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UVP MEASUREMENT ON MAGNETIC FLUID SLOSHING

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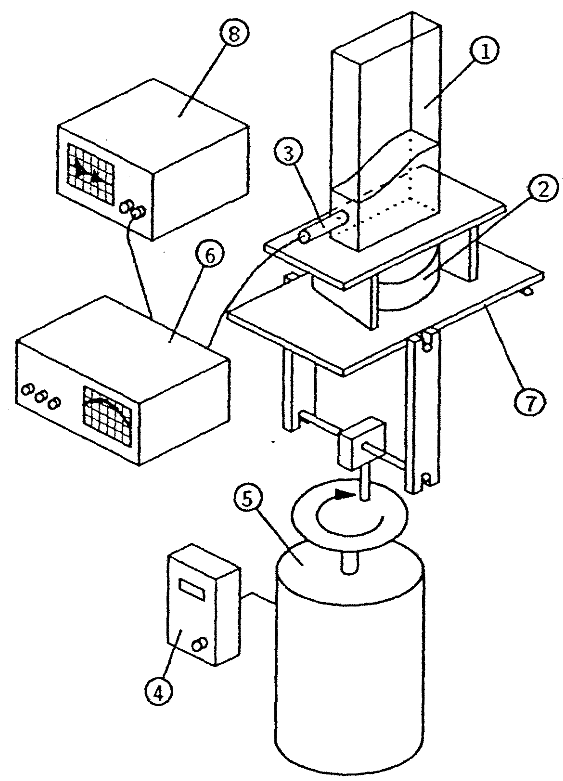
1. Introduction

A magnetic fluid is a stable suspension of solid magnetic particles(5∼15nm). These particles are coated with a layer of surfactant which inhibits their coalescence. As a result, the magnetic fluid is a stable colloidal dispersion of rather small surfactant-coated magnetic particles in a liquid carrier. When a magnetic field is applied to a sample of magnetic fluid, the magnetic particles in the fluid tend to remain rigidly aligned with the direction of the orienting field. Then, several interesting behaviors have been observed[1].

Recently, interfacial instability of a magnetic fluid in an applied magnetic field has attracted the attention. Zelazo and Melcher[2] studied dynamic behavior of a magnetic fluid in an oscillated container. Dodge and Garza[3] demonstrated a simulation of liquid sloshing in low-gravity by using a magnetic fluid. Sawada, et al.[4] investigated two-layer liquid sloshing of a magnetic fluid and a silicon oil in a rectangular container, and clarified effects of magnetic field on



1.Container	2.Magnet	3.US Transducer
4.Controller	5.Motor	6.UVP Monitor
7.Shaking table	8.Oscilloscope	

Figure 1: Experimental Apparatus

the resonant frequency. Ohaba and Sudo[5] examined surface responses of a magnetic fluid in a vertically vibrated container subjected to a normal magnetic field.

The sloshing problem does not seem easy from a mathematical point of view. Obvious nonlinearities are occurring especially in the vicinity of the resonant frequency. In order to understand and explain this complex problem, a nonlinear approach and detailed measurement of internal velocity profiles are necessary. However, any optical method like laser Doppler anemometry or flow visualization technique have not been applicable because a magnetic fluid is opaque. An ultrasonic velocity profile(UVP) measurement is a method for measuring a velocity profile on a line with respect to the velocity component along this line[6,7]. The aim in the present paper is to examine the applicability of UVP measurement to a magnetic fluid sloshing which has periodic velocity field. We attempt also to obtain nonlinear sloshing responses up to the third order perturbation. These experimental and theoretical results are compared.

2. Experiment

Figure 1 shows a schematic diagram of the experimental apparatus. The rectangular container measures 80mm×20mm×150mm, and is made of transparent acrylic resin. The adjustable crank is mounted on the output shaft of the motor. The frequency of the motor is controlled continuously by the inverter. The shaking table is oscillated sinusoidally and its range of oscillation is $1.17\text{Hz} \leq f \leq 4.33\text{Hz}$. The amplitude of the oscillation is X_0=1.5mm for all experiments. Magnetic field is applied by a cylindrical permanent magnet whose diameter is 110 mm. We use a water–based magnetic fluid. Its kinematic viscosity, density and sound velocity are $\nu=4.2\times10^{-6}$ m^2/s, $\rho=1.24\times10^3$ kg/m^3 and c=1410m/s at 25°C, respectively. The fluid depth is h=40mm in the present experiment. Since magnetic particles in the magnetic fluid are too small as reflecting particles for the ultrasonic wave, we use porous SiO_2 powder with a mean diameter of 0.9μm(MSF-10M, Liquidgas Co., Ltd.). The ultrasonic(US) transducer is fixed on the side wall of the container in order to measure the horizontal velocity profile V_x. Its nominal diameter is 5mm, and the measuring volume has a thin-disc shape, ϕ5mm×0.71mm. The UVP monitor is X-1 PS manufactured by Met-Flow AG. The basic frequency is 4MHz and the pulse repetition frequency is 3096Hz.

