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LABORATORY MODEL OF SELF-ORGANIZED CRITICALITY PARAMETRIC MODULATION AND THE RESULTS OF EXPERIMENTS FOR APPLICATIONS IN SEISMOLOGY

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Summary: *The paper represents the laboratory model of self-organized criticality parametric modulation for applications in seismology. The main characteristics of the Earth's seismic process show that earthquakes should be attributed to phenomena of self-organizing criticality. In accordance with this representation, an earthquake, or the energy discharge of fault, is an unpredictable phenomenon determined by entire system development. But periodic tension modulation can synchronize the triggering moments and change the behavior of system near the critical state. Earthquake statistics of Caucasus demonstrates such changes caused by tidal periodicities and indicates the existence of a class of natural phenomena of self-organized criticality with parametric modulation of criticality conditions. This class of phenomena was investigated and its existence was confirmed on the laboratory model by the use of sand avalanches in cylinder with modulated rotation. This model can serve as a basis for creating an idea of partial predictability of self-criticality. We represent the model and the results of criticality parametric modulation experiments.*

Key words – self-organized criticality model; parametric modulation; critical state laboratory experiment.

1. INTRODUCTION

In the Caucasus we have all physical conditions for the existence of self-organizing criticality processes [1]. Also, the important factor determining the dynamics of this system is constant stress caused by tectonic plates; the variable tension caused by Earth luni-solar solid tide and revealed earthquakes tidal triggering synchronization mechanism [2]. The region represents a system of connected, continuously charging and changing their physical states "faults-relaxators". The discharge of each fault-relaxator we observe as an earthquake. The power and time of discharges is determined by the evolution of the entire system, proceeds in accordance with the laws of self-organizing criticality, which in principle excludes predictability. However, tidal, or other external excitement can synchronize the time moments of discharges [2] and provide conditions for predictability. In general, external factors time behavior can be calculated or may be known.

The simple model is used to describe the principles of used triggering synchronisation approach. The stress $P(t)$ increases monotonically as time function, with constants P_0 – initial stress in start moment t_0, and the stress rise velocity b. If the process undergo the influence of external variable stress with amplitude, frequency and phase, correspondingly a, ϖ and f, the resulting stress and the stress limit P_m, which determines the discharge time moment are connected by equation

$$P_0 + b(t - t_0) + a\cos(\varpi t + f) = P_m.$$

The process is described more clearly, if we represent the equation in the form

$$b(t - t_0) = P_m - P_0 - a\cos(\varpi t + f)$$.

The solutions of equations for relaxators with different start moments t_0 correspond to discharge moments. If one represents both parts of the equation graphically, the intersection of the graphs will correspond to the instants of the discharge time. Figure 1 demonstrates the process: inclined lines (3) correspond to a set of charge processes with different t_0, sinusoid (1) – to variable external stress, horizontal line (2) – to stress limit. Solutions – discharge time moments, obviously reveal time "gaps" (4), or – time intervals when discharges are "forbidden" and critical, discharge time interval (5). Figure also demonstrates that the width of the time gap depends on the coefficient b – stress growth velocity.

This known approach underlies the nature of synchronization of the variety of technical devices. We found similar mechanism it in the synchronization of earthquakes [2], in phenomena belonging to the class of self-organizing criticality [1]. The model will help to take a fresh look at the predictability of self-organized processes and substantiate our and many other research projects.
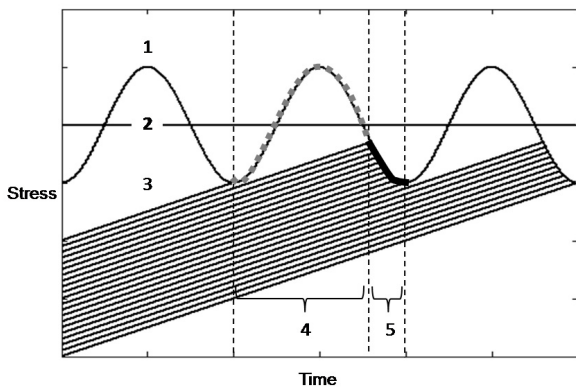

Fig 1.

Fig. 1. External synchronization of relaxator by quasi periodic modulation factor (1) of stress near the breaking limit value of charge process (2). Each relaxator (3) may exist and be charged inside time interval (4), and discharged in time interval (5).

