Multi-Eigenmode Compensator for Multifrequency Atomic Force Microscopy

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Funding: Masdar Institute, A. S. by DAAD., FP7/2007- 2013, GA 318804 (SNM)

Introduction

In multifrequency Atomic Force Microscopy (AFM), signals of higher harmonics and actuated higher eigenmodes are captured to retrieve information about the material of the sample under investigation. Here, the fundamental resonance is utilized to obtain the topography of the sample and to keep a set distance of the cantilever tip to the surface. For example in bimodal AFM, the first two flexural eigenmodes are actuated, where the second eigenmode's phase shift is one order of magnitude more sensitive to material compositions than the first eigenmode [1]. In contrast, active Q control of the fundamental eigenmode has been reported to also enhance its phase's sensitivity to material properties [2]. In this work, multifrequency methods are combined with active Q control to modify the dynamics of fundamental and higher eigenmode separately and independent of each other. The cantilevers utilized in this investigation are active, as they are self-actuated (bimorph) with piezo-resistive displacement proportional sensors [3].

Compensator

The compensator, based on a prediction estimator and controller, allows the arbitrary modification of the cantilever's system poles. It means that natural frequency, Q factor or a combination of both can be set for every eigenmode. Each eigenmode of the cantilever can be satisfactorily described by a second order dynamic system. Hence, the Kalman estimator is needed to supply each vibrating eigenmode's unmeasured velocity proportional signal. Following, a cantilever model describing two or more eigenmodes can be created by a superposition of each individual eigenmode's model. The compensator is implemented in a digital form into two different Xilinx FPGA based platforms for performance comparison. The prediction form of the estimator, combined with a state-machine implementation, allows maximum loop rate and minimal computational delay times. In addition, floating point representation minimizes the risk of numerical saturation. The implementation in a Virtex-5 LX110 has a maximum compensator feedback loop rate of 5.56 MHz. This is about twice as fast as in the case of a Spartan-3A DSP with a loop rate of 2.77 MHz. Hence, higher eigenmodes up to the Megahertz range can be modified by the compensator.

Result

Figure 1 shows the independently modified first two flexural resonances of an active cantilever. The color of each frequency sweep refers to a specific combination of Q factors of the first eigenmode (Q1) and second eigenmode (Q2). The different Q factors can be noticed in the phase signal as well. A promising combination is a low Q1 and high Q2. As the first eigenmode is used for the topography feedback imaging, the low Q1 results in a high bandwidth of that resonance and hence fast scanning ability. In addition, the higher forces exerted on the sample enable the improved sensitivity in the higher eigenmode that can be further enhanced with a high Q2. As a result, a flexible imaging system is introduced that allows flexible tuning of different tasks that are split onto two or more cantilever eigenmodes.

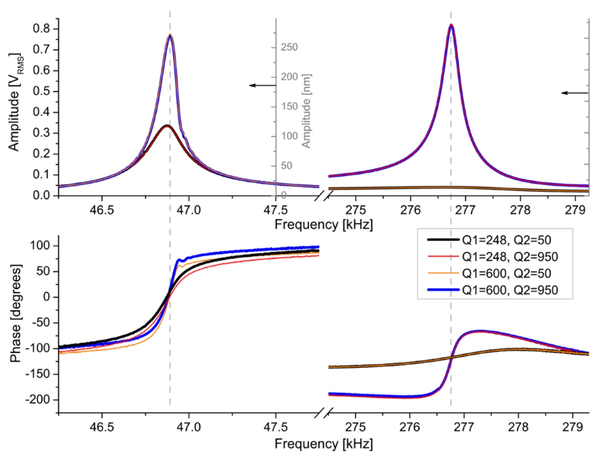

Fig. 1: The first two flexural eigenmodes under Q control. As indicated, each eigenmode can be assigned with individual Q factors

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