registration of tested rocks tensometric parameters. In this system, converted and amplified signal comes to ADC of the LA-I24USB registrator, whence quantized voltage values are transferred to the computer. Conversion efficiencies of the deformation conversion scheme are the following: for the MHR050 – k=0,5034 mV/μm, for the MHR010 – k=0,9469 mV/μm. Conversion efficiency for load conversion scheme for MHR 050 sensor is k=64,64 mV/t. Based on multiloop feedback scheme, the Butterwort low-pass filter of 6th order with cutoff frequency 0,25 Hz, is used for data processsing. Cutoff frequency is chosen according to the Kotelnikov theorem, because the digitizing rate is 1 Hz.

3. Experiment methodology

For the tests, the marble specimens of parallelepiped-shape with 100x50x25 mm^3 sizes have been assorted. Marble as a model material fits nice for tests, first of all as pseudoplastic material which exposes to semibrittle fracture. Experiments have been conducted with indoor temperature and humidity. Electromagnetic pulses to produce an effect have been supplied by graphite electrodes maintained on lateral surfaces of a specimen. It is essential that the platen contacting to specimen butt ends are electrically isolated one-of-another with the aids of a dielectric spacer placed between the average traverse of the press and AE sensor, with preamplifiers and ball joint. At the same time it allows to avoid external noise induction in a closed loop and, thereby, provide purity of an experiment. Experiments have been conducted both with only mechanical loading, and with additional action of external source of EM field. The following model sources of EI have been used: the rectangular pulse generator G5-54, the capacitor disharger (CD), creating electric pulses with steepness of edge about 1 μs and peak voltage about 1kV, and also the inductance coil for magnetic field induction. In the case of CD the scheme of 10 dischargers following in 15 second intervals (2,5 minutes in tote) has been used. Amplitude of pulses has been chosen 800V stably. In the case of G5-54 generator the following parameters have been set: positive polarity, frequency 2 kHz, duration 60μs, amplitude 50V. Duration of generator operation has been chosen 1 hour. During a session with combined action 10 capacitor discharges have been supplied 2 times, each 10 discharges series have followed by half-an-hour period of G5-54 generator action. Choice of the generator G5-54 as a source of quasi-periodic electric pulses is stipulated also for the following reasons. A laboratory experiment with a source of electric pulses of such a form is identified with the natural experiments, which actually had taken place during the period of using geophysical MHD-generators on the Harm and Bishkek polygons (Tarasov et al., 1999; Tarasov & Tarasova, 2004). The scheme of the experiment with crossed electromagnetic field (Cr.EMF) is described in work (Bogomolov & Zakupin, 2008). It involves both: stages of constant load (CL), and that of growing load with the rate of 300 kg per hour. AE signals represented a flow of random pulsed train of an experimental specimen surface's acoustic oscillation. (Greshikov & Drobot, 1976; Stantchitz & Tomilin, 1984). The spectrum and dynamic range of these signals are wide enough, that is why it is necessary to have wideband sensors and low-noise measuring amplifiers for their registration. It is also important to note the importance of registration and visual control of AE signals form for rejection of man-made noise and interference in AE events flow, which appear as a result of scattered electromagnetic fields effect when switching of current pulses simulating an electromagnetic effect on the geological medium. For the rejection, great work in viewing of wave form of tens of thousands AE events has been carried out, that has provided validity of the data passing the further stages of mathematic processing and interpretation. Experimental data interpretation has been realized on the basis of analysis of diagrams of AE activity time dependence. Such a representation form reflects changes of specimen deformation mode most informative. The processing by moving window has been fulfilled to calculate the AE activity by experimental data (files of registered signals). The width of the window is determined by average time to accumulate the certain number of events. As a result we have received the time dependences reflecting quantity of AE acts per second (this value mathematically identified with the derivative dN/dt). The meaning of the AE activity estimated by such manner is correspondent with the standard parameter "activity of the AE events". This is presented (with amplitude and duration) in the most of hardware for technology applications of AE (Greshikov & Drobot, 1976). The analysis of AE activity means determination of a reaction (response) of a loading specimen to the electromagnetic field effect. This reaction is expressed in variations of AE activity, which amplitude exceed the root-mean-square deviation of the AE's temporal dependence, the RMS deviation being defined by the prehistory (for times before the EI source power up). The experiments with effect for the specimens series have been conducted with loads more than 50% from fracture (in our previous works it has been shown that the medium sensitivity to EM field is observed with loads more than 75-80% from fracture load) with load incremental step over 100 kg.

4. Results

In this chapter we will describe results of the experiments with marble specimens. It consists of six experiments. One of them was performed without any external EM actions and other with several sources of EM field or their combinations.

4.1 The experiment without electromagnetic field effect

Let's begin with the experiment where only mechanical loading has effected on the specimen. During the experiment three periods have been realized: CL and with load increase of 300kg per hour. In the fig.2 the diagrams reflecting load and extension changes during all the experiment are shown.

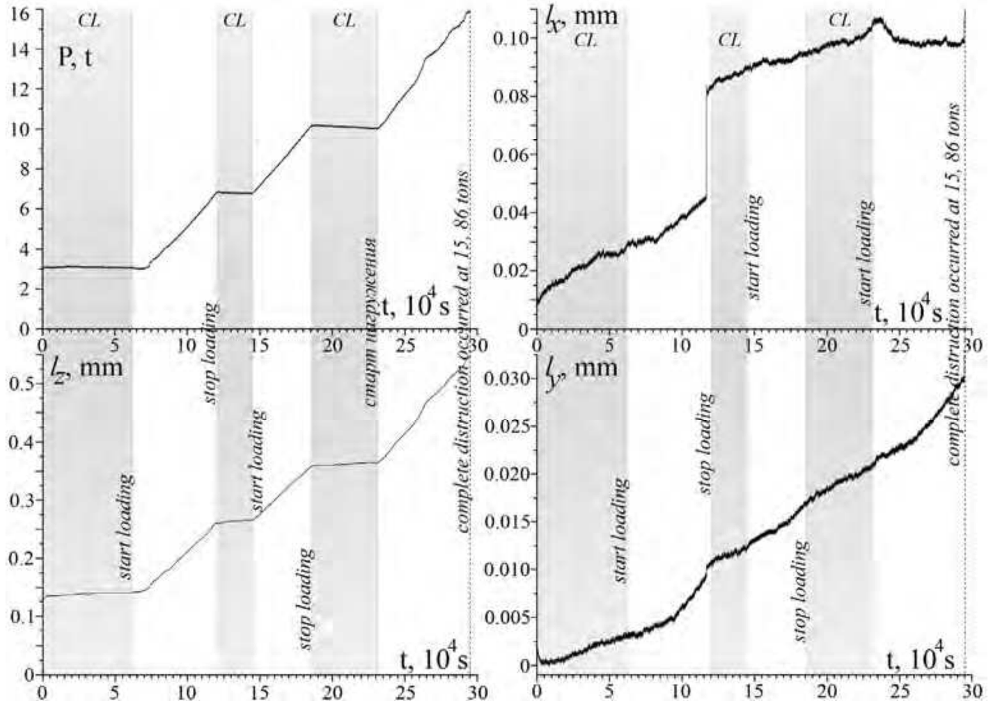

Fig. 2. Change of specimen's load and extensions (shortenings) in three directions (x, y, z).