2. THE MODEL

The model and the laboratory device should be as simple as the models and experiments of self-organizing criticality. Granular structures, in particular sea or river sand, are considered as the main working substances of experiments [3-9]. In some experiments, the criticality was studied with the help of a granular structure placed in a rotating cylinder [6-9]. This approach is acceptable for us – modulation of critical state can be carried out by modulating cylinder rotation speed.
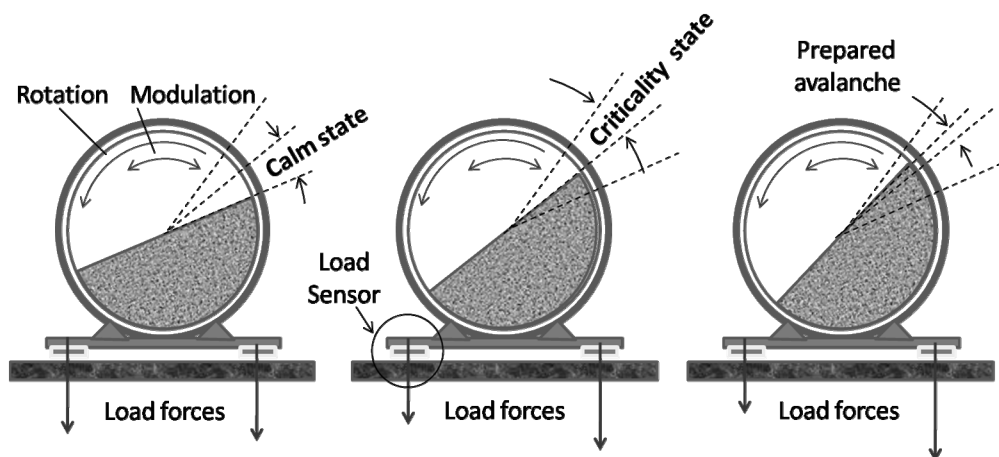

Fig. 2. Sand avalanche laboratory model for self-organized criticality parametric modulation study.

Fig. 2 represents our model and experiment. Left picture corresponds to calm state of sand; load sensors signals difference increases with rotation and is modulated by a variable speed of rotation. Central picture corresponds to the sand reached critical state; load forces difference corresponds to experiment start and time series minimum value. Right picture corresponds to self-organized criticality state – the avalanche grows and prepares for destruction; load forces difference reflects the growth process and avalanche mass.

Fig. 3 represents the example of experiment time series without rotation modulation. Sand avalanches are discharges of different weights sand relaxators. Their distribution form corresponds to self-organized criticality and distribution characteristic to earthquake Gutenberg-Richter law – Fig. 4.
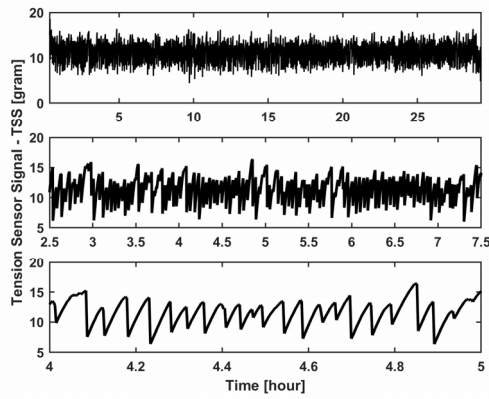
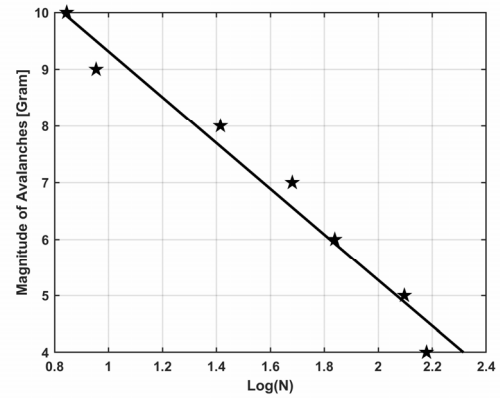**Fig.. 3. Experiment time series examples, rotation without modulation**

Fig. 4. Distribution of avalanches corresponds to self-organized criticality and distribution characteristic to earthquake Gutenberg-Richter law.
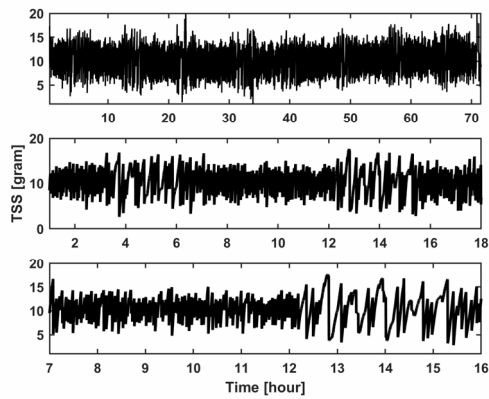

