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Bridging the scales: Direct SEM imaging of micrometer vibrations for the analysis of stick-slip behavior at microscale

M.-A. Schröter (1), C. Weimann (1), H. Sturm (1,2), and M. Holschneider (3)

(1) BAM - Federal Institute Materials Research, FB 6.9, 12000 Berlin, Germany, (2) TU Berlin, Institute Machine Tools and Factory Management, Pascalstr.8-9, 8-9, 10587 Berlin, Germany, (3) University Potsdam, Institute Applied and Industrial Mathematics, 14415 Potsdam, Germany

Since earthquakes are regarded as a result of stick-slip motions between plate boundaries with instantaneous release of stored elastic energy, the similarity to friction plays an important role in the understanding of this large scale phenomenon. Recent works study by means of Atomic Force Microscopy (AFM) the frictional ageing at nanoscale due to the formation of interfacial bonds and compare it to the evolution effect of static friction at macroscale due to the increase of contacting asperities of rocks. Thus, AFM experiments can be used for a better understanding of the multiscale nature of geophysical phenomena.
To this aim, the AFM tip in contact with a surface is used as the basic unit of elementary frictional processes and large scale phenomena, such as friction on macroscopic scale, are addressed in terms of the cooperative action of multiple single events and their long range correlations. Additionally, analysis of vibrations before, during and after a stick-slip process can help to understand basic mechanisms of geological faults.
The cantilever spring gives the possibility to store elastic energy and to exploit natural resonances (modes) and non-linear properties (harmonics, bifurcation, etc.) for the performance of experiments. For this reason we propose in this work a new analysis technique that allows the direct observation of vibrational and frictional dynamics at the nanoscale. A cantilever is placed in the chamber of a Scanning Electron Microscope (SEM) and the vibrational dynamics are analyzed with the help of the synchronous dynamic response of the electron detector signal using lock-in techniques. The oscillation itself is excited by a piezo crystal at the base of the cantilever in several different resonance modes. Images of the superimposed AC-modulation such as amplitude/phase shift and real/imaginary part moduli can be obtained at any position of the vibrating cantilever. Thanks to the precise local definition of the electron beam and to the lock-in techniques vibration images exhibit high spatial resolution and the vibrational motion can be acquired with sub-nanometer resolution.
In this work, first measurements of different oscillating cantilevers are presented. We propose a theoretical model for the quantitative interpretation of the obtained images. Such a model relates the properties of the images to the physical interaction between electron beam and cantilever. Forthcoming experiments are discussed, expanding the ability to describe dynamic friction processes and the dynamic behavior of this unit cell of friction, with and without elastic energy stored in spring and sample.