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Investigation of Dynamics of Temporal Distribution of Acoustic Waves Caused by Stick-Slip Process

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ABSTRACT. We investigated dynamics of acoustic wave generation during stick-slip motion of sample rocks. For that, laboratory spring-slider system has been developed enabling registration of acoustic waves generated by stick-slip (SS) at different sliding regimes and relative external forcing. To create these time series, experimental recordings were conditioned, wave trains separated and onsets of the acoustic emission (AE) detected. For quantitative evaluation of changes in dynamics of acoustic wave generation, nonlinear recurrence quantitative analysis (RQA) and Tsallis entropy calculation method have been used. It was shown that the amount of deterministic structure in dynamics of acoustic wave temporal distribution depends on movement regime. *© 2010 Bull. Georg. Natl. Acad. Sci.*

Key words: *stick-slip, forcing, dynamics, determinism.*

In this paper we aimed to investigate dynamical characteristics of nonlinear elastic wave generation in the SS frictional system. It is known that friction develops between sliding surfaces and results in transmission and dissipation of the energy of relative motion. At the same time, frictional processes are not always stationary and at constant drive rates SS oscillations may occur. SS inherently suggests instability and represents intermittent motion when the stress builds up to a threshold value, then (when friction pumps to the system more energy than can be dissipated by the stationary process) stress is rapidly released [1]. When stress suddenly changes, part of the stored strain energy is released in the form of elastic waves, including ones with sonic frequencies; it is important to mention that reverse effects are also observed, namely, elastic waves from vibrations can affect friction [2]. Thus one of the most fundamental aspects of SS friction is an AE process that involves oscillations of atoms. Elastic waves generation related to SS oscillations are often observed and investigated in spring-slider systems. Spring-slider systems are not less interesting from the geophysical point of view too, because they are considered as a proxy of geological faults under tectonic stress. Hence dynamical aspects of acoustic wave generation in spring-slider systems is the object of intense research in geophysics, seismology and tectonics [1, 3]. Furthermore, nonlinear spring-slider systems can be used to investigate the phenomenon of anomalously high sensitivity to small changes regarded as physical mechanism underlying complex dynamics. Besides its general scientific value, analysis of the dynamics of AE in nonlinear spring-slider system may help in understanding the controlling and triggering phenomena taking place in complex systems: e.g. induced seismicity, earthquake triggering and synchronization, etc. [3]. At the same time, results of analysis of dynamics of elastic wave generation in a spring-slider system as well as influence of small external impacts on wave generation will be interesting also for fundamental friction science, as far as

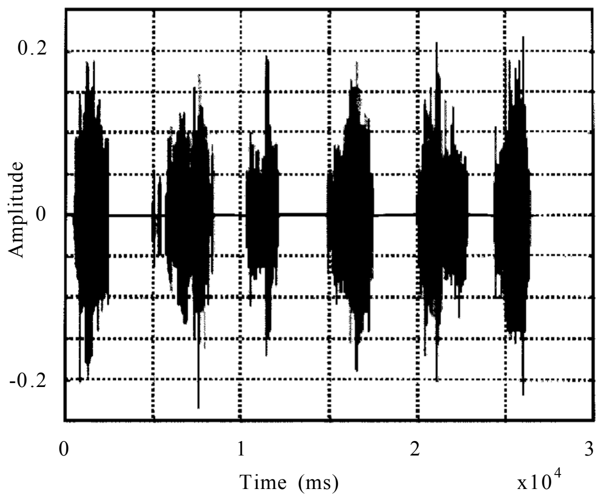

Fig. 1. Sample SS AE recordings after wave trains separation.

they indicate some fine details of the investigated process in SS regime.

Methods. Experimental spring-slider system of our SS AE experiments represents two horizontally oriented plates of the same roughly finished basalt. The height of surface asperities was in the range 0.1-0.2 mm. A constant pulling force in the range of 4-10 N was applied to the upper (sliding) plate. In order to investigate the influence of weak external impacts on the dynamics of a SS AE, the same plate was subjected to periodic mechanical or electric perturbations with variable frequency. Further details of our experiment are given in [3]. Experimental recordings from laboratory system were conditioned, filtered and wave trains separated (Fig. 1). Then onsets of the AE signals were detected and series of time intervals between consecutive AE bursts (ΔtAE) and between AE maximums (ΔtAE_{max}) were created.

Results and discussion. To investigate the dynamical properties of acoustic waves generation and assess its deterministic structure the method of RQA [4] has been used. Here the results of the RQA statistics, called % determinism (% DET) are presented. After, in order to quantify tiny changes in the dynamics of acoustic wave generation we calculated Tsallis entropy [5]. It was shown that, without forcing, RQA %DET measure of the analyzed time series increases from 18 to 27 when driving force rises (spring becomes twice stiffer); thus AE reveals more deterministic structure. Thus, RQA characteristics show an increase of the amount of the deterministic structure (Fig. 2, a) in ΔtAE and ΔtAE_{max} time series when the relative force of external influence rises to about 20%. This means that small external influences lead to increase of an order of dynamics in acoustic wave generation during the nonlinear process of the stick-slip process.

