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Influence of a magnetic field on ultrasound propagation in a magnetic fluid

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Abstract

Experimental results for anisotropy and hysteresis of the ultrasonic propagation velocity (1 MHz) in a magnetic fluid subject to a magnetic field are reported. Measurements were made by the pulse method while the magnetic field intensity was varied from 0 to 570 mT and the angle between the magnetic field direction and the direction of ultrasonic wave propagation was varied between 0° and 180°. Some interesting results that seem to be caused by cluster formation in the magnetic fluid were obtained.

Keywords: Magnetic fluids; Ultrasound; Anisotrophy; Sound velocity; Clusters

1. Introduction

When a magnetic field is applied to a magnetic fluid, interesting flow behaviors have been observed. In order to better understand the characteristics of these interesting flow behaviors, it is useful to make detailed measurements of internal velocity profiles. Ultrasound Doppler velocimetry is a relatively new method of measuring a velocity profile along a beam line that has the added benefit that it can be applied to opaque fluids such as a magnetic fluid [1,2]. In order to use this method for velocity profile measurement of a magnetic fluid flow, it is important to have an accurate measurement of the sound velocity in a magnetic fluid in a magnetic field. The accurate measurement of the sound velocity is difficult because, when an external magnetic field is applied to a magnetic fluid, some of the colloidal particles coagulate and form chain-like clusters [3]. These clusters cause anisotropy of sound propagation in the magnetic fluid. Several studies have been performed to investigate this anisotropy [4,5]; however, its mechanism is still not clear. In the present paper, we also carry out the precise measurement of sound velocity in a magnetic fluid under a uniform magnetic field and anisotropy of the propagation and hysteresis are discussed.

2. Experimental apparatus

Fig. 1 shows a block diagram of the experimental arrangement. The ultrasonic measurement scheme is based on the pulse method. The pulse echo propagates in a test cell of 32 mm length and using an ultrasonic wave frequency of 1 MHz. The magnetic field is applied by an electromagnet and the angle between the field's direction and the direction of ultrasonic wave propagation is freely adjustable. The temperature of the magnetic fluid is controlled at 25°C by circulating water at a constant temperature. The magnetic fluid in the test cell is W-40 with 40% weight concentration of fine magnetite particles (Fe_3O_4) in a water carrier (made by Taiho Industries Co., Ltd.), having a viscosity and density of 1.41 mPa s and $1.38\times10^3\,kg/m^3$ at 25°C, respectively. Its intensity of saturated magnetization is 38.0 mT.

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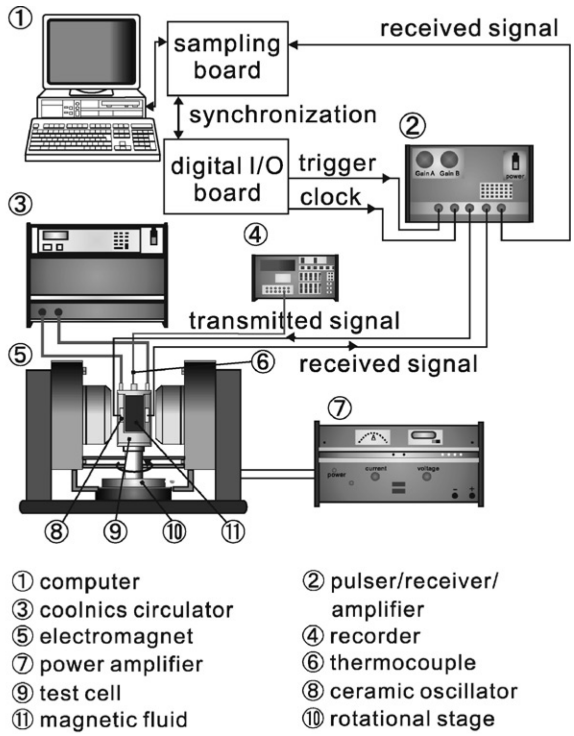

Fig. 1. Experimental apparatus.

