ULTRASONIC PROPAGATION IN A MAGNETIC FLUID

Masaaki Motozawa[1] and Tatsuo Sawada[2]

Department of Mechanical Engineering, Keio University, Hiyoshi, Kohoku-ku, Yokohama 223-8522, Japan
[1]motozawa@sawada.mech.keio.ac.jp, [2]sawada@mech.keio.ac.jp

Keywords: Anisotropy, Clusters, Magnetic fluid, Sound velocity, Ultrasonic propagation

ABSTRACT

When an external magnetic field is applied to a magnetic fluid, some of the colloidal particles coagulate and form chain-like clusters. These clusters result in interesting ultrasonic propagation properties, such as anisotropy and hysteresis. We measure the ultrasonic propagation velocity (1 MHz, 2 MHz and 4 MHz) in a magnetic fluid subject to a magnetic field. Measurements were made using the pulse method, first, while the magnetic field intensity was varied from 0 mT to 570 mT, and, second, while the angle between the magnetic field direction and the direction of ultrasonic wave propagation was varied between 0° and 180°. Some interesting results were obtained that seem to be caused by cluster formation in the magnetic fluid.

1. INTRODUCTION

A magnetic fluid is a stable colloidal dispersion of rather small surfactant-coated magnetic particles in a liquid carrier such as water or kerosene. 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 fields. However, because magnetic fluids are opaque, optical methods such as laser Doppler anemometry or flow visualization techniques such as particle image velocimetry can not be applied. Thus, there have been few experimental studies with respect to velocity field in magnetic fluid flows.

A technique called the Ultrasound Velocity Profile (UVP) measuring technique is a method of measuring a velocity profile along a beam line, that is, measuring with respect to the velocity component along the ultrasound beam. This method is useful in that it can be applied to opaque fluids and it has recently been applied to magnetic fluids (Sawada, Kikura and Tanahashi, 1999).

In order to use this method for velocity profile measurement of a magnetic fluid flow, it is first important to have an accurate measurement of sound velocity in a magnetic fluid when the fluid is in a magnetic field. However, the accurate measurement of sound velocity is somewhat more difficult in a magnetic field because, when an external magnetic field is applied to a magnetic fluid, some of the colloidal particles coagulate and form chain-like clusters (Goldberg, Handford and Heerden, 1971). These clusters cause anisotropy of sound propagation in the magnetic fluid. Several studies have been performed to investigate this anisotropy (Skumiel, Labowski and Hornowski, 1995), however its mechanism is still not clear.

In the present paper, we precisely measure sound velocity in a magnetic fluid under a uniform magnetic field and discuss the resulting anisotropy of the propagation.

2. EXPERIMENT

Figure 1 is a block diagram of the experimental apparatus. Figure 2 shows a detailed view of the area the test cell. The ultrasonic measurement scheme is based on the pulse method. The rectangular test cell is filled with a magnetic fluid, has a 32 mm length and is equipped with two ceramic oscillators, an emitter and a receiver. The test cell is placed in a cylindrical container filled with water. In a first experiment, the temperature of the magnetic fluid is varied, while in subsequent experiments, the temperature of the magnetic fluid is kept at 25 °C by circulating water, which is supplied by a temperature control unit. We use three different ceramic oscillators to provide three frequencies of ultrasonic wave: 1 MHz, 2 MHz and 4 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 magnetic fluid in the test cell is W-40 with 40 % weight concentration of fine magnetite particles (Fe_3O_4) in a water carrier. The viscosity and density are 1.41 mPa·s and 1.38×10^3 kg/m^3 at 25 °C, respectively.

When a signal from the personal computer (PC) is transmitted to the ultrasonic wave generator, a burst wave is generated and is transmitted to the ceramic oscillator attached to the test cell. An ultrasonic pulse is generated and propagates through the magnetic fluid over a distance of 32mm. The signal is received at the other ceramic oscillator and is amplified. The resulting pulse-echo train is observed on a CRT display. Ultrasonic propagation velocity in a magnetic fluid is calculated by measuring the travel time of the ultrasonic pulses.