The experiment has lasted for 81.86 hours in total. As one can see from the diagram the load increase arouses the adequate increase of longitudinal deformation. Lateral dimensions of the specimen have smoothly changed also demonstrating the growth. However in the two cases, we note sharp changes of specimen size in the X direction. By Y component the displacement increase has evenly progressed, going a bit faster during transition from CL into loading mode. Displacement by X has reached the maximum value of 0.11 mm, whereas by Y component it has been only 0.03 mm. Longitudinal shortening at the end of the experiment has been marked at the level of 0.54 mm. On the diagram of AE activity (fig.3) one can see variations after 7.4 tons. Activity slowly grows and about 11 tons sharply increases up to 80 events per second. This scattered activization ends with sharp decrease and during transition in the CL mode the activity goes to zero. During increasing load, the AE activates fast enough opposite to previous time, reaches a certain level, and however doesn't exceed 0.15 events per second. After transition in the CL mode, the character decrease is observed. Before the third period of increasing load its value has made up a little bit more than 10 tons, and AE activity has been close to zero.

The load beginning to rise once again has excited the activity about 0.2 events per second quickly enough, and then short-term spike up to 0.6 events per second. After 5 hours a fracture has come when maximum quantity of AE signals has been 131 events per second.

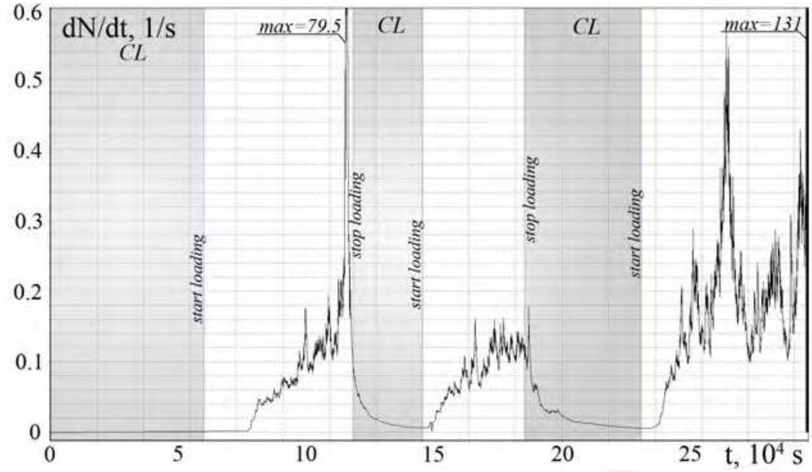

Fig. 3. AE activity during deformation in the CL and load constant increase modes.

4.2 The experiments with the discharges and G5-54 generator effect

The results of the experiment with the G5-54 generator have not revealed any changes in deformations during the generator work, and AE responses have been comparable with the responses registered in the experiments on the spring presses (on granite, salt and gabbro). Note only that, as earlier, the medium reaction has followed with some (sometimes prolonged) delay. The specimen has failed with most big loading, which has been 19.4 tons. We won't stop on this experiment in detail, because in the early works (Bogomolov et al., 2004; Zakupin et al., 2006) the main data volume has been received just by using this source of influence. In the experiment with the G5-54 on the marble specimen its high bearing value has become the general outstanding feature, it will be considered in detail when comparing the data in the following chapter (results discussion). Let's proceed to the experiments where effect to a specimen has been carried out by the CD. The two following experiments have foreseen EI to a specimen by the capacitor discharges with sessions according to the scheme: a) 10 discharges have been supplied during two minutes with a pause of half an hour, b) 10 discharges have been supplied during two minutes for one time per hour. In the first case, six such sessions have been conducted, and the three of them in the CL mode. The fracture loading has amounted 11.78 tons. The experiment has lasted for 47.7 hours in total. Changes of the specimen lateral dimensions in the course of the experiment are inessential. The single significant change of the X component (increase for 0.066 mm) has occurred because of sharp increase of load for 150 kg. Note that at the initial stage of the loading the lever press has one particular point, when transition to the ball bearing in the junction of third and second levers occurs. At such point sharp leaps of load (not always) are possible, which cause sharp shifts of a specimen faces, in this case such variations have taken place by Z component. In this experiment some sessions have been conducted in the CL mode and it is interesting that some changes of the longitudinal deformation l_z may be tied with influence of discharges series (fig.4). On the diagram it is seen that the longitudinal deformation has slightly decreased in the CL period, and three times sharply increased, two times in the moments of dischargers supply in the CL mode at its final part.

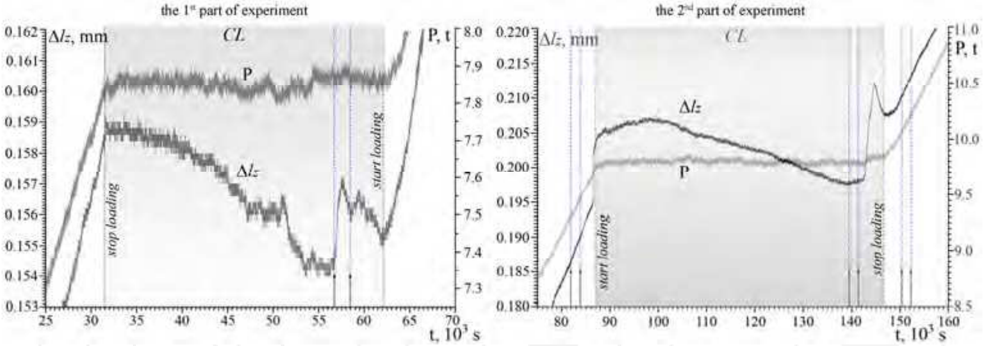

Fig. 4. Change of the load and longitudinal deformation, the supply moments of capacitor discharges of 800V are marked with arrows

The first time it was without a delay with increase for 0.003 mm and second time it was with a delay of 23 minutes and increase for 0.016 mm. Finally one more time l_z has increased in the mode of growing load in 40 minutes after discharges supplying (increased for 0.011 mm). Note that supply of discharges at the initial stage of the CL has not effected to the level of longitudinal deformation. Also the pulses in the mode of increasing load have not exerted influence on l_z. The experiments don't reveal significant influence on the components of deformations, when only 10 discharges (rather than 20) occurred. Note that in this experiment we have not conducted the sessions in the CL mode. At the same time at the late loading stages AE responses have been registered clear enough both in this and another case (fig.5).

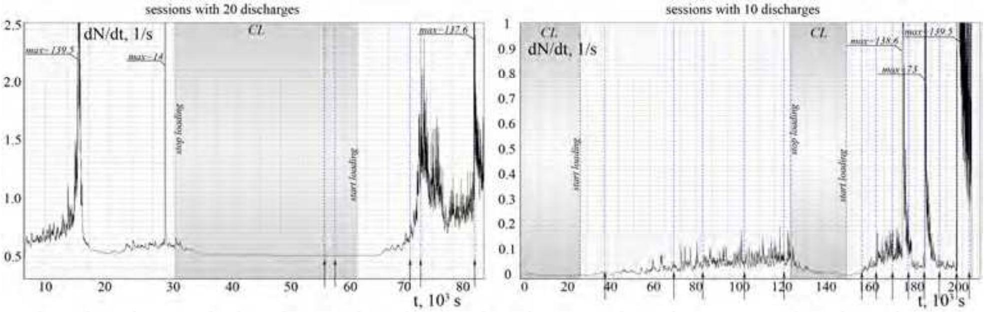

Fig. 5. The acoustic emission activity

Note, that in three sessions (fig.5) AE peaks have been observed immediately after supply of the discharges. It is important that maximal response activity has been by three orders greater than background level.