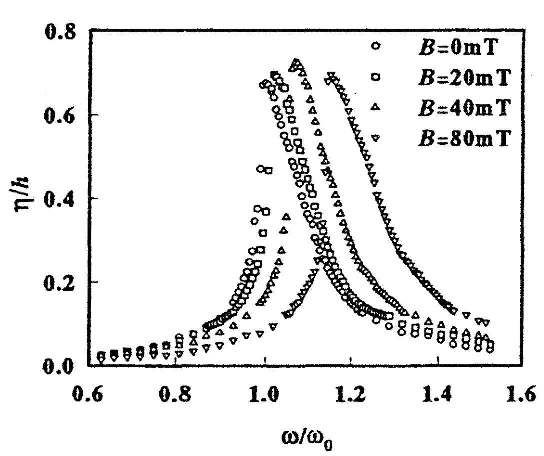


Fig.2 Frequency responses of the free surface of a magnetic fluid

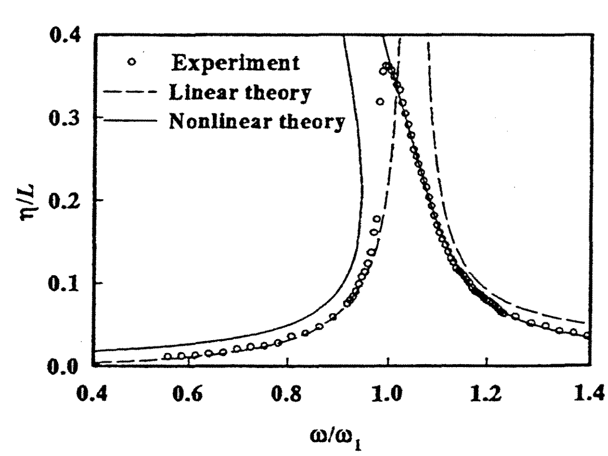


Fig.3 Comparison with theoretical and experimental results of frequency response for B=40mT

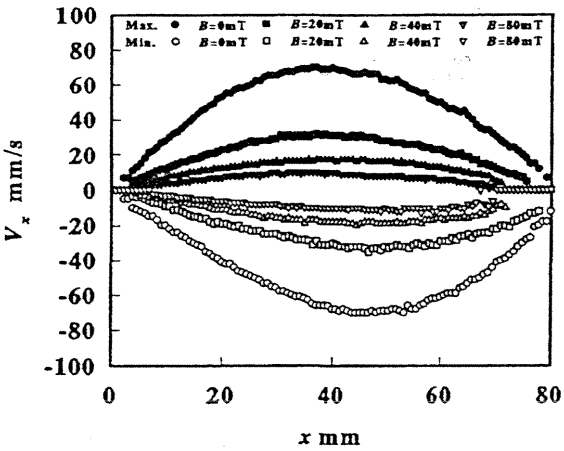


Fig.4 Maximum velocity profiles for f=2.75Hz at h_z=10mm

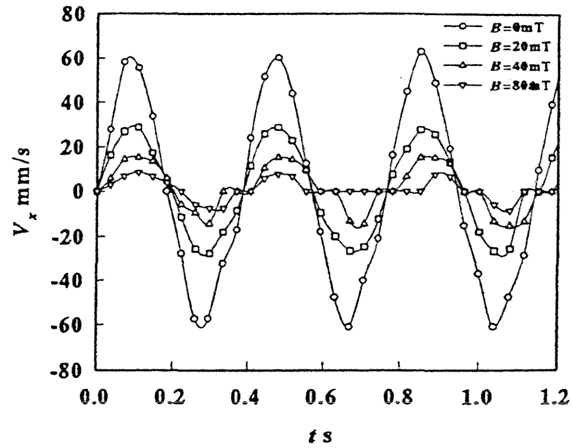


Fig.5 Time dependent velocity profiles for f=2.75Hz at x=39.96mm and h_z=10mm

3. Results and Discussions

Frequency responses of the free surface of a magnetic fluid are shown in Fig.2. Here B is the surface magnetic field induction at the center of the permanent magnet, η is the maximum free surface elevation at the side wall and ω_0 is the first resonant angular frequency for B=0. As the forcing frequency increases, the surface elevation also increases and the free surface is intensively shaken near the resonant frequency. When the frequency goes over the resonant frequency, the surface disturbance is repressed. The first resonant frequency is shifted to the high frequency region as the magnetic field intensity becomes large. Assuming a potential flow and using a perturbation method, we have obtained nonlinear sloshing responses up to the third order perturbation $O(\varepsilon^3)$, where ε is $(X_0/L)^{1/3}$ and L is the length of the container. In Fig.3 experimental results are compared with the linear and nonlinear theoretical results for B=40mT. Here ω_1 is the first resonant angular frequency obtained by the linearized wave theory. In the low frequency range, the nonlinear solution is larger than experimental values because calculated amplitude does not become zero with a decrease of the frequency[8]. Experimental and nolinear theoretical results have a good agreement in a high frequency region.