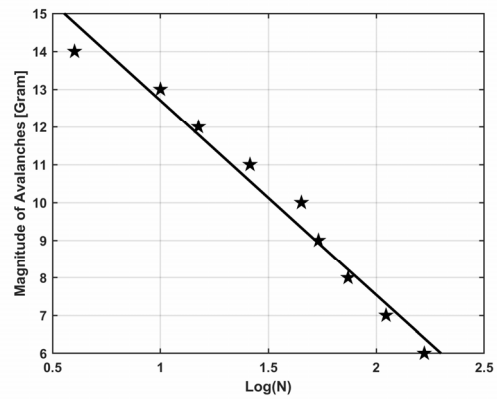**Fig. 5. Example of time series with modulation**

Fig. 6. Distribution of avalanches in experiment with modulation
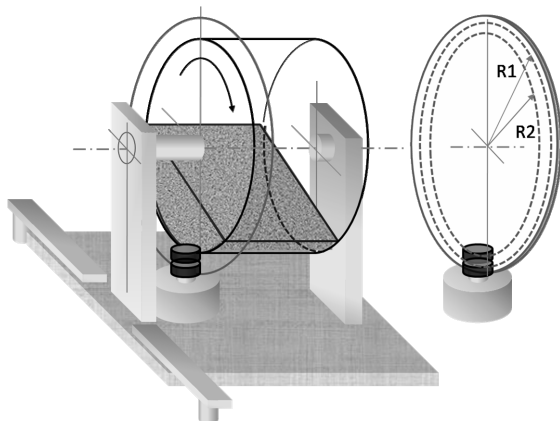

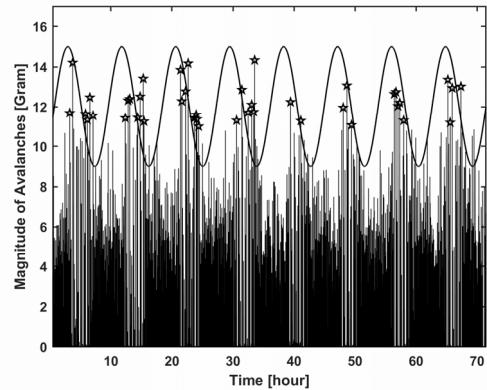**Fig. 7. Schematic representation of laboratory model.**

Fig. 8. The evidence of avalanche triggering synchronization mechanism existence.

In our experiment, the cylinder with sand has the diameter equal to 190mm. His thickness is equal to 50 mm. The sand mass is 600 gram. To perform the rotation, cylinder has 215 mm diameter wheel with friction coupling with stepper motor. The contact is made by means of a two rubber rings on an axis of the motor. Rings are in contact with the surface of the wheel. The modulation of rotation is obtained by using two friction rings. Friction rollers interfere with each other – their equal angular velocities set by the stepper motor, cannot provide rotation with different linear velocities corresponding to radii R1 and R2, see Figure

7. Their elasticity modulates the magnitude of the step of transmitted motion, correspondingly, the rate of approach to the critical state. The stepper motor rotates with velocity 1 step per 12 seconds. In the experiment modification without modulation, one revolution of the cylinder takes place in 6 hours. Using two friction rings, we obtained a modulation period of 9 hours, which is represented in Figure 5. Their distribution form still corresponds to self-organized criticality and the distribution characteristic for the earthquake is again the Gutenberg-Richter law – Figure 6.

In this modification of experiment, one can obviously see the existence of avalanche triggering synchronization mechanism. The process represented in Figure 8 is in full accordance with concept represented in Figure 1.

3. CONCLUSIONS

The experiment indicates the existence of a class of phenomena of self-organized criticality with parametric modulation of criticality conditions. Our laboratory model clearly demonstrates the existence of a specific class of phenomena of self-organizing criticality whose behavior can be partly predicted if the phenomenon of modulation exists and if the frequency of modulation of the physical variable responsible for the critical state is known.

The synchronization and triggering factor was not taken into account earlier in the study of self-organized criticality dynamics. It should be noted that the problem of synchronization of triggering was considered in the study of stick- slip problems [10], which also should be attributed to the tasks of self-organization.

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