4.3 The experiment with combined effect of discharges and G5-54 generator

In the previous experiments we have revealed AE responses to effect of discharges. They have been observed both in the mode of 10 discharges per session, and in the mode of 20 discharges. The responses to the effect of series of light pulses from G5-54 generator have been weaker and with a delay. Note that during sessions, the deformations have not been changed. It has been interesting to conduct an experiment, where in a session the G5-54 generator effect precedes a series of powerful discharges. Let us speak about the experiment with combined variant of EI. So, as mentioned above, for EI the G5-54 generator and CD have been used. Scheme of EI order has been described in the methodic chapter. Fracture load for this specimen has made up 14.9 tons. The experiment has lasted for 81.49 hours in total. Fig.6 shows diagrams reflecting load and extension changes during all the experiment.

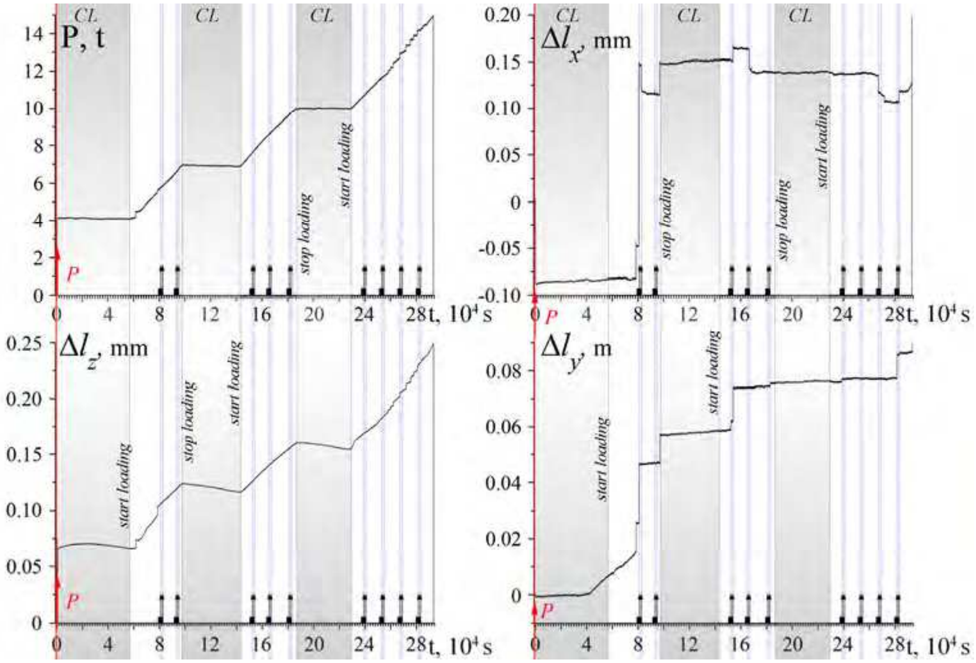

Fig. 6. Change of specimen’s load and extensions (shortenings) in three directions (x, y, z).

Note that in the specimen some decrease of longitudinal shortening value has been observed in the CL mode by practically constant load and lateral sizes. The fact of strengthening may be related to influence on the specimen, because at the first CL such effect has not been observed. The longitudinal deformation has also grown during load increasing. All the nine sessions with the effect has been conducted in the mode of increasing load and have not exerted an influence on the longitudinal deformation. At the same time very interesting data have been received for the displacements in the lateral directions. Opposite to the first experiment, the change of these parameters is characterized with sharp spikes. It is notable that all significant variations accurately concur with the first or second series of discharges. In the fig.7a the results of tensometric measurements for lateral components of deformation (displacement) are shown. For example, in the first session lx on first series of discharges has increased only for 0.03 mm, and after half an hour on second series responded with decrease for 0.02 mm, and l_y has only increased. Second series of discharges has effected on synchronous increase of l_y and l_x for 0.01 and 0.02 respectively and so on. In the third session the responses by both components have taken place, and l_y have responded to both discharges series with a value increase, and l_x has responded only to the last discharges and also by increasing. In the fourth session the first discharges series has induced decreasing of the shift value by l_x, and on l_y it has not influenced at all. The fifth and sixth sessions are similar to each other. One could see the responses of l_y values. The difference is that in the fifth session a response has been induced with the first series of discharges and in the sixth session it has been the second series. Just one session №7 in the experiment, not to provoke some changes in the displacement values, has been conducted by the load of 11.535 tons. In the eighth session l_x has decreased for 0.012mm, and l_y has not changed. In the last ninth session only the value of l_y has increased to the first series of discharges, to the second series only l_x, and both for the value about 0.01mm. Using the results of earlier experiments with the action of the capacitor discharges only, one can distinguish the role of the periodical action of G5-54 generator pulses. It seemingly consists in some material preparation before effect of powerful discharges. The results of AE processing involve nine sessions of the EI. As in the case with the specimen which has not been exposed to the EI effect, there is first phase of AE acts accumulation, which ends by 6 tons up to 64 acts per second. The difference is that little variations are present after the spike and they are attached to the first two sessions of the effect. The two following stages involve a lot of spikes, and again after EI. The fig 7b demonstrates the results of last part of the experiment, which involves 4 sessions.

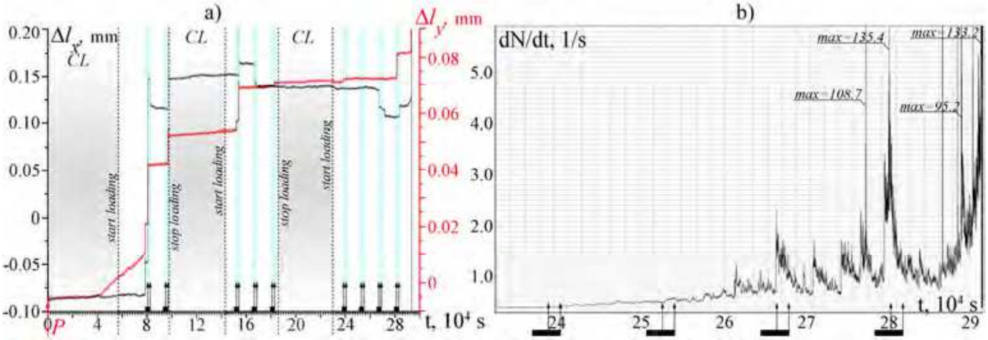

Fig. 7. a) Change of extension (shortening) of the specimen in the y, x directions; b) AE activity

Influence of the last two sessions has been effective, while the medium response has been clearly distinguishable on the background of AE fluctuation (at loads more than 80% from fracture). And if in the next to last session the activity increases times to the first discharges series, in the last session it has already occurred at the stage of G5-54 action, and discharges series has led to the second, but very powerful release. As in the many earlier results, a trigger character of the effect is evident here, because energy released is limited by its reserves and doesn't occur at the last ten discharges (in both cases) after its activation decrease (response). In tote the results by this experiment show the character of response to EI both in AE, and in deformation measurements.

4.4 The experiment with the crossed electromagnetic field effect

For the experiment with crossed electromagnetic field no less interesting results have been received. Fracture load for this specimen has made up 11.85 tons. The experiment has lasted for 70.1 hours in tote. As it follows from the results, the effect of crossed field has not practically affected on the deformation components change. Only the fifth session has a little variation in the longitudinal direction (growth has sharply slowed down) and during the sixth session in the y direction a little shortening has occurred (fig.8a).

