Tribology International 44 (2011) 811–819

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Investigation of acoustic emission accompanying stick-slip movement of rock samples at different stiffnesses of spring–block system

Teimuraz Matcharashvili*, Tamaz Chelidze, Natalia Zhukova, Ekaterine Mepharidze

M. Nodia Institute of Geophysics, 1, Alexidze str., 0171, Tbilisi, Georgia

A R T I C L E I N F O

Article history:
Received 26 June 2010
Received in revised form
11 October 2010
Accepted 7 February 2011
Available online 15 February 2011

Keywords:
Friction of rocks
Acoustic emission
Spring stiffness
Dynamics

A B S T R A C T

Understanding of friction process, especially, transition from stable to stick-slip motion, is very important in various fields from mechanical engineering to seismology. It seems that analysis of acoustic emission (AE) accompanying the friction process can be a sensitive tool for revealing fine details of the friction process. In the present work, acoustic emission accompanying the stick-slip movement of basalt samples has been investigated in laboratory slider-spring device. Exactly, the influence of spring stiffness on the statistical and dynamical characteristics of stick-slip generated AE has been studied. Different time series compiled from recorded AE wave trains have been analyzed using statistical and dynamical data analysis methods. We found that statistical and dynamical changes in acoustic emission of stick-slip movement depend on the stiffness of spring in spring–block system. The obtained results show that dynamics of stick-slip process undergoes both qualitative and quantitative changes at transition from stick-slip to stable sliding friction caused by increased stiffness of frictional system. Extent of regularity in stick-slip process, assessed by analysis of AE temporal distribution characteristics, increases at stiffer springs.

1. Introduction

We observe the phenomenon of friction, or frictional resistance, in multitude of natural and mechanical systems, ranging, e.g. from earthquake faults to micro-electro mechanical devices wherever two surfaces move against each other. Being always in the focus of scientific interest since the work of Amonton and Coulomb, significant advances have been made in the understanding of the mechanisms of friction especially in the last decades. Among others it was established that friction could not be considered as an intrinsic material property and that depending on internal and external conditions (e.g. sliding rate, cumulative slip, roughness and other features of contact area, contact time, normal stress, spring stiffness, presence of gouge, fluids, environmental conditions, etc.) different static and dynamic regimes in frictional system may occur [1–8]. At the same time, in spite of long history of friction researches, there are still many unanswered questions. These questions mostly are addressed to the statistical and dynamical aspects of behavior of frictional systems in general, as well as to its dependence on sliding conditions and properties of contacting materials. Among others further investigation of friction process between rock surfaces and revelation of characteristic changes at transition between different movement regimes is of special interest. This is mostly caused by the increased interests to rock friction from geological, geophysical and seismological points of view.

From experimental studies of frictional movement between rock surfaces (like for many other materials), it is known that when the static friction resistance is overcome, two main modes of sliding regime can be observed. In the first mode, depending on system's conditions (such as velocity of movement, roughness, contact time of surfaces, stiffness, etc.) the two surfaces may slip steadily at a relative velocity equal to the load point velocity [9–11]. This sliding mode was referred as a stable sliding in the past [9,12] or steady-state sliding [13–15] in more recent terminology, and it is considered as an analog of fault creep in geophysics. Change of one or several characteristics of system's conditions will result in the appearance of the second mode, when the frictional surfaces suddenly slip, lock and then slip again in a repetitive manner. This cyclic unstable transition from the static friction to kinetic one is known as a stick-slip. The basis for this instable regime consists of the condition that the friction process provides (transmits) more energy to a system than that system can dissipate [16]. In geophysics this stick-slip movement mode is considered as a proxy of the earthquake occurrence along a preexisting crustal fault [17,18].

In opposite to the stable sliding, at stick-slip movement the sliding velocity on the surface can be significantly higher or lower

* Corresponding author.
E-mail address: matcharashvili@gtu.ge (T. Matcharashvili).

0301-679X/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.triboint.2011.02.005

than the velocity of load point; in other words, the dynamics of load point and moving object is different. This means that stick-slip inherently comprises multitude of different dynamical regimes. Moreover, it is clear that the lower is the velocity of load point (i.e. the force applied to a driving object increases slowly), the more complicated will be the observed movement regime(s). This is why the low velocity regime often is characterized as an "irregular" and "chaotic" stick-slip motion, which is basically determined by the interplay between static and kinetic friction forces at slowly increased tension in frictional system [4,19–21].

Thus being abundant in different systems ranging from seismology, basal ice flow and biology to microelectronic devices, the exact character of stick-slip movement may be qualitatively and quantitatively very different depending on the frictional system's conditions [1,22–25].

In the past this problem of dynamical regimes of unstable stick-slip movement under different conditions of frictional system always has been the subject of intense scientific studies. Namely dry friction-like behavior at a low driving velocity and a lubricated-like behavior at higher driving velocities occurring during stick-slip process often have been investigated for different contacting materials, including rocks. Generally, this process is well described in the framework of large-scale molecular dynamics simulations [26–30], rate, and state models [10,31–34] or the so-called minimalistic phenomenological models [7,35–37]. At the same time, revelation of features of dynamical behavior of system at stick-slip movement, as well as the disclosure of the character of its dependence on sliding system's conditions, still remains a fundamental physical problem of prime practical importance [7,10,11,38,8].