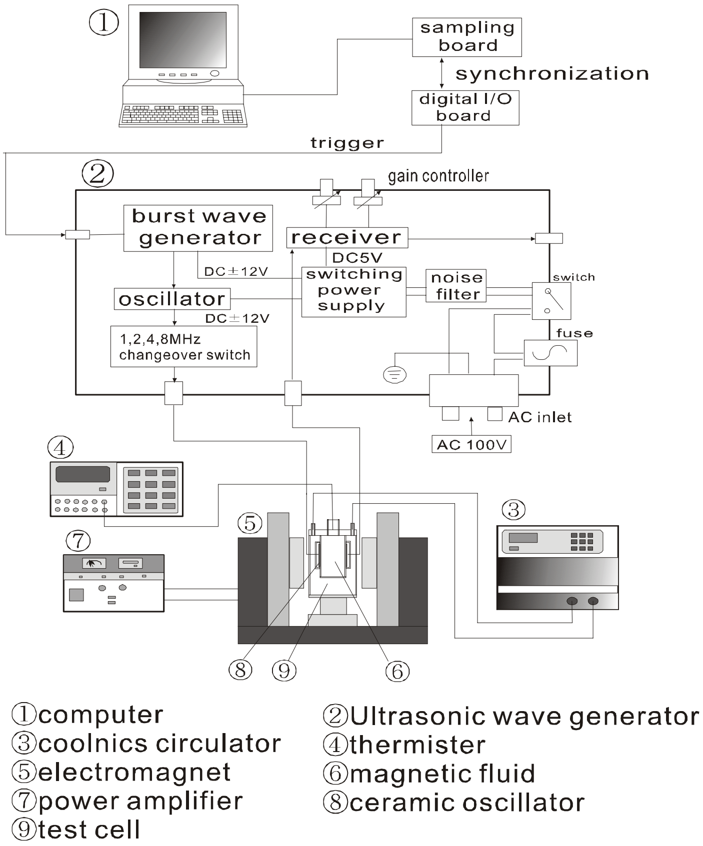

Figure 1. Experimental apparatus

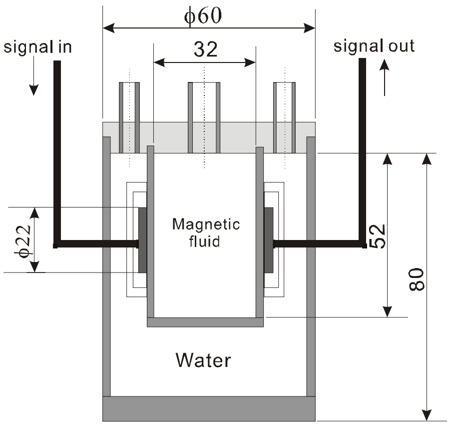

Figure 2. Test cell

3. RESULTS AND DISCUSSION

3.1 Temperature dependence

The temperature dependence of the ultrasonic velocity is shown in Figure 3 for signals of 1 MHz, 2 MHz, and 4 MHz, respectively. The solid line indicates sound velocity in pure water as obtained by Crosso and Mader (1972). In spite of the magnetic fluid being water-based the ultrasonic propagation velocity in a magnetic fluid is smaller than that in pure water. This result is caused by the magnetic particles in the magnetic fluid and surfactant layers. As the temperature increases, the ultrasonic propagation velocity in the magnetic fluid decreases for each signal. This seems to be due to an increase in thermal Brownian motion of the magnetic particles.

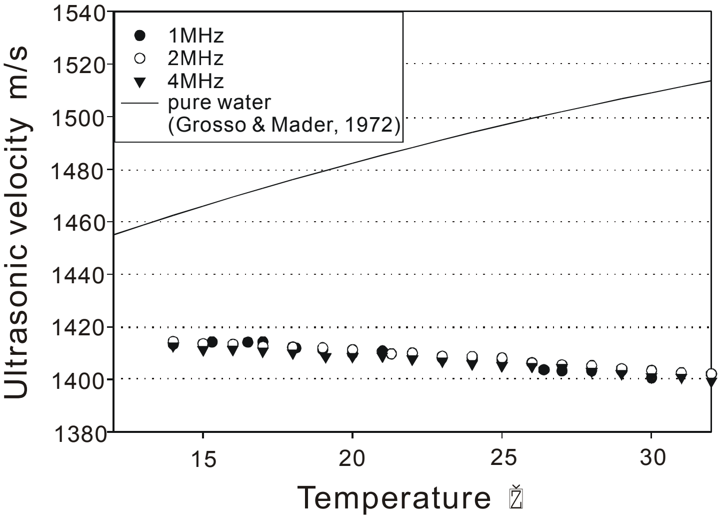

Figure 3. Temperature dependence of the ultrasonic propagation velocity

3.2 Hysteresis

Figure 4 shows 2 MHz ultrasonic propagation velocity *V* versus the magnetic flux density. Here, ϕ=0 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 $\Delta V=V-V_0$. Clearly, there is hysteresis in relation to the applied external magnetic field (Sawada, Nishiyama and Tabata 2002). In this experiment, the magnetic field is applied using the following processes: from 0, increase the magnetic field intensity 15 mT every 2 minutes until reaching 570 mT. Thereafter, decrease the magnetic field intensity by 30 mT every 2 minutes. In the decreasing process $\Delta V/V_0$ increases and shows large variations with changes in the magnetic field intensity.