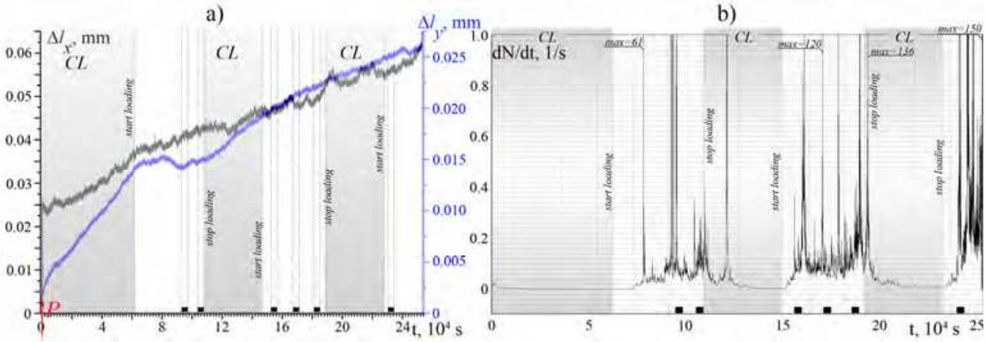

Fig. 8. a) Change of extension (shortening) of the specimen in the y, x directions; b) AE activity

In tote, the deformations smoothly increased during all the experiment. It is worth to note that in comparison to the previous specimens the lowest value of longitudinal shortening has been observed in this case. On average by the series of tested specimen to the moment, when load of 12 tons (about 100MPa) acts to a specimen, longitudinal shortening amounts more than 0.35 mm, but in this case it has not exceeded 0.09 mm. It is very notable that the general result by the medium reaction to the crossed field has been revealed in the AE activity (fig.8b). On the fig.8b all the six sessions of this experiment are shown. In five sessions (except the first one) the sharp peaks of AE activity during the period of field effect are noted. And it is not difficult to single out sharp and very big (by amplitude) peaks of activity (responses to EI), although in the time of session the beginning activity demonstrates some growth typical for the increasing compressive load as it is. So in the third and the sixth sessions the activity growth has reached 100-150 acts per second on a peak. Also, a durable aftereffect may be called a typical one. In our experiment this effect has been noted in some other form. In principle, in the earlier experiments we may not see it, because we have conducted the sessions only in the mode of constant compressive stress. In the new experiments it has been noted that after deformation transition from loading mode to the CL (especially at low loads) the AE activity either immediately ceases, or goes down to small values quickly enough. At the same time, as it is seen from the fig.8 that the second and the fifth sessions have been conducted exactly before the loading cutoff, but AE activation has being continued in the CL as a result of the effect. After the response to the second session it has been even the repeated peak. The relevant and possibly the most interesting results have been received in the tests on the lever press in the semipermanent deformation mode on the specimen of granite under action of crossed fields (Zakupin et al., 2009).

4.5 Comparison of the results

Comparing the results of deformations measurements and acoustic emission one can reveal the following features of the specimens' deformation in the CL and constant increase of load modes. In the CL mode the load is constant, and the longitudinal deformation may have tendencies both to little increase, and decrease. For example, in the case of the test of the specimen №1 (without EI) l_z in the CL has slightly increased, however the lateral sizes in this mode have grown as well. On the contrary, the lateral sizes of the specimen №2, which has exposed to the effect of discharges of the capacity discharger, by some decrease of l_z have remained invariable. Acoustic emission activity in the CL mode, as in the early experiments, is characterized with the Omory's law (Utsu et al., 1995). The relaxation release process of the energy, obtained by a specimen during tightening weight, revealing in the form of powerful AE flow, is a natural analogue of the aftershock activity known in seismology. In the both cases these processes have a damping character. The classic Omory's law for the time dependence of aftershock process can be described by means of the simple formula $n=k/(t_0+t)$. Here n is a number of aftershocks per time unit, the constant k depend on the main shock magnitude (or, in our case, on the main compressive stress and its increase), t_0 – the value, approximately equal to thirty six hours. In the generalization [Sobolev &Ponomarev, 2003] it is noted, that behavior of the AE events flow after mechanical tightening weight conforms to the Omory's law. It is shown there that the AE activity change on the drooping line after a tightening weight can be described using the activity value instead n, new parameters, determined the initial AE activity and its relaxation intensity after a tightening weight, instead k and t_0 coefficients. Depending on the load value t_0 will slightly change, however in the general case it has not to exceed 1-2 hours (the time, after which fast decrease of the activity ceases). Our dependencies have also been close to this law with fair accuracy. As it is seen from the diagrams 5-7, it is typical both for low and for high levels of load acting on the specimen. In the experiments on the spring press (PLT) we have observed some spontaneous activity on the decaying trend after a tightening weight, however in those experiments the loading has been more rigid. Under the rigid loading we mean a tightening weight for 2-3 tons during the period of 2-3 minutes. By the tests on the lever press a soft mode of loading practically approaches the received dependencies to the Omory's law without applying of approximation. Interesting result obtained in the experiment with the the Cr.EMF action is that the AE activity, which had begun after the pulses of Cr.EMF, is continuing even after the loading stop. And as it is seen from the figure 8, the activity peaks in the CL mode (aftereffect) have occurred higher than the major responses. It is worth to remark that EI by prolonged CL close to its end doesn't lead to responses such as described in the original works (Bogomolov & Zakupin, 2008) as well. Starting from 3 and more tons in the specimen, the slow increase of AE activity begins (during 10 hours), which then rapidly changes with a phase of fast release of acoustic emission, when the activity increases in hundreds times. The fast phase lasts about 25 minutes, and upon its completion the activity goes to zero at that (it occurs by load about 6 tons). This process may be considered as the first phase of fracture and the EI is ineffective here, although there may be exceptions. Then the similar phase of the avalanche cracking is observed in the specimens, but by one of the sources of EI it significantly differs from simple loading. Responses to EI reduce average level of AE intensity, and quantity of powerful spikes increases. Let's turn to the characteristics of the described effect of the EM field with respect to stress-strain properties of the specimen and its fracture. In the table 1 the general characteristics are shown (Explanations: P – loading without EI, for σ and ε the maximum values are given).

EI	σ, MPa	$\varepsilon_x\ 10^{-3}$	$\varepsilon_y\ 10^{-3}$	$\varepsilon_z\ 10^{-3}$	AE counts	AE response	Def. response
CD (20)	142	0,06	4,4	6,5	11977	+	+
CD (10)	93	0,02	0,2	2,5	55195	+	-
G5-54+CD(20)	119	3,4	3,2	2,5	36458	+	+
P	122	2	1,25	5,5	18129	n/a	n/a
Cr.EMF	95	1,1	0,91	0,9	16887	+	+
G5-54	155	1,5	2	4,6	17456	+	-

Table 1. Macrodeformative parameters of the tested marble specimens

From the results represented in the table, it can be concluded that maximal number of the AE acts fall to the specimen suffered minimal lateral deformations. Also in this case the minimal fracture load has been registered. Maximal lateral deformations have been observed for the third specimen (G5-54+CD). Only in this experiment the value of longitudinal deformation has been even less than lateral components, but it is necessary to note, that only here the hardening effect (decrease of longitudinal component by a constant load) has been observed. And finally, only in this experiment the nice responses to EI both on the deformation and on the acoustics have been received. As it is seen, the character of deformation and fracture of the specimens under the EI effect is varied and points to simple laws. That is why let us note only the most evident. The case with fracture of the specimen, which has not undergone to EI, can be supposed as classic. We have observed the prevalent axial component and moderate lateral components, which are less but comparable to axial one. By the acoustics in this case we observe a slight growth of the activity and minimal number of the sharp peaks (only two). All the rest cases essentially differ from the "classic" in one or another aspect. It is well-known (Lyakhovsky et al., 1997; Ben-Zion and Lyakhovsky, 2006) that the mechanical aspects of existing damage in a solid are modeled by generalizing the strain energy function as follows:

$$U = 1/\rho\cdot\left(\tfrac{\lambda}{2} I_1^2 + \mu I_1 - \gamma I_1 \sqrt{I_2}\right)\cdot \tag{1}$$