Results of Tsallis entropy calculation are in good accordance with RQA results. Indeed, as is shown in Fig. 2, b, the value of Tsallis entropy sharply decreases at the same value of relative forcing. This also indicates a decrease of the extent of complexity or increase of order in dynamics of AE at small external influence.

Our analysis shows that dynamics of acoustic wave temporal distribution depends on sliding regime and can be modified through weak forcing. These results are important, shedding light on the possible controlling effects of external small/moderate periodic forcing on the temporal behavior of complex dynamical systems (including seismic process), as well as from the general elastic wave generation point of view.

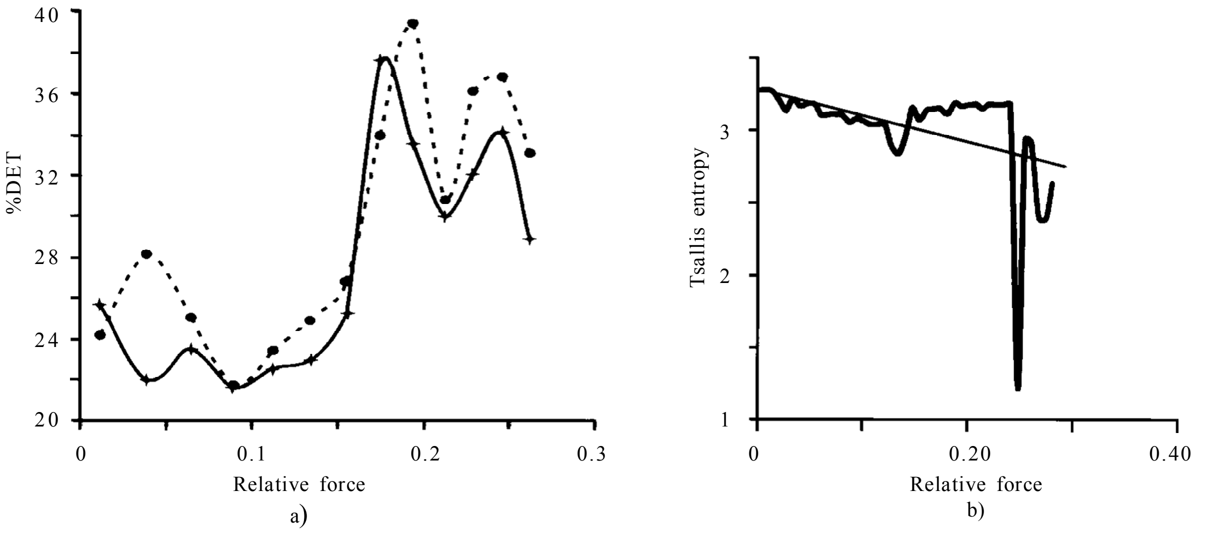

Fig. 2. a) RQA %DET measures of ΔtAE (dotted curves) and ΔtAE_{max} (continuous curves) time series vs. relative external forcing; b) Tsallis entropy calculation of ΔtAE data sets.

გეოფიზიკა

არათანაბარი ხახუნის პროცესით გამოწვეული აკუსტიკური ტალღების დროითი განაწილების დინამიკის გამოკვლევა

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ნაშრომში შესწავლილია ბაზალტის ფილების არათანაბარი ხახუნის რეჟიმში მოძრაობის დროს წარმოქმნილი აკუსტიკური ტალღების დინამიკა. ამისათვის შეიქმნა ზამბარა-მცოცის ტიპის ექსპერიმენტული დანადგარი, რომელიც საშუალებას იძლევა შევისწავლოთ არათანაბარი ხახუნის პროცესი აკუსტიკური ემისიის სხვადასხვა პირობებში და გარე ზემოქმედებისას. დროის ინტერვალების სერიების მისაღებად განხორციელდა მონაცემების ფილტრაცია და დადგინდა აკუსტიკური ემისიის პირველი შემოსვლის მომენტი. აკუსტიკური ტალღების წარმოქმნის დინამიკის ცვლილების რიცხობრივი შეფასებისათვის გამოყენებული იქნა არაწრფივი რეკურენტული რიცხობრივი ანალიზი და ცალისის ენტროპიის გამოთვლის მეთოდი. ნაჩვენებია, რომ აკუსტიკური ტალღის განაწილების დინამიკის დეტერმინისტული სტრუქტურა დამოკიდებულია მოძრაობის პირობებზე.

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