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Phase-Locked loops lock-in range in Frequency Modulated-Atomic Force Microscope nonlinear control system

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ABSTRACT

Since the mid 1980s the Atomic Force Microscope is one the most powerful tools to perform surface investigation, and since 1995 Non-Contact AFM achieved true atomic resolution. The Frequency-Modulated Atomic Force Microscope (FM-AFM) operates in the dynamic mode, which means that the control system of the FM-AFM must force the microcantilever to oscillate with constant amplitude and frequency. However, tip-sample interaction forces cause modulations in the microcantilever motion. A Phase-Locked loop (PLL) is used to demodulate the tip-sample interaction forces from the microcantilever motion. The demodulated signal is used as the feedback signal to the control system, and to generate both topographic and dissipation images. As a consequence, a proper design of the PLL is vital to the FM-AFM performance. In this work, using bifurcation analysis, the lock-in range of the PLL is determined as a function of the frequency shift (Ω) of the microcantilever and of the other design parameters, providing a technique to properly design the PLL in the FM-AFM system.

1. Introduction

The Atomic Force Microscopy started with the development of the Atomic Force Microscope (AFM) in 1986 by Binnig [1]. Simple contact measurement techniques resulted in many discoveries and developments to the surface investigation science. However, contact AFM cannot generate true atomic resolution images in a stable operation, and the samples are frequently damaged due to the contact with the microcantilever tip during the scanning process. On the other hand, noncontact AFM achieve true atomic resolution without sample damage.

The Frequency-Modulated Atomic Force Microscope (FM-AFM) is a noncontact AFM technique. In the FM-AFM the microcantilever is deliberately vibrated (Fig. 1) and is driven to oscillate at a fixed amplitude and frequency [2,3] by the Automatic Gain Control loop (AGC) and by the Automatic Distance Control (ADC) loop, respectively. In addition, the AGC and ADC control systems generate the dissipation and topographic images (Fig. 2).

The PLL synthesizes the AGC signal (Fig. 2) in order to control the microcantilever oscillation amplitude. In addition, the PLL also provides the feedback signal to the ADC loop [4,6,7], since the feedback signal is the frequency-demodulated tip-sample interaction forces.

The PLL (Fig. 3) is a control system that synchronizes a local oscillator to an incoming signal, playing important roles in communication, computation and control systems [8,9]. PLLs are nonlinear devices, and behaviors such as bifurcations and

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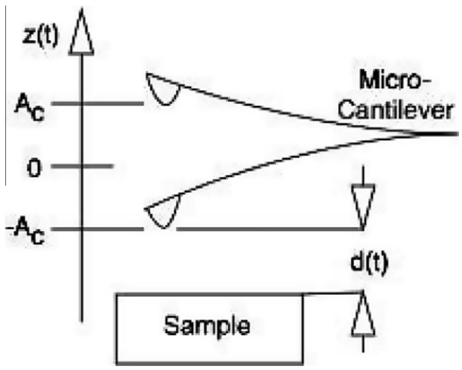

Fig. 1. Schematic view of the microcantilever oscillation.

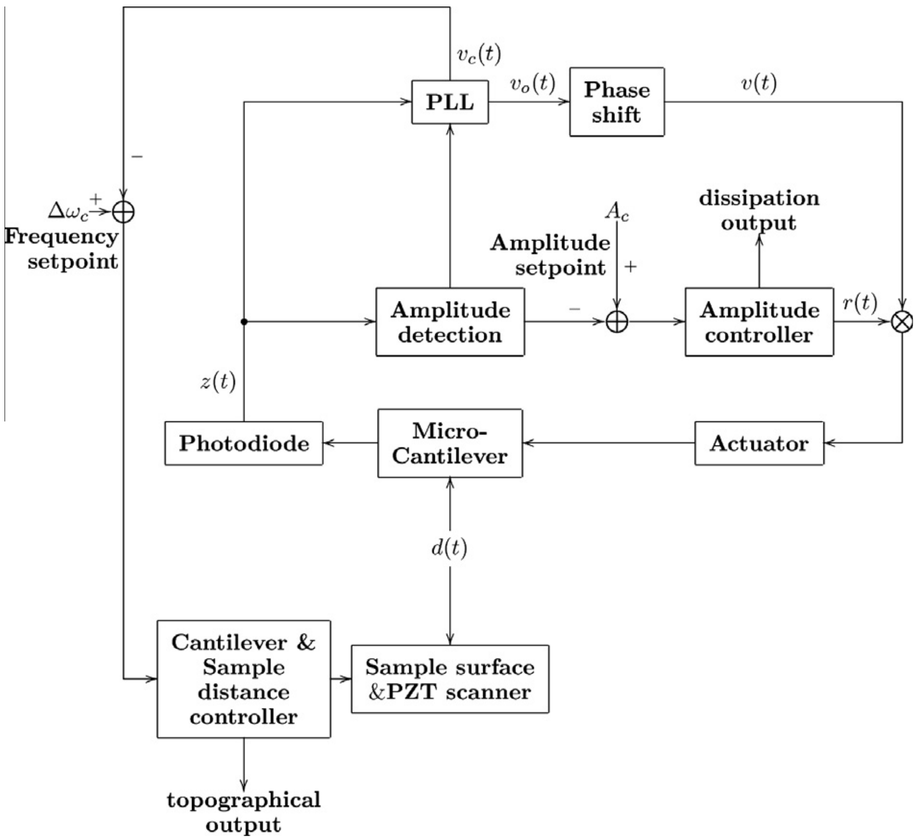

Fig. 2. FM-AFM control system.

chaos may arise [10,12], additionally, ripple oscillations such as the Double Frequency Jitter (DFJ), generated by the phase detector (PD), corrupts the synchronization quality [13]. Therefore, PLL design is crucial to demodulation systems and, consequently, to FM-AFM [4,5].

In Section 2 the FM-AFM mathematical model is presented. In Section 3 the lock-in range of the third order PLL with second order Sallen–Key filter is determined by means of bifurcation analysis. In addition a design technique is discussed. Finally, in Section 4 the simulations results are shown.

2. FM-AFM mathematical model

The mathematical model of the FM-AFM is developed accordingly the block diagram in Fig. 2, i.e., considering the interactions between the microcantilever, PLL and the amplitude detector.