where $I_1 = \varepsilon_{kk}$ and $I_2 = \varepsilon_{ij}\,\varepsilon_{ij}$ are the first and second invariants of the elastic strain tensor ε_{ij}, ρ is the mass density, λ and μ are the Lame´ parameters, and γ is a third modulus of a damaged solid, introduced in (Lyakhovsky et al., 1997b). The first two terms of (1) give the classical strain potential for the isotropic elastic media. But the presence of damages (microcracks with some dominant orientation) allows "non-isotropic" third term in (1). This term was derived in (Lyakhovsky et al., 1997) by using the effective medium theory with noninteracting cracks or by expanding the strain energy potential as a general second-order function of I_1 and I_2 and eliminating nonphysical terms (Ben-Zion & Lyakhovsky, 2006). So, the third term in (1) describes the seeming "contribution" of damages to the energy function and thus the interrelation between AE signals flow and changes in parameters of a specimen straining (tensometry). The following stress-strain relation is correspondent with the above energy function (1):

$$\sigma_{ij} = \rho\, \partial U/\partial\varepsilon_{ij} = \left(\lambda - \gamma \sqrt{I_2}/I_1\right)\cdot I_1 \delta_{ij} + \left(2\mu - \gamma I_1/\sqrt{I_2}\right)\cdot\varepsilon_{ij} \tag{2}$$

Expression (2) describes the reason why damage accumulation (growth of factor γ) recorded by AE data may entail seeming change in elastic module. One can see that the signatures of damage growth in (2) may produce an impression of "strengthening" (due to bracket with λ) when the increment of γ takes place in a short time, without considerable variations of macro-parameters σ, and ε. This is correspondent with the enhanced value of averaged angular coefficient for σ-ε plot in case with Cr.EMF. But the stress-strain diagram for Cr.EMF case does not mean physical strengthening, because subsequent re-distribution of local deformation inside specimen is to result in great "delayed" growth of the main deformation (axial shortening). Such behavior (similar to pseudo-plasticity) of specimens under action of linearly growing compression and crossed EM field was described by (Urusovkaya, et al., 2000). Experiment of (Urusovkaya, et al., 2000) was performed on specimen of ionic crystals, the loading conditions differ from our case by faster stress growth and application of electric and magnetic fields of major strength. Unfortunately, no acoustic emission measurements were represented in that work. In our experiments the AE responses have been observed by the best way in the experiments with the crossed fields, capacitor discharges and combined effect (G5-54+CD20). In all these cases the low values of longitudinal deformation and low strength properties of the specimens have been observed. In case with combined field influence specimen has failed later than the two others (CR.EMF, CD10). A comparison of shortenings of these three specimens shows that the specimen G5-54+CD20 has the most significant changes of the lateral deformations. In spite of a small sampling (every experiment has been repeated 2 times), the results are valid surely. Actually, the limiting load dispersion was no more than 20% that is without EI influence, the specimens have fractured by the loads from 15 to 18 tons of compressive strength. This fact provokes interest to the group of specimens with high sensitivity to EI. As we see, the combined effects have found a reflection not only in the AE responses and deformations, but significantly decreased the material strength. In this sense the result with the capacitor discharges looks strange, when the discharges' number increase has not affected on the limiting load, although the AE responses have been significant. So, specimens of the same size and from the same material have fractured by different loads and it may depend on the kind of external EI. Another detail is that the most high stress-strain properties have proved to belong to the specimens, which have high flow degree (ε_z). In this case the pronounced dilatancy and high ability to compression resistance is owing to continuous structure transformation at present. But it is necessary to note the fact that concentration of released acoustic energy has fallen on two short periods. From the viewpoint of artificial influence on the geological medium, the listed aspects can play an important role when choosing zones for local removal of an overstress.

All the experiments confirm that starting from loads close to 70% from fracture, when time of forming of second part of the crack is coming (fracture planes), EI becomes efficient and excites several "tides" of AE activization at the level in 15-20 times more than the similar in the P experiment. The example with G5-54+CD on second phase of the main fracture forming is very demonstrative, when several "tides" of gain of the AE intensity initiated by EI stand out very good. At the same time, the effect of the mentioned sources on AE significantly differs in the first case quantity of acts is in 3 times more. The interesting result has been registered with the G5-54, when σ_{max} has increase on 18% by practically the same values of the deformations and AE in comparison to P. So, for example, as in the case of the experiment with CD, maybe a rapid fracture of separate zones with high concentration of stresses following with many shocks of low energy (in our estimations) would be preferable. However, the database of major volume is necessary for the final conclusions.

5. Discussion and the model of mechanism of electric pulses influence

The peculiarities of the AE and deformation responses to effect of electromagnetic pulses, described above, have raised the urgent question about the physical mechanism. The model ought to explain similarity of the effect of acoustic emissive response for such dissimilar materials as granite and rock salt. In the physics of condensed state and in the physical material science the whole variety of instances of electromagnetic fields with structure defects interaction (atom-vacancy defects, charged dislocations, microcracks) is known (Zuev, 1990; Kuksenko et al., 1997; Urusovskaya et al., 2000; Bogomolov et al., 2004; Shpeizman & Zhoga, 2005). By these interactions, and in fact by elementary processes in the certain materials, the electroplastic effect, plastomagnetic effect, cracks stopping and initiation in electric field and etc are explained on the semiqualitative level (Finkel et al., 1975; Finkel et al., 1977; Molotskii, 2000; Alshitz et al, 2008). However such processes are not universal enough and cannot be accepted for the basis of the model of acoustic emissive responses excitement in the materials with various physicochemical and rheological properties by themselves. At the same time the trigger influence of weak vibrations on inelastic deformation has such universality that it is established and well explored at the various scales from centimetric (laboratory) to one-kilometer-wide and more (natural) (Mirzoev,et al., 1991; Sobolev et al., 1993; Belyakov, et al., 1999; Sobolev & Ponomarev, 2003; Kocharyan & Spivak, 2003; Kocharyan et al., 2006). This allows a qualitative model of the possible mechanism of AE activation of loading rock specimens. The model appeals to triggering due to microvibrations produced by the action of electromagnetic pulses (Bogomolov et al, 2004, 2004a). However, when passing from qualitative to quantitative explanation level the following troubles appear. On the one hand, by estimations from the works (Bogomolov et al., 2001, 2004a), the effect of rock's AE activity response is revealed, when the amplitude of pressure oscillation becomes of the order of 10^{-6} from the main stress level. But on the other hand, the well known traditionally considered mechanisms of transformation of electrical energy into mechanical: piezoelectric effect, ponderomotive forces, thermal dilatation when medium heating cannot explain such amplitude of disturbances of stresses σ and deformations ε when acting of pulsed fields with electric field strength $E \sim 1000$ V/m typical for the experiments described above with applying of G5-54 generator as a supply. Actually, in dielectric mediums (specimens of granites, marbles, rock salt) Joule heating is ruled out, and thermal dilatation knowingly cannot play a role. As to a piezoelectric effect, it can provide relative disturbances of σ, ε about 10^{-7} from main compressive loadings only for quartzite specimens with longitudinal piezoelectric modulus $d_E \sim 10^{-14}$ -10^{-12} m/V, where the upper value approaches to the value of d_E modulus for quartz monocrystals (Parhomenko,1965). It follows from the formula of electromechanical coupling $\delta\varepsilon \sim d_E \cdot E \sim 10^{-11}$-$10^{-9}$ with specified typical field strength E. If we take into account the fact that elastic moduli are about 10^{10} N/m^2, then just the value for maximal disturbances $\delta\sigma \sim 10$ Pa, corresponded to10^{-7} from the level of main compressive stress, will be received. For the specimens of granite and marble typical values of d_E are 4 orders lower (Parhomenko, 1965). In the same proportion the $\delta\sigma$ disturbances tied to piezoelectric effect ought to decrease.