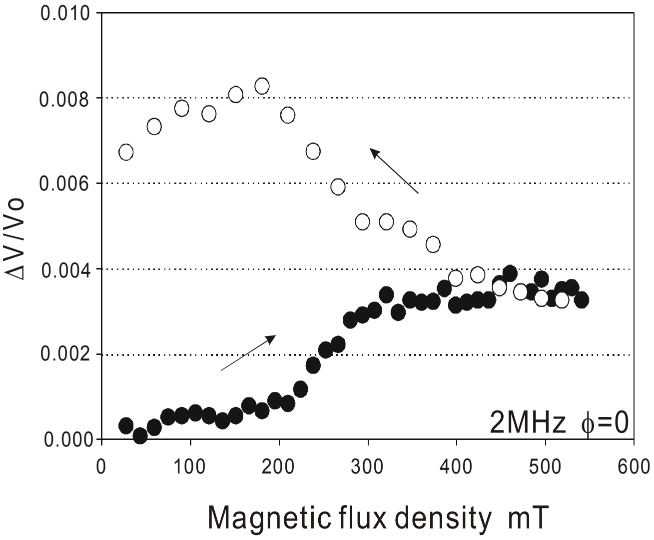

Figure 4. Hysteresis of the ultrasonic propagation velocity

These interesting results are caused by magnetic particle cluster formation in the magnetic fluid. The chain-like clusters are formed in the direction of the magnetic field in proportion to its intensity. The growth of the chains occurs by end-to-end paring or side-by-side aggregation. When the magnetic field decreases, it is supposed that the chain-like clusters do not break instantly.

3.3 Anisotropy

The anisotropy exhibited for the 2 MHz and 4 MHz ultrasonic propagation velocities are shown in Figures 5 and 6, respectively. In these two experiments, before the measurement begins, the magnetic field is applied for 10 minuets at ϕ=0°. The ultrasonic propagation velocity is then measured every 3°. It can be seen that the minimum ultrasonic propagation velocity is obtained near ϕ=90°. Figure 7 shows 4 MHz ultrasonic propagation velocities obtained using similar measurement techniques to those of Figure 6, however, the measurements are carried out after a one hour application of the magnetic field at ϕ=0°. By comparing Figures 6 and 7, it can be seen that cluster formation develops over time and is not as significant in the initial stages.

4. CONCLUDING REMARKS

The ultrasonic propagation velocity in a magnetic fluid subject to a uniform magnetic field are investigated experimentally. Measurements are made using the pulse method and while changing the angle between the magnetic field direction and the direction of ultrasonic wave propagation. Hysteresis is exhibited as the magnetic field increases and decreases. Anistropy of the ultrasonic propagation velocity is also observed. These interesting results are believed to be dependent on the concentration of magnetic particles, external magnetic field intensity, the frequency of the ultrasonic wave and “excitation” and “relaxation” time connected with magnetization. In order to understand these interacting factors, it is necessary to investigate Brownian motion of the magnetic particles and the process of chain-like cluster formation.

ACKNOWLEDGMENTS

This work was partially supported by a Grant-in-Aid for Scientific Research (B) of the Japan Society for Promotion of Science.

REFERENCES

V. A. Del Grosso and C. W. Mader (1972). *Speed of sound in pure water*, J. Acoust. Soc. Amer., 52, pp. 1442-1446.

T. Sawada, H. Kikura and T. Tanahashi (1999). *Kinematic characteristics of magnetic fluid Sloshing in a rectangular container subject to non-uniform magnetic fields*, Expt. Fluids, 26, pp. 215-221.

T. Sawada, H. Nishiyama and T.Tabata (2002). *Influence of a magnetic field on ultrasound propagation in a magnetic fluid*, J. Mag. Magn. Mater., 250, in press.

A. Skumiel, M. Labowski and T. Hornowski (1995). *Investigation of the ultrasonic propagation velocity anisotropy in magnetic liquids in a constant magnetic field*, Acoust. Lett., 19, pp. 87-92.

