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Interfacial phenomena of magnetic fluid adsorbed to two magnets subjected to vertical vibration

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Abstract

The dynamic behavior and frequency characteristics of a system consisting of two permanent magnets and magnetic fluid, subject to vertical vibration were investigated. The effects of the volume of magnetic fluid adsorbed to two magnet on the natural frequency of the system were revealed. The harmonic and subharmonic responses of magnetic fluid surface were also observed.

Keywords: Magnetic fluids; Fluid vibration; Natural frequency; Pogo oscillation

1. Introduction

The free surface of magnetic fluid is formed in several application devices very often. Several interfacial phenomena can occur when a magnetic fluid is subjected to a magnetic field. Therefore, extensive investigations on the interfacial instability of magnetic fluids under the action of magnetic fields have been conducted by a number of researchers [1]. For example, the dynamic behavior of a magnetic fluid in a moving container has been studied by Zelazo and Melcher [2]. Surface disintegration and drop formation of magnetic fluid in the cylindrical container vibrated laterally with the natural frequency of a liquid-container system under the influence of magnetic field applied tangentially to the magnetic fluid surface have been studied by one of the authors [3]. The dynamic behavior of a magnetic fluid drop on a non-magnetic solid base subjected to magnetic fields and vertical vibration have been studied experimentally and theoretically by the authors [4]. However, there is no study on the dynamic behavior of magnetic fluid adsorbed to a magnet subjected to the vertical vibration.

In the present paper, interfacial phenomena of a magnetic fluid adsorbed to two magnets subjected to the vertical vibration and the frequency characteristics of the system are investigated.

2. Experimental apparatus and procedure

Experiment was performed on a vibration-testing system. The electrodynamic shaker was operated by the automatic vibrating controller at a given frequency, displacement and acceleration. A block diagram of the experimental apparatus is shown in Fig. 1. The dynamic behavior of the free surface of the magnetic fluid was analyzed by a three-dimensional motion analysis system.

The test system was composed of two permanent magnets in disk shape and a magnetic fluid. Sample magnetic fluid used in the experiment was kerosene-based ferricolloid HC-50 (the saturation magnetization $M_s = 33.42\,\mathrm{kA/m}$, the viscosity $\eta = 9\,\mathrm{mPa\,s}$ at a temperature of 25°C, the surface tension $\sigma = 0.0277\,\mathrm{N/m}$ at a temperature of 19°C) made by Taiho Industries Corporation. The volume of magnetic fluid adsorbed to the two magnets was changed. The two magnets–magnetic fluid system was put on the vibrating table of the electrodynamic shaker. The excitation frequency was

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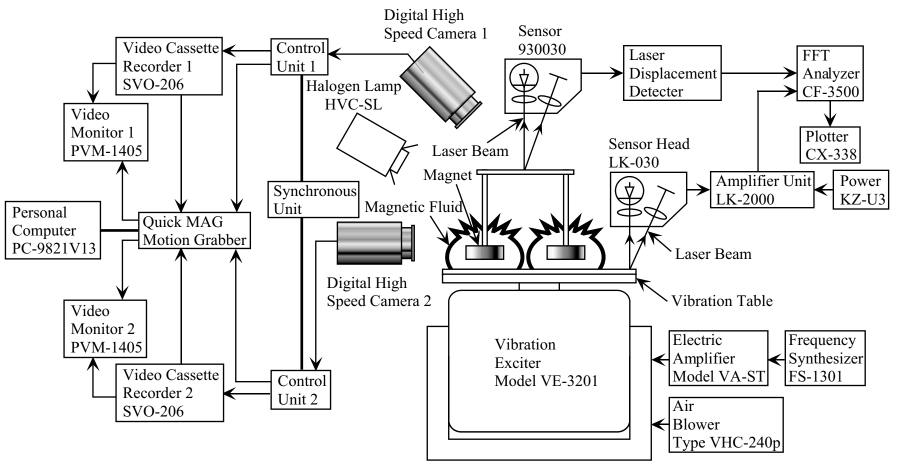


Fig. 1. Schematic diagram of experimental apparatus.

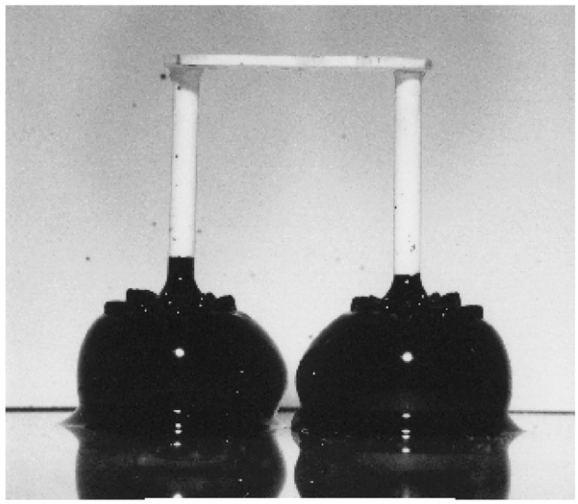
set as desired, and the vibration table connected to the exciter was vibrated vertically at an arbitrary level of excitation amplitude. The time-dependent amplitudes of the two permanent magnets were measured using an optoelectronic device, and the interfacial phenomena of magnetic fluid was recorded by two high-speed video cameras.

3. Experimental results and discussion

3.1. Frequency characteristics of the system

Fig. 2 shows a photograph of the surface shape of the magnetic fluid adsorbed to the two permanent magnets. Two larger liquid drops of magnetic fluid are formed by the two disk magnets. This test system (two permanent magnets–magnetic fluid system) was vibrated sinusoidally in the vertical direction.