For the specimens without piezoelectric properties, the contribution of ponderomotive forces, as evaluated for simplified model of isotropic dielectric, lead to the lesser disturbances of the stress by the same values of $E \sim 1000$ V/m, $\delta\sigma/\sigma_0 \sim 10^{-8}$ from the main compression. This estimate is based on the standard model of the electrodynamics of continua (Landau & Livshitz, 1982) and equivalent to regard of the attraction force of the electrodes fixed on the specimen faces and formed a capacitor. Note that accuracy of received estimations match the parameter of applicability of the known formula for average energy density U of the quasi-harmonic electric field with slowly changing amplitude (Landau & Livshitz,1982):

$$U = \frac{1}{2}\varepsilon_{e0}\frac{\partial}{\partial\omega}(\omega\varepsilon_e)\cdot < E^2 >, \tag{3}$$

where ω – cyclic frequency, ε_e – dielectric permittivity, ε_{0e} =8, 85 10^{-12} F/m, the "e" index is introduced for clear distinction from deformations symbol.

In some works (Shpeizman & Zhoga, 2005; Bogomolov et al.,2006) the attempts have been taken to explain influence of electrical fields on a fracture by their energy contribution with the density (1) in common energy balance in the volume $(2l)^3$ around the crack with a length of 2l. In the work (Shpeizman & Zhoga, 2005) in neglect of the dispersion ε_e the following generalization of Griffith criterion with an electrical polarization is present:

$$\frac{\sigma^2 l}{G} = \frac{2\gamma_S}{\pi} - \left(\frac{2\Lambda}{\pi}\right)\cdot \varepsilon_{e0}\varepsilon_e\cdot < E^2 > l\,, \tag{4}$$

where γ_S – specific surface energy, G – elastic modulus, with <> average by time is marked. In the formula (4) the numerical coefficient Λ is introduced, it takes into account that activation volume, where the electric field significantly changes with crack's concerned "virtual" extension, may slightly differ from adopted in the (Shpeizman & Zhoga, 2005) value 4*l*×4*l*. The right part of the (4) just describes the drop of effective Griffith parameter γ_S (energy of new surfaces formation) in the presence of electric field. The further generalization of crack instability condition, allowing to take into account the dispersion of ε_e, involves replacement of the parameter ε_e in (4) by the derivative $\partial/\partial\omega$ (ω ε_e), according to (3). The value of γ for the rock specimen and ceramics is about J/m^2, and the parameter $\varepsilon_e<100$. So, the electric field influence on submillimetric cracks becomes essential only when its strength is E~ 100kV/m. It is important that in some heterogeneous mediums, in particular containing bound water in the pore-fractured space, the factor $\partial/\partial\omega$ (ω ε_e) can reach for hundreds and even thousands during high amplitude electromagnetic disturbances (Chernyak,1987; Svetov, 1995). Meanwhile, the minimal field strength E which is able to influence on stability criteria of the mentioned cracks (*l* ~ 0,05-1mm) decrease to the value ~10 kV/m. In the experiments with model electromagnetic effects (Bogomolov et al., 2004; Zakupin et al., 2006) such fields have been induced by supplying to the tested specimens pulse voltage of 500-5000 V (from a capacitors battery or inductive discharger). By these effects the activization of crack formation has actually occurred with a delay from hundreds to thousands seconds (Bogomolov et al., 2004a; Zakupin et al., 2006). The delay interpretation may appeal to the fact that the vibrations produced by the electric pulses can influence on microcracks with sizes of the order of 0,01 mm, and this channel has turned out more effective than change of stability condition (4). For the ionic crystals, the electroplastic effect (immediate influence of the field E on dislocation mobility) takes place by the action of more powerful fields E ~ 1 MV/m, (Zuev, 1990). However, by less strength E ~ 1000 V/m, typical for cases of G5-54 generator action, the presented result about AE activity increase can not be explained by the equation (4). It is important to note the availability of compliance in the estimations of field strength threshold, fallen into the range of E ~10-100 kV/m, by which it, on the one hand, is able to shift a bit the critical strength by Griffiths criterion, and, besides, it excites stress oscillations with amplitude of the order of 10^{-7}-10^{-6} from main compression.

To the authors' opinion, the problems of explanation of electric pulses influence with strength E ~ 1kV/m (typical experimental conditions of the effect triggered by the action of G5-54 generator (Bogomolov et al., 2004a; Zakupin et al., 2006)), are related to lack of the quasi-stationary field model. The derivation of the condition (4), proposed in the (Shpeizman & Zhoga, 2005), is based on this model; this condition reflects more rapid change of the medium and average field polarization with a following crack growing by already sustained characteristics ε_e, $\partial\varepsilon_e/\partial\omega$, $\langle E^2 \rangle$. Principle stand of the nonstationarity factor (sharpness of the field E changes) has been realized on the experiments stage yet. As a source of electric pulses the G5-54 generator has been chosen just because it provides steep edges of square pulses, and by this the wave effects may become significant. However, the theoretical description of electromagnetic pulses interaction with growing defects is extremely difficult, like the excitons problem (Knox, 1966). It goes far beyond the scope of this work. Heuristically, to discuss the mechanism of anomalous microvibrations excitation in loading specimens under the effect of electric pulses with steep edges, such "excitation" may be compared to the known in nonlinear optics effect of induced Brillouin scattering. This effect describes light scattering on the time fluctuations of dielectric permittivity, appeared because of the mediums density fluctuations (in particular by rapid deformation), by which the frequency change occurs (Shubert & Vil'gelmi, 1973). Low-frequency analogue of the induced Brillouin scattering effect is a nonlinear interaction of sonic and electromagnetic waves with a resonance on the difference frequency. As a result, the sonic wave with a frequency $\omega_S = (\omega_1 - \omega_2)$ magnifies, where ω_1, ω_2 – frequencies of EM waves, distinguished from spectrum of the pulse by the resonance condition. In the loading specimens when microcrack forming in the surrounding matter volume, undoubtedly, non-uniform deformation disturbances take place. If these disturbances get additional energy and pulse from an external field, and the acoustic Q- factor of the medium is high enough (like of rocks), then oscillations spread and exert a trigger influence on growth of the neighbor crack. Then the process is repeated and, in that way, self-acceleration of the microcracks growth may occur, it reveals in experiments as temporary increase of AE activity. In the range of compressive loadings 0,7-0,9 from fracture in semibrittle materials (rocks) there are zones of plasticity localization and domains (mesovolumes), remained in the bounds of elastic strain (Panin & Grinyaev, 2003; Makarov, 2004). But although within domains microcracks may appear or lengthen, they don't influence on character of the mesovolume deformation in tote, and acoustic Q factor in these areas is higher than in average by over the specimen. In such mesovolumes the most favorable conditions are composed for resonance on the difference frequency (related to nonlinear three-wave interaction).

