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Self-excited oscillation for high-viscosity sensing and self-excited coupled oscillation for ultra-senseitive mass sensing

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Abstract

In the paper, we introduce the applications of self-excited oscillation to high-viscosity sensing and mass-sensing. Vibration-type sensing allows us to do the instantaneous and continuous measurements of changes in viscosity, mass and so on occurring with time. In the usual procedure, the external or forced excitation has been employed to the resonators. The viscosity sensing is carried out by using the change of the resonance amplitude in the frequency response curve, i.e., Q factor, depending on the viscosity. The mass sensing is carried out by using the shift of the resonance frequency corresponding to the natural frequency, depending on the mass. In order to realize the high-viscosity sensing and the mass-sensing in viscosity environments, we introduce the application of self-excited oscillation as an excitation method.

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Keywords: Self-excited oscillation, MEMS, viscometer, mass sensor, feedback control,

1. Introduction

Vibration-type sensing allows us to do the instantaneous and continuous measurements of changes in viscosity, mass and so on occurring with time. In the usual procedure, the external or forced excitation has been employed to the resonators. The viscosity sensing is carried out by using the change of the resonance amplitude in the frequency response curve, i.e., Q factor, depending on the viscosity[2,3]. The mass sensing is carried out by using the shift of the resonance frequency corresponding to the natural frequency, depending on the mass[1]. In order to realize the high-viscosity sensing and the mass-sensing in viscosity environments, we introduce the application of self-excited oscillation as an excitation method. We apply the velocity feedback control to artificially decrease the viscosity effect on the oscillator due to the viscosity of a sample. When the feedback gain reaches the critical one, the self-excited oscillation is produced through Hopf bifurcation[4] and the critical feedback gain corresponds to the viscosity of the sample to be measured. Because this method does not rely on the frequency response curve under the external

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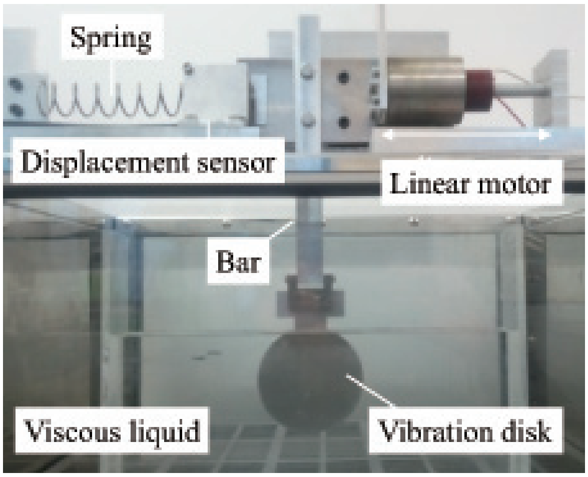

Fig. 1. Basic principle of vibration type viscometer and mass sensor.

excitation, even for high viscosity samples in which the peak in the frequency response curve does not exist, the method is applicable[5,6]. At the critical point, the oscillator exhibits the nature of the oscillator, in which the damping effect is removed, and responses with the natural frequency. In the case of multi-degree-of-freedom systems, we can derive also the linear eigenmode by the production of self-excited. Utilizing this advantage, we propose the application of the mass-sensing by weakly coupled cantilevers, which has been based on the external excitation[7,8]. The self-excited oscillation makes it possible to directly detection of the mode-shift even in the viscous environments and realizes the measurement of biological samples in liquid[9,10]. In this paper, we review the viscosity sensing and and mass sensing from the viewpoint of the utilization of self-excited oscillation.

2. Basic equation of motion of vibration type sensor

Figure 1 shows an experimental system including the fundamental structure of vibration-type viscometer.

2.1. Viscometer

The equivalent mass of the movable part m consisting of the mover of the linear motor and the bar with a disk receiving the viscosity of the fluid to be measured (damping coefficient is c). The mass is subjected to the restoring force by the spring with spring constant k and the thrust force by the linear motor F.

$$m\frac{d^2x}{dt^2} + c\frac{dx}{dt} + kx = F \tag{1}$$

In case of the usual external excitation, the external force is set as

$$F = f_a \cos \nu t \tag{2}$$

As well known, in high viscosity range of c it is very difficult to find the resonance peak because of the widening of the half band. In much higher viscosity range, the resonance peak does not appear in the frequency response curve. To overcome such difficulties, the excitation force F is applied according to the feedback

$$F = c_{cont}\frac{dx}{dt}, \tag{3}$$

where c_{cont} is a velocity feedback gain. Equation (5) is written as

$$m\frac{d^2x}{dt^2} + (c - c_{cont})\frac{dx}{dt} + kx = 0 \tag{4}$$