Among others the influence of stiffness in frictional system on the movement regime during stick-slip process calls to be investigated in detail. Results of few studies known to us for tackling this problem convince that [1,39] special attention should be paid to the analysis of statistical and dynamical characteristics of transitional regimes between stick-slip and sliding and vice versa.

Importance of such analysis is caused by the mentioned above ubiquity of irregular stick-slip behavior in nature and technique, as well as by the lack of knowledge of systems behavior at different conditions and contacting materials [5,35,40,41].

Independently of driving regime, one of the most important features of frictional process in solids, including rocks, is that unstable stick-slip movement gives rise to the stress oscillations and excites vibrations that may lead to radiation of sound to the surrounding media. Such sound radiation, or AE, generally can be detected in different systems on vide spatio-temporal scales, e.g. in earthquakes and rock bursts, initiation and growth of cracks, melting, twinning, and phase transformations in metals and in living organisms [10,15,23,42]. It is important to underline here that AE generated in solids is often considered as a kind of indirect measure of the structural changes (e.g. damage accumulation) in the system. The unique combination of advantages such as low cost, positioning flexibility, simple installation and processing, real time capability, and high sensitivity makes very popular the application of AE technique for different technical and scientific purposes [42,43]. For example the distribution of noise amplitudes accompanying crack generation has been investigated for several materials such as concrete, paper, wood, glass, etc. [44–46]. Experiments also show that AE is much more efficient in revealing micro-scale fracture processes in real time than traditional strain measurements, which are only sensitive to large enough bulk deformations [47], namely, AE confirms nucleation of cracks in solids in the low stress (Hook) domain, where stress–strain dependence is practically linear.

Taking into consideration close cause-effect relationship between stick slip and AE, in the present research we aimed to investigate characteristics of acoustic emission at different movement conditions. Exactly, in this work we represent results of statistical and dynamical analysis of AE, accompanying stick slip of basalt samples, as well as the influence of spring stiffness on its characteristics. We argue the necessity of this and similar researches by the importance of practical applications and the overall research interest in stick-slip motion of rock surfaces.

2. Materials and methods

In this work AE, as a signature of elastic waves that appear during stick-slip experiments in a frictional pair composed of two basalt samples, has been registered and analyzed. AE was recorded by specially developed laboratory setup. Commonly, experimental base to investigate stick-slip process is presented by the physical model consisting of spring-slider systems (see, e.g. [8]). Use of such spring–block experimental devices is one of the most popular laboratory approaches widely applied in different fields of science to investigate friction processes (e.g. [18,38,39,48]). This is caused by the fact that the laboratory stick-slip experiments enable us to easily model different regimes of friction movements through variation of surface roughness, velocity of movement, spring stiffness, normal force, etc.

Description of main principles of our stick-slip AE experimental setup is presented in Chelidze et al. [49]. Our laboratory setup consists of supporting (fixed) and sliding plates of roughly finished basalt samples: the sliding and fixed blocks' length, width and thickness were accordingly sliding—10 cm $\times$ 10 cm $\times$ 2 cm; fixed—25 cm $\times$ 10 cm $\times$ 2 cm. The load point or "free end" of the spring, attached by the other end to sliding block, is driven with a constant velocity V_d=2.9 mm/s. Numerous experiments have been carried out for eight different values of stiffness of pulling spring K_s (78.4, 143.1, 235.2, 555, 1068, 1705, 1999.2, and 2371.6 N/m). Thus eight different regimes of stick-slip movement have been investigated. The resulting friction force F is proportional to the deflection of the spring.

First four of these regimes were named as soft, next one as medium and last three as stiff spring movement conditions. The AE accompanying the consecutive slip events of stick-slip process was amplified and then recorded on a PC sound card. The sensor for the AE was a lead circonate–titanate unit with a natural frequency of a piezoelectric crystal 100 KHz. At lower frequencies (from several Hz to 20 KHz) the response of crystal is much weaker, but still measurable and almost constant. This weak LF signal was amplified by a special standard broadband amplifier, with practically flat amplitude–frequency characteristic (deviation of the order of 0.1 db) in the range several Hz to 20 KHz. Thus, though the maximal sensitivity of sensor was at 100 KHz, amplification allows recording of AE signals at frequencies down to dozens of Hz without very strong distortion. Typical examples of AE recordings at different values of dragging spring stiffness are presented in Fig. 1. For each value of pulling spring stiffness (K_s), ten runs of AE experiments have been carried out. In order to ensure comparable standard roughness and avoid ageing effects of contacting surfaces [14], sliding surfaces were carefully sanded up by sandpaper (with grade 150) before each experimental run. Grinding was carried out uniformly in all directions in order to ensure isotropic morphology of contacting surfaces and thus avoid appearance of privileged directions of sliding. After this in order to diminish influence of dust and gouge on the movement regime sliding surfaces of samples were cleaned by a vacuum cleaner. Though exact reproduction of surface characteristics in stick-slip experiments is practically impossible, these procedures help to maintain general reproducibility of experimental conditions and stationarity of measured data sets.

When recording of accompanying stick-slip acoustic emission has been accomplished we proceeded to the compilation of characteristic AE data series. This procedure consisted of several steps.