Let us consider a more detailed interaction of electromagnetic and sonic waves similar to the Brillouin scattering by arrangement of the experiment with Cr. EMF. Electrodes, on which the pulses of the G5-54 generator had been supplied, were fixed on the opposite side faces of tested specimen. At that, the transient processes are described as spreading of two electromagnetic waves with Poynting vectors pointed opposite to each other. In the theoretical model of the induced Brillouin scattering, it corresponds to the case of the "backward scattering" (Shubert & Vil'gelmi, 1973), by which the following conditions must be satisfied for the frequencies ω_S, ω_1, ω_2 and wave vectors $\mathbf{k}_S$, $\mathbf{k}_1$, $\mathbf{k}_2$ of the sonic and electromagnetic waves:

$$\omega_1 = \omega_2 + \omega_S , \quad \vec{k}_1 = \vec{k}_2 + \vec{k}_S \tag{5}$$

Absolute values of the vectors $\mathbf{k}_S$, $\mathbf{k}_1$, $\mathbf{k}_2$ are defined by known expressions:

$$k_S = \omega_S / V_S , \quad k_{1,2} = \omega_{1,2} / C , \tag{6}$$

where V_S – the sonic wave velocity, C – the electromagnetic waves velocity, and for the continuous consolidated medium usually $V_S/C \sim 10^{-5}$. Because the direction of the vector $\mathbf{k_2}$ is opposite to $\mathbf{k_1}$, then it follows from the equations (6), that condition of the sonic wave gain by interaction of electromagnetic waves with frequencies ω_1, ω_2 may be written in the form:

$$\omega_S = \frac{V_S}{C} \cdot (\omega_1 + \omega_2) \approx 2 \cdot \frac{V_S}{C} \cdot \omega_{1,2} \tag{7}$$

For pulses of the G5-54 generator, steep rising edges with width less than 0,1 μs provide excitation of great numbers of the harmonics in the frequency range over or of the order of 10^7 1/s. That is why the condition (7) is compatible with the requirement $\omega_S = \omega_1 - \omega_2$ in the case of close to each other values of ω_1, $\omega_2 \sim 10^7$ 1/s, and then the frequency of sonic waves ω_S falls into the range from hundreds 1/s to 10^3 1/s. A hypothesis about the mechanism of trigger influence of electric pulses on AE through low-frequency vibrations excitement looks like unexpected, because there is a widely held idea that the medium reaction (change in the destruction process) begins at the lowest scales levels, and high frequencies correspond to small sizes. In this connection it is necessary to note that the immediate response of the rock specimens on stimulation by low-frequencies vibrations (with a frequency ~ 200 Hz in the experiments (Bogomolov et al., 2001; Kuksenko et al., 2003), and frequencies 1-2 kHz in the experiments with another microvibrator (Bogomolov et al., 2004a; Mubassarova et al., 2011)) has been demonstrated. Applying a classic (unquantized) representation of the induced Brillouin scattering model (Shubert & Vil'gelmi, 1973), let's estimate amplitude of sonic oscillations, which can be excited by electromagnetic waves taking part in transient processes on the pulses edges. In this representation, in one-dimensional case the original equations for the stress waves $\sigma_{\sim}(t,z)$ and electric field strength can be written in the following form:

$$\frac{\partial^2 \sigma_{\sim}}{\partial t^2} - V_S^2 \frac{\partial^2 \sigma_{\sim}}{\partial z^2} = -\varepsilon_{e0}\, \varepsilon_e \cdot \left(\frac{d\varepsilon_e}{d\sigma} \right) \cdot \frac{G^2}{2\rho} \cdot \frac{\partial^2 E}{\partial z^2} - \Gamma_S \frac{\partial \sigma_{\sim}}{\partial t} , \tag{8}$$

$$\frac{\partial^2 E}{\partial t^2} - C^2 \frac{\partial^2 E}{\partial z^2} = -(\varepsilon_{e0}\, \varepsilon_e)^{-1} \cdot \left(\frac{d\varepsilon_e}{d\sigma} \right) \cdot \frac{\partial^2 (\sigma_{\sim} E)}{\partial z^2} , \tag{9}$$

where ρ – material density, Γ_S – acoustic absorption factor, expressed through Q factor by the ratio $\Gamma_S = \omega_S / 2\pi$ Q. It is necessary to note that the member with Γ_S, taking into account friction loss of a sonic wave energy, is written in the simplest way, although from the hydrodynamic equations follows a proportionality of this summand $\partial^3\sigma_{\sim}/\partial z^2\partial t$. According to the (Shubert & Vil'gelmi, 1973), the wave equation (6) models a situation, when, on the one hand, dielectric permittivity disturbances linked to the stress oscillations: $\delta\varepsilon_e \cong (d\varepsilon_e/d\sigma)\,\sigma_{\sim}$, and, on the other hand, in a sonic wave density oscillations of (deformations) and stress may be supposed to be proportional. In the usual terms of the experiment in the nonlinear optics these interconnections are undoubted. The right part of the electromagnetic waves spreading equation (9) describes a disturbance of electric polarization. It is believed that a length, where sonic waves subside, is bigger than microcrack dimension (initial disturbance source), but it is much less than the length of electromagnetic waves damping.

Search for solutions of the system (8), (9) in the form of quasi-harmonic waves: sonic wave $\sigma_{\sim} = \sigma_a \exp(i\, k_S z - i\omega_S t)$ and two electromagnetic waves $E_{1,2} = E_{a1,2} \exp(ik_{1,2}z - i\omega_{1,2}\, t)$, their frequencies and wave numbers satisfy (7), and complex amplitudes are smooth time functions, brings the following resulting expression for σ_a amplitude:

$$\sigma_a = -i\pi\,\varepsilon_{e0}\,\varepsilon_e\left(\frac{d\varepsilon_e}{d\sigma}\right)\cdot G^2\,k_S\cdot\frac{E_{a1}\,E_{a2}^*}{2\rho V_S \Gamma_S}\,, \tag{10}$$

where with the sign * means the complex conjugation. Actually this is a well known formula of nonlinear optics. Other equations from the system describing the evolutions of harmonics $E_{a1,2}$,(Shubert & Vil'gelmi, 1973), are not necessary for our consideration. The main feature is that the amplitudes of these harmonics are steady in a case of action of enough powerful field. To estimate a maximal value of the amplitude σ_a by the formula (10) the derivative $d\varepsilon_e/d\sigma$, formed its right part, may be changed by the ratio $(\varepsilon_e\text{-}1)/G$ with order accuracy. At the same time presence of the significant density fluctuations in the crack, emitted acoustic waves (AE), neighborhood is automatically taken into account. Conversions in the (10) with applying of the ratio $V_S^2 \cong G/\rho$ and other known formulas bring to the expression:

$$\sigma_a \sim \pi^2 Q\cdot\frac{1}{2}\varepsilon_{e0}\varepsilon_e E_a^2\,,\quad E_a \sim E_{a1} \sim E_{a2}\,, \tag{11}$$

which in pictorial form pointed to physical sense of the effect. It has happened that in result of resonance on the difference frequency ω_S the amplitude of stress oscillations may increase in ~ Q times more in comparison to a usual case of quasi-stationary field, when the expression $\delta\sigma \sim \delta U \sim \frac{1}{2}\,\varepsilon_{e0}\,\varepsilon_e\,E_a^2$ by dimensionality and order of the value correspond to the surface density of ponderomotive forces and, simultaneously, to the energy of electric field. Such result of sonic waves gaining may be expected as a natural demonstration of the general physical principle of a resonance, and the harmonic beating with close frequencies ω_1, ω_2 of electric field play the external effect role. For the rocks without large cracks Q factor by atmosphere pressure, Q ~ 100-400, and in compressed station it can reach for several thousand or tens of thousands (Nazarov & Radostin, 2007). If we suppose that in the experiments of G5-54 generator applying the amplitude of high-frequency harmonics has been compared with the pulses amplitude (~ 1000 V/m), then the expression (11) gives the estimate of σ_a ~ 1-10 Pa, fallen just in the range 10^{-7} -10^{-6} of the level of main compressive stress. For the vibrations with amplitudes from this range the mentioned above effect of vibrating stimulation of acoustic emission activity is established. That is why the presented model of the mechanism of microvibrations excitement by the effect of electric pulses to the rock specimens may be considered as a serious candidate for explanation of trigger influence of electric pulses with steep wave fronts on AE, in particular pulses of the G5-54 generator. This model shows a similarity of the effects of acoustic emission responses to the action of weak low-frequency vibrations and electromagnetic pulses, which has been noted in works (Bogomolov et al., 2004, 2004a; Mubassarova et al., 2011). It should be noted that in a real situation, as opposed to one-dimensional task, the σ_a value by resonance interaction of sonic and electromagnetic waves may occur less then estimation (11) because of waste of excited wave divergence and other factors. Proposed model remains a believable hypothesis, its attraction is determined by possibility of removal (or essential decrease) of mentioned above mismatch in the amplitudes of the first-excited microvibrations.

