

The atomic force microscope can be considered as a non-linear mechanical system which exhibits non-linear interactions and chaotic modes of motion. We have computed the Correlation Dimension, the Bifurcation Diagram and a Poincaré Map for experimental data obtained by dynamic atomic force microscope. From the analysis we infer a period doubling mode and chaotic modes of the system.

Atomic-force microscopy (AFM) is a nowadays widely used tool for surface analysis. Dynamic AFM methods like tapping modeTM or non-contact mode are commonly used for imaging although a thorough understanding of the data can be difficult due to the nonlinear tip-sample interaction. In the tapping-mode the micro cantilever is resonantly forced to oscillations with an amplitude of about ten to one hundred nanometers. Close to the specimen the tip periodically interacts with the surface which reduces the oscillation amplitude.

From theoretical investigations it is known that the nonlinear interaction with the specimen can lead to chaotic dynamics although the system behaves regularly for a large set of parameters. The nonlinear tip-sample interaction also leads to the generation of higher harmonics. These harmonic signals allow one to reconstruct the transient tip-sample interaction forces.

In this contribution we analyze the non linear dynamics of amplitude modulation AFM. While changing the most important control parameter, the tip-sample distance, one observes a wide range of states – some of them in particular known from chaotic systems.

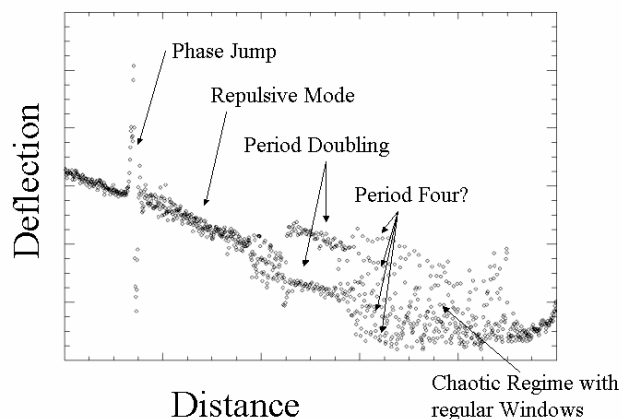


Fig. 1. Bifurcation Diagram for the experimentally recorded AFM data. The large panel shows a close-up for the transition from regular to chaotic behavior. After a transition from the attractive to the repulsive mode the system undergoes a period-doubling and finally ends in a chaotic regime.

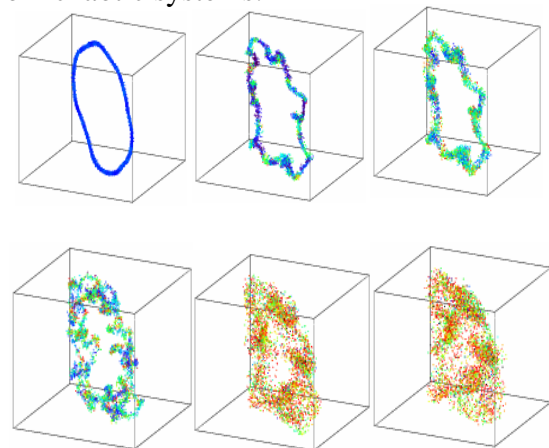


Fig. 2. 3-D phase space embeddings for six different epochs. The first panel shows the return plot in the regular region. The second panel is located at the phase jump from the attractive to the repulsive mode. The fourth panel represents the period doubled mode. The fifth panel shows a period four mode and the last panel coincides with the chaotic regime.

The system under consideration shows features that are typical for a dynamical system with a low number of degrees of freedom in the regular and chaotic regime. Far away from the surface the system is in a regular regime, while during the approach a phase jump, a period-doubling regime and a chaotic regime develop. System characteristics of this type have been observed for the Duffing-oscillator which can serve as a model system for an AFM.

References:

- F. Jamitzky, M. Stark, W. Bunk, W. M. Heckl, R. W. Stark, "Nonlinear dynamics of a micro-cantilever in close proximity to a surface", Proceedings of the IEEE NANO 2004 collaboration with M. Stark, R.W. Stark and W. M. Heckl