The time-dependent amplitudes of the test system were measured by the optical displacement detector system at the point on the plate connected with two magnets as shown in Fig. 1. Fig. 3 shows the frequency characteristics of the test system. In Fig. 3, δ_m is the response amplitude, X_0 the excitation amplitude, and $V_{m1} + V_{m2}$ the volume of magnetic fluid adsorbed to two magnets. It can be seen from Fig. 3 that the dimensionless amplitude of the test system, δ_m/X_0 varies with the excitation frequency, f_0 under the condition of constant X_0. The peak in the frequency response shows the natural frequency of the test system, that is, the natural frequency of the test system is $f_n = 16.0$ Hz in the case of $V_{m1} + V_{m2} = 6.0$ cc. The data for the lower volume of magnetic fluid $V_{m1} + V_{m2} = 2.0$ cc shows the complicated peak. This peak collapse is attributed to the impact between the table and magnets. The natural frequency of the test system decreases with the increase of the volume of magnetic fluid. At the excitation frequency of $f_0 = f_n$ the test system showed "pogo "oscillation (large-amplitude vertical oscillation). Fig. 4 shows the relation between table oscillation and the system response. In Fig. 4, X is the displacement of the table, and Δ is the displacement of the system. Compared with the input and output signals, the phase difference between these two signals is clear. At the excitation frequency $F_0 \approx f_n$, the phase difference between input and output signals is $\phi = \pi/2$.



$V_{m1}+V_{m2}=8.0\times10^{-6}\text{m}^3$

Fig. 2. Photograph of the test system.

3.2. Surface response of magnetic fluid

The motion of magnetic fluid adsorbed to magnets showed various response to the vertical vibration. The

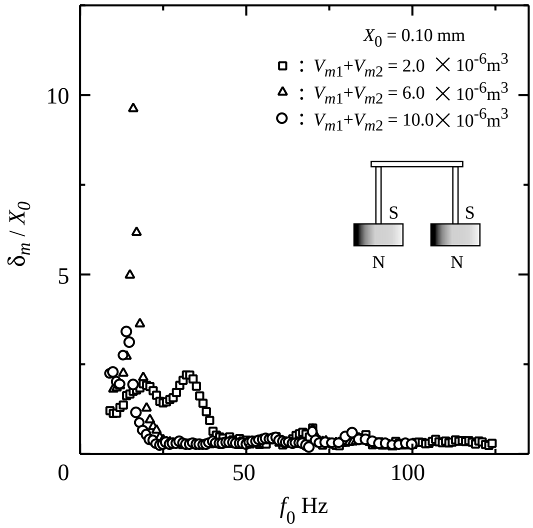


Fig. 3. Frequency characteristics of the system.

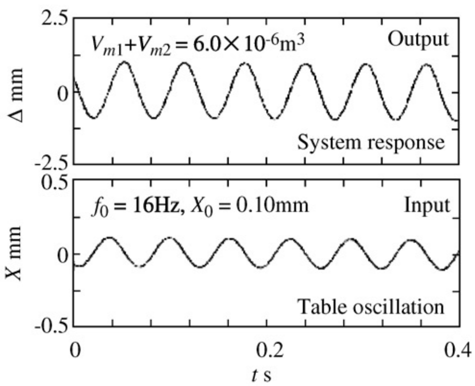
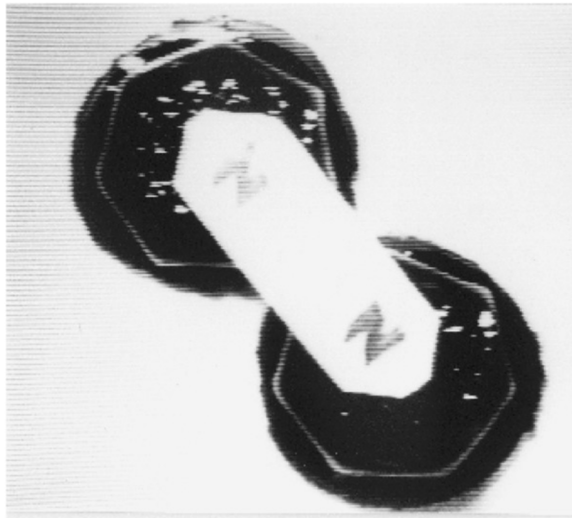


Fig. 4. Relation between input and output signals.

magnetic fluid spikes formed at the upper part of the magnetic fluid bulk responded to the excitation in the elongation and contraction of their heights. This phenomenon is produced by the variation of apparent gravity.

Furthermore, the $\frac{1}{2}$-subharmonic response of liquid was observed clearly at the higher frequencies ($40\,\text{Hz} < f_0 < 85\,\text{Hz}$). Fig. 5 shows the overview photograph of the polygonal mode of the $\frac{1}{2}$-subharmonic response. The surface disintegration was also observed by the increase of the excitation amplitude.



f_0=85Hz, X_0=0.10mm, $V_{m1}+V_{m2}$=6.0× 10^{-6}m^3

Fig. 5. Top-view photograph of the polygonal mode. Magnetic fluid vibration.

4. Conclusions

The interfacial phenomena and frequency characteristics of a two permanent magnets–magnetic fluid system subject to the vertical vibration were studied. The results obtained are summarized as follows: (1) The natural frequency of the system decreases with the increase of the volume of magnetic fluid. (2) The magnetic fluid spikes on the liquid surface respond to the excitation in the elongation and contraction of their heights. (3) The $\frac{1}{2}$-subharmonic response of magnetic fluid shows the polygonal mode at higher excitation frequencies.

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