As it has been mentioned above that during microcrack formation or growing (AE events), vibrations and dielectric permittivity disturbances appear, and the last predetermine a possibility of interaction with electromagnetic waves. Thanks to pulse and energy transmission to sonic waves with a resonance (difference) frequency in the medium with high Q factor, the low-frequency vibrations continuing for a time significantly exceeding duration of the high-frequency AE signal may be excited. These vibrations are able to initiate other microcracks growing. But if the undercritical sites sensitive to external influence, are absent (that is naturally by very low background activity, in other words by the loading low level), then a stimulated increase of the events number would not occur. As concerns to the case of high background activity (big loadings), for it the conditions of excited oscillations of dielectric permittivity coherence becomes important. If the following AE event spontaneously appears soon after the first, then besides it the oscillation phase on the frequency ω_C would break because of disturbances from a new crack and the resonance interaction with external waves becomes less effective. Typical time for the fluctuation of a density and dielectric permittivity may be estimated as $\delta t \sim$ 10-50 μs (travel time of sonic wave with rate $V_S \sim (2\text{-}4)\ 10^3$ m/s over a specimen of dimension 5-10 cm). Then time of coherence saving including by interaction similar to induced Brillouin scattering will be of the order of $Q \cdot \delta t \sim$10-50 ms (accepted $Q \sim 1000$). By the pulse-repetition frequency of the G5-54 generator 2-10 kHz during this time from 20 to 500 serial pulses may pass, their edges make a contribution in the amplitude of high-frequency harmonics $\omega_{1,2} \sim 10^7$ 1/s. In the case when background activity will exceed 20 1/s, the interval between some events will be shorter 10-50 μs, and real coherence time will shorten. The number of passed fronts will decrease, and in the wake of it, the amplitude $E_{a1,2}$ in the formulas (8-11) will decrease as well. By the corresponding decrease of maximal σ_a from (11), the absence of the effect of acoustic emissive response to electric pulses may be explained. It is necessary to affect by pulses with higher electric field strength or with higher frequency of pulses passing for the effect observing. It is confirmed with several instances of responses observing on gabbro specimens, stood under the loading close to the critical (0.98 from the fracture). In these cases the activity level has amounted from the tens to hundreds of events per second, but effect with maximum possible parameters (the series of 900-volts pulses from the capacitor discharger, $E \sim 5 \cdot 10^4$ V/m) leads to greater activity increase, in 600-800 s after which a relaxation rather than a macrofracture has followed.

The other check of the hypothesis by the independent experimental data involves the aspect of low-frequency vibrations generation before the basic AE response to EM effect. This follows from the model essence. A special experiment has not been conducted, but it is possible to use the results of measurements, when the seismic mini detector (piezoelectric geophone A1605) has been fixed to the granite specimen in the form of parallelepiped for the sake of the hardware adjustment. After the calibration the hardware units have been used for geological acoustic monitoring in the boreholes at the Bishkek test site (Zakupin, 2010), so received by the geophone signals in the range of 10^2 -10^3 Hz may be called as GAE – geoacoustic emission (Gavrilov et al, 2008). The specimen has been tested on the lever-gravitational press by a stepped uniaxial compression with application of EIs (capacitor discharges) on every step. By the previous experiments a character of AE responses of the specimen from this series is known (Bogomolov & Zakupin, 2008). In the measuring sessions by a fixed load either high-frequency channel with AE sensor or low-frequency one with geophone has been turned on, to avoid a cross-effect of primary piezoelectric transducers. For the tested granite specimen by the loads of 85-95% from fracture the AE activity response to EM field pulses (condensing dischargers) has occurred with a delay of 600-1000 s. The change of GAE amplitude level during the session by such pulses effect for 1-5 min is shown on the fig.9. In the session 16 condensing discharges (maximal voltage is 600 V, duration ~ 2ms) with equal intervals in the first 15 minutes have been conducted. Diagrams discontinuity is tied with pause in the registration needed for the data downloading. Increase of the GAE level has been occurred earlier as compared with the typical delay of the response of high-frequency AE activity. It just should be observed, according to discussions about the resonance gain of low-frequency vibrations because of the induced Brillouin scattering. So, the proposed hypothesis (model) of the primary vibrations generation is confirmed by involvement of the new data, it allows understanding a number of aspects of the acoustic emission responses to electromagnetic field action.

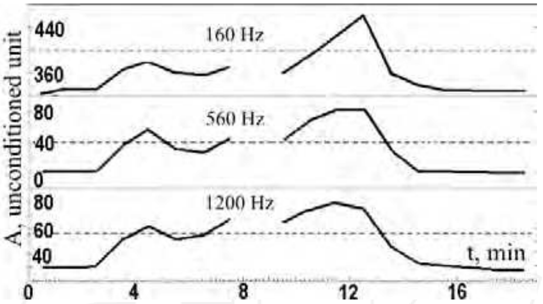

Fig. 9. The time dependence of the low-frequency emission amplitude.

6. Conclusion

The new results of variations of acoustic emission activity of rock specimens (marble) under the effect of electric pulses have reflected the short-term increase of the number of microcracks initiation and stretching acts. The analysis of AE responses to electromagnetic effects has been conducted by a detail research of the macrostrain characteristics of the specimens. As in the previous works, the reaction of rock specimen to EI is a short-term increment of AE activity. From the viewpoint of EI effect on AE and volumetric deformation, the results show the high efficiency of external electromagnetic fields effect on cracking kinetics in loading rocks. The proposed model relates the mechanism of electric pulses influence on the crack formation velocity in loaded rock specimens with initial excitation of low-frequency vibrations in them owing to the nonlinear resonant interaction of electromagnetic waves similar to the effect of induced Brillouin scattering. The model establishes the correlation between the electric pulses amplitude and the parameters of the specimen material (acoustic Q- factor and dielectric permittivity) which is a necessary condition of AE response generation at steady loads. From the viewpoint of analysis and interpreting of laboratory experiments, one can see a convincing reason for geoacoustical surveys in the vicinity of a source of electromagnetic soundings of the Earth's crust.

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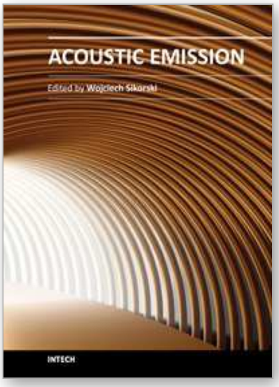

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Acoustic emission (AE) is one of the most important non-destructive testing (NDT) methods for materials, constructions and machines. Acoustic emission is defined as the transient elastic energy that is spontaneously released when materials undergo deformation, fracture, or both. This interdisciplinary book consists of 17 chapters, which widely discuss the most important applications of AE method as machinery and civil structures condition assessment, fatigue and fracture materials research, detection of material defects and deformations, diagnostics of cutting tools and machine cutting process, monitoring of stress and ageing in materials, research, chemical reactions and phase transitions research, and earthquake prediction.

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