RESPONSE AMPLITUDE OF NONLINEAR SELF-EXCITED MICROCANTILEVER PROBE.

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For the measurement of biological samples which can be deformed on weak impact, it is an important subject to oscillate a microcantilever probe with a low-amplitude without contact of the tip of the cantilever to the sample. To this end, we proposed a control method based on the production of the nonlinear dynamics of van der Pol oscillator in the microcantilever probe and experimentally confirmed the validity of the control method.

INTRODUCTION

When you observe biological samples in liquid by using an Atomic Force Microscopy (AFM), it is difficult to estimate the natural frequency of the microcantilever from the frequency response curve based on external excitation, because of low Quality factor of the frequency response curve due to the high viscosity [1]. For the measurement of biological samples which can be deformed on weak impact, it is an important subject to oscillate the cantilever probe with a low-amplitude without contact of the tip of the cantilever to the samples. In order to overcome these difficulties, we have proposed a control method by nonlinear feedback and realized the dynamics of van der Pol oscillator in the microcantilever probe [2, 3, 4]; van der Pol oscillator has the response frequency corresponding to the natural frequency and produces a limit cycle due to the nonlinearity. By applying the linear and nonlinear viscous damping forces based on the feedback of the deflection of the microcantilever, we experimentally establish a van der Pol-type self-excited microcantilever probe. High-gain nonlinear feedback carries out low response amplitude with 5 nm. It is confirmed that the response frequency is approximately equal to the natural frequency of the microcantilever probe.

ACHIEVEMENT OF STEADY-STATE SELF-EXCITED OSCILLATION DUE TO NONLINEAR FEEDBACK

Van der Pol-type self-excited oscillation always oscillates at the natural frequency regardless of the viscosity of the measurement environment. It is known that there is a steady state oscillation with finite amplitude by the nonlinearity. Namely, we are able to reduce the amplitude response in resonant condition of the cantilever and solve the problems on the contact with the sample in the liquid environment. When the motion of cantilever is limited to the first mode, the dynamics is equivalent to spring-mass-damper system with the mass m, the spring constant k, and the viscosity coefficient c_l as Eq. (1). In order to produce the dynamics of van der Pol oscillator in the system, we apply the linear velocity feedback $K_l\dot{x}$ and nonlinear feedback $-K_n x^2\dot{x}$ as Eq. (2). Then, the system is equivalent to van der Pol oscillator as shown in Eq. (3).

$$m\ddot{x} + c_l\dot{x} + kx = 0 \tag{1}$$
$$m\ddot{x} + c_l\dot{x} + kx = K_l\dot{x} - K_n x^2\dot{x} \tag{2}$$
$$m\ddot{x} - \{(K_l - c_l) - K_n x^2\}\dot{x} + kx = 0 (K_l > c_l), \tag{3}$$

where K_l and K_n are the linear velocity feedback gain and the nonlinear feedback gain, respectively. Self-excited oscillations with small amplitude are carried out by adjusting the linear feedback gain K_l and nonlinear feedback gain K_n.

EXPERIMENT

Experimental setup is shown in Fig. 1. The tube type scanner (Fuji ceramics, A41.5H11.8X13C-FHAuC(C-82)) moves the sample stage in the vertical direction depending on the applied voltage. When we move up the sample stage keeping the tip of the microcantilever probe to contact with the sample stage, the microcantilever is deflected and the deflection ange is measured by an optical lever. On the other hand, the displacement of the tube type scanner, i.e., of the sample stage is also measured by a capacitance-type micro-displacement meter (Japan ADE, 4810, the probe 2806L). Therefore, the correspondance between the outputs of the displacement of the tip of the microcantilever probe and its deflection angle are determined. These measurement data are recorded by a data logger (OMRON, ZR-MDR10). We measured the frequency response curve by using external excitation method and estimated the natural frequency from the resonance peak; 116.73kHz. The force curve is shown in Fig. 2. The horizontal axis represents the distance between the tip of the microcantilever and the sample surface (mica). The vertical axis is the optical lever output expressing the deflection angle of the cantilever. We obtained the relationship between the optical lever output voltage and the deflection angle of the cantilever from the force curves in Fig. 2. By using the results, we calculated the conversion factor (17nm / V). Figures 3 and 4 show experimental results when self-excited oscillation is produced in the microcantilever by linear and nonlinear