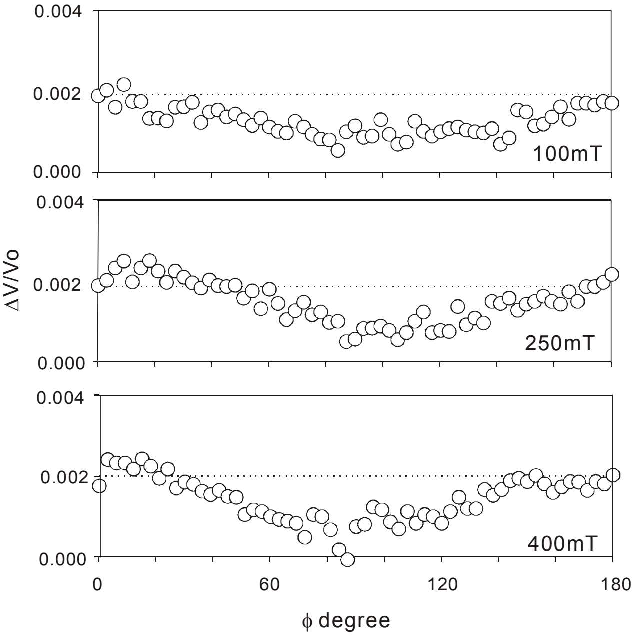

Figure 5. Anisotropy of the ultrasonic propagation velocity (2MHz)

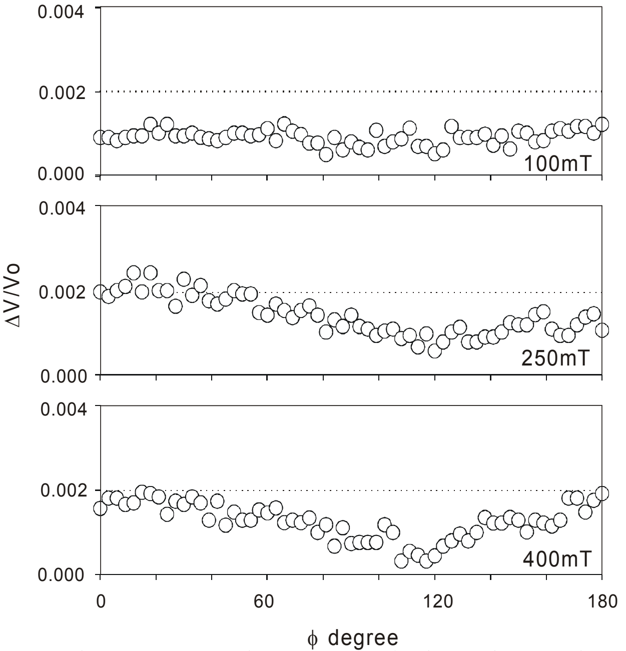

Figure 6. Anisotropy of the ultrasonic propagation velocity (4MHz)

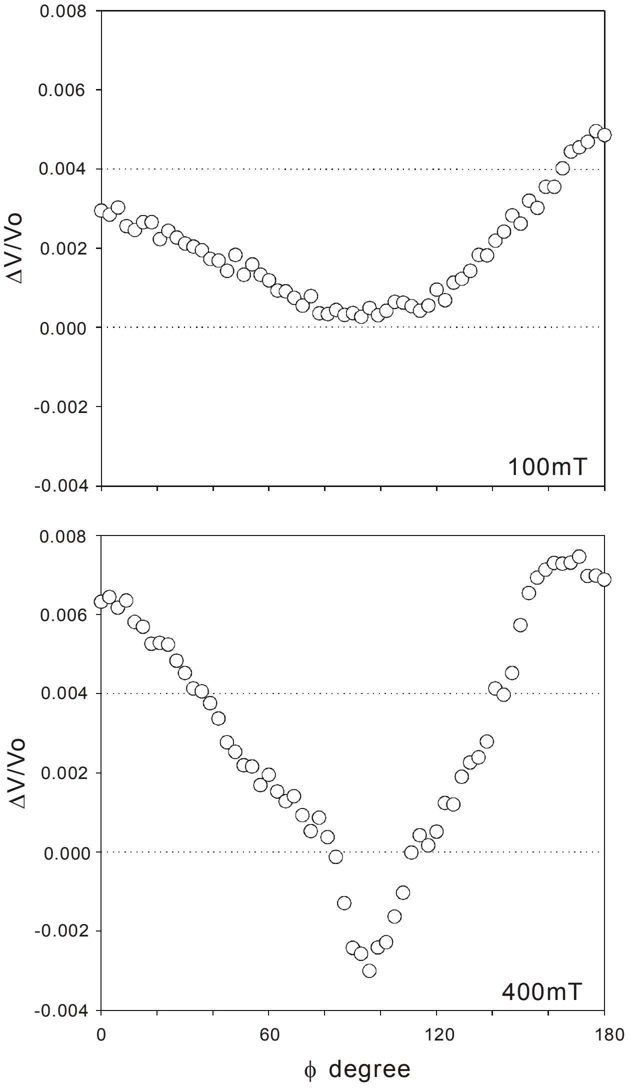

Figure 7. Anisotropy of the ultrasonic propagation velocity (4MHz)