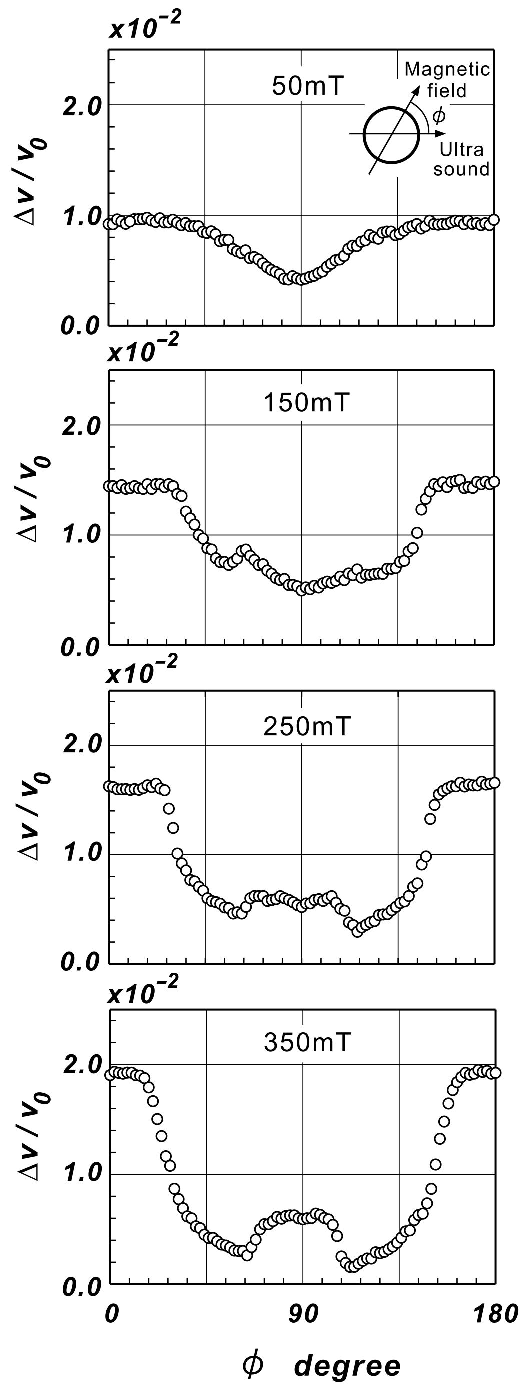

Fig. 2. Anisotropy of the ultrasonic propagation velocity.

3. Results and remarks

Fig. 2 shows the anisotropy of the ultrasonic propagation velocity V for various external magnetic fields. Here ϕ is the angle between the direction of ultrasonic wave propagation and the direction of the external magnetic field, V_0 is the ultrasonic propagation velocity without an external magnetic field, and $\Delta V = V - V_0$. At every angle, we waited for 1 min before measurement. When the magnetic field intensity increases, the ultrasonic propagation velocity also increases, particularly in the region where the direction of the ultrasonic wave propagation is almost parallel to the external magnetic field. The minimum value of ΔV is obtained at $\phi = 90^\circ$ for weaker magnetic field intensities, however, for stronger magnetic field intensities, the ultrasonic propagation velocity indicates local minima near $\phi = 60^\circ$ and 120°. Similar results were also obtained by Skumiel et al. [4].

Figs. 3 and 4 show the hysteresis of the ultrasonic propagation velocity in relation to external magnetic field. The magnetic field is applied using four continuous processes, one following the other, and taking measurements throughout, a → b → c → d, as follows:

a increase the magnetic field intensity by 5 mT every 2 min

b,d decrease the magnetic field intensity by 25 mT every 10,min

c increase the magnetic field intensity by 25 mT every 10 min

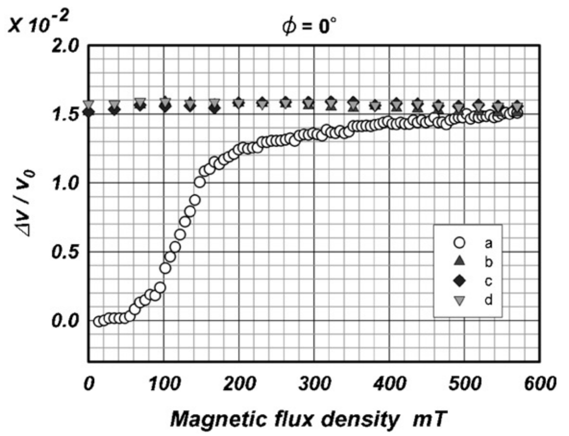

Fig. 3. Hysteresis of the ultrasonic propagation velocity for $\phi = 0^\circ$.

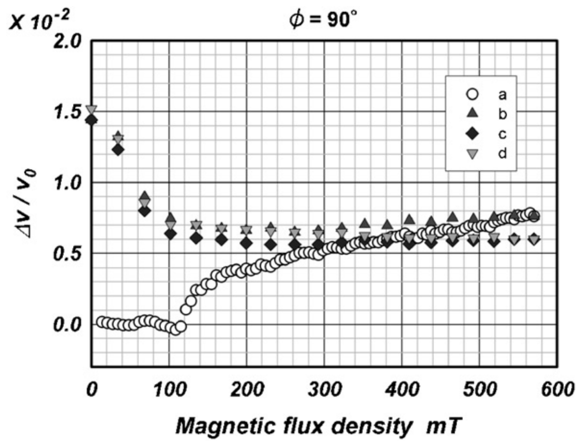

Fig. 4. Hysteresis of the ultrasonic propagation velocity for $\phi = 90^\circ$.

In process a, $\Delta V/V_0$ changes with the magnetic field intensity for both $\phi = 0^\circ$ and 90°. In the case of $\phi = 0^\circ$, the last value of $\Delta V/V_0$ in process a remains unchanged throughout processes b–d. On the other hand, $\Delta V/V_0$ in processes b–d for $\phi = 90^\circ$ also show a large variation and the value of $\Delta V/V_0$ in zero magnetic field in processes b–d is almost the same as the constant value found for $\phi = 0^\circ$.

These interesting results are believed to be caused by the magnetic particle cluster formation in the magnetic fluid. In order to better understand the relationship between the anisotropy and hysteresis of the ultrasonic propagation velocity and cluster formation, we are planning to carry out further experiments to observe Brownian motion of magnetic particles using an optical microscope system with a cardioid condenser lens.

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