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feedback. The wave before big amplitude is noise. Although there is a side-band near the peak frequency, this is due to the time variation of the amplitude seen in Fig. 3. Because the peak frequency is virtually-united in the natural frequency which is estimated from the external excitation method, the waveform in Fig. 3 indicates the occurrence of the self-excited oscillation. In addition, it can be seen that the tip of the cantilever oscillates with the amplitude less than 5nm.

CONCLUSIONS

To achieve complete non-contact observation in a liquid environment by using a microcantilever, we produce in the microcantilever probe the nonlinear dynamics similar to van der Pol type self-excited oscillator by using a linear-plus-nonlinear feedback. As a result, the self-excited oscillation with 5nm amplitude is experimentally confirmed.

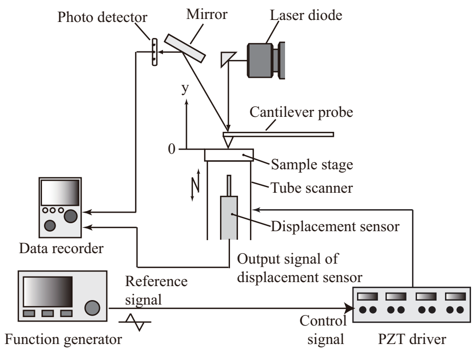

Fig.1: Experimental setup of Atomic Force Microscopy

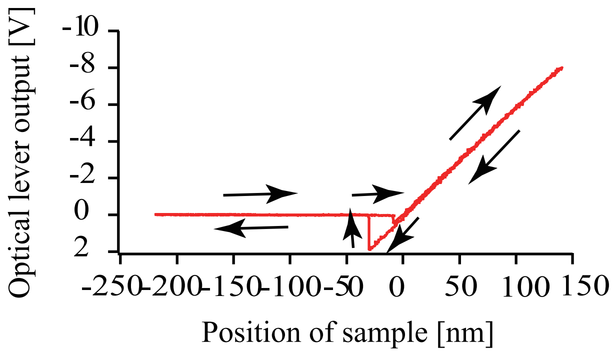

Fig.2: Force curve

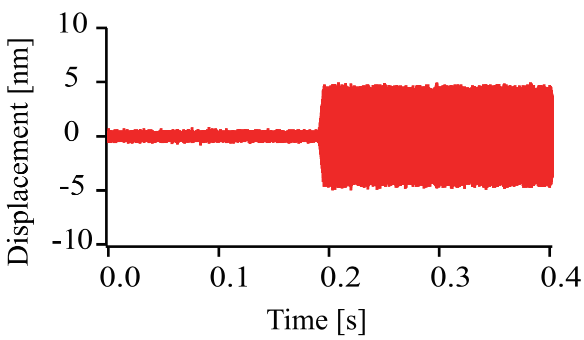

Fig.3: Time history of deflection of a self-excited cantilever prove in air

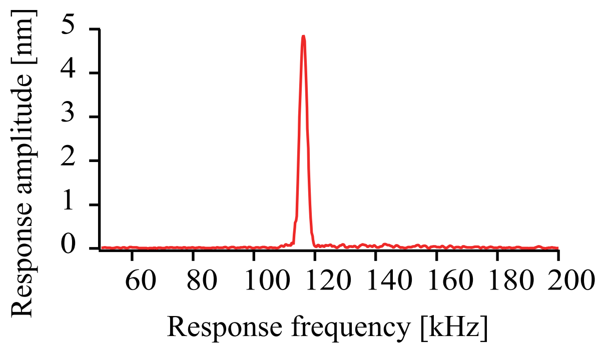

Fig.4: Power spectrum in air

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