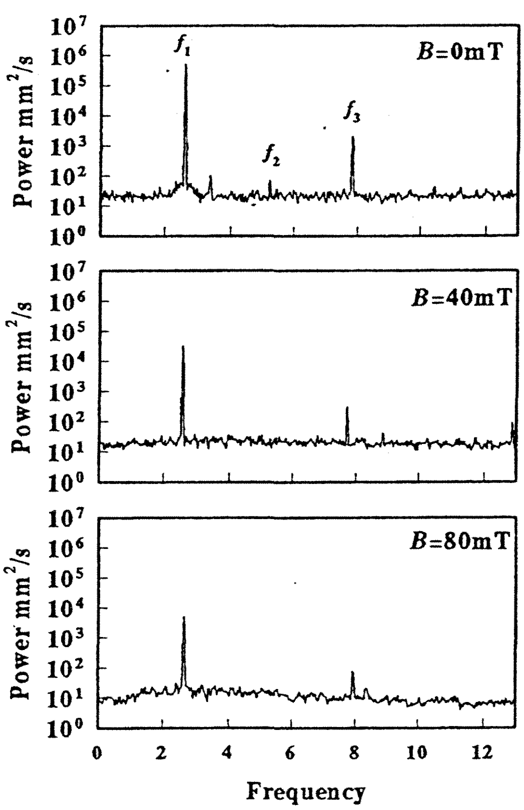


Fig.6 Averaged power spectra for f=2.75Hz over 30.34mm$\leq x \leq$50.32mm at h_z=10mm

UVP measurements were mainly carried out at near-resonant frequencies.

Figure 4 shows maximum velocity profiles for several applied magnetic fields. There are 1024 measurement points along the measurement axis and each datum point represents the maximum velocity value over a 39ms period. Time dependent velocity profiles at the middle point are illustrated in Fig.5. Here x is the distance from the side wall where US transducer is fixed, and h_z is the position of the US transducer from the bottom wall. f=2.75Hz is the resonant frequency for B=0. Positive velocity means the flow direction away from the US transducer. When the magnetic field increases, the velocity decreases because of the magnetic force. The spatial velocity profiles are not symmetric with respect to the center axis(x=40mm) as shown in Fig.4. It is caused by nonlinearity of the fluid motion.

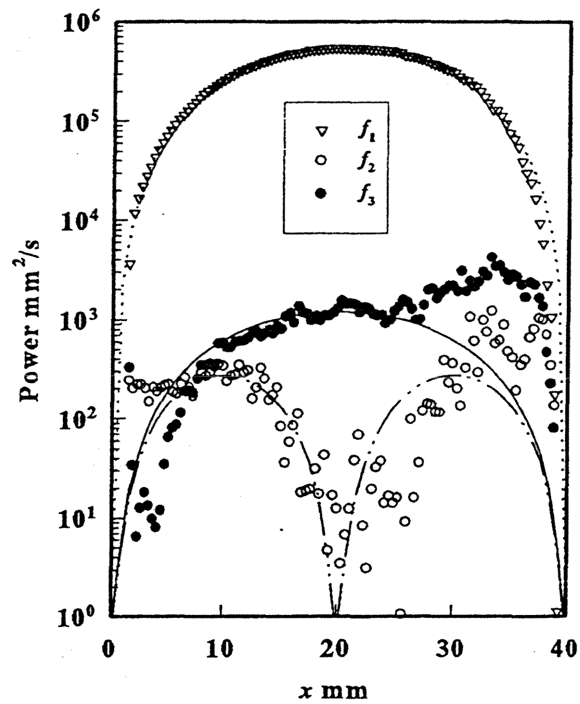


Fig.7 Spatial distributions of the power spectra for f=2.93Hz and B=40mT

From measured velocity data, we calculated 128 power spectra by using a fast Fourier transform in time domain. Figure 6 shows the power averaged over a center region(30.34mm$\leq x \leq$50.32mm, h_z=10mm). The most dominant peak is f_1, which corresponds to the forcing frequency. f_2 and f_3 represent the twice and third times the forcing frequency, respectively. Every height of peaks decreases with increasing B because the disturbance of the fluid is suppressed by the magnetic field.

Figure 7 illustrates time averaged spatial distributions of the power spectra for f_1, f_2 and f_3 at a resonant state(f=2.93Hz) for B=40mT. Nonlinear theoretical spatial spectra for f_1, f_2 and f_3 are drawn by broken line, chain line with two dots and full line, respectively. Distributions of the frequency component f_1 are in agreement with theoretical results. But other power spectra deviate from theoretical lines, especially near the side wall away from the US transducer. The clustering and chaining of the magnetic particles of a magnetic fluid are formed under an applied magnetic field. Consequently, it is supposed that the US echo signal diminishes.

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