UVP MEASUREMENT ON TAYLOR-COUETTE FLOW OF MAGNETIC FLUIDS WITH SMALL ASPECT RATIO

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ABSTRACT

In this paper, the application of ultrasonic velocity profile (UVP) method to investigate magnetic-fluids flow is described. The objective of the research is to measure the internal flow of a magnetic fluid on Taylor-Couette flow with small aspect ratio using the UVP method and to analyze the influence of the applied magnetic field. The flow structure of a magnetic fluid in a concentric annular geometry with a small aspect ratio of 3 and a radius ratio of 0.6 for an inner-cylinder rotation was investigated. Axial velocity distributions were measured using the UVP measurement technique. A non-uniform magnetic field was applied to the flow field using a permanent magnet, located outside of the cylinders. The results demonstrated that the UVP method was capable to provide the information on the structure of Taylor-Couette flow with small aspect ratio in a magnetic fluid.

Keywords: Magnetic fluid, Taylor-Couette Flow, UVP, Ultrasound, Velocity Profiles, mode Bifurcation

INTRODUCTION

The magnetic fluids contain solid, magnetic, single domain particles coated with a molecular layer of a dispersant in a liquid carrier such as water or kerosene. Since the diameter of these particles lies in the size range of 5 - 15 nm, and due to the thermal agitation, the resulting random walk and random rotation, i.e. Brownian motion, the ferromagnetic particles remain suspended steadily. To achieve a stable dispersion in non-polar or polar solvent, the particles are coated with a single or double layers surfactant.

The importance of such magnetic fluids has been increasing in various fields of engineering application. This leads to the increased interests in studying flows of the magnetic fluids. Conventional methods for flow investigations, such as laser-Doppler-techniques (LDA) and Particle Image Velocimetry (PIV) are not applicable for investigating the magnetic fluid flows. Because, the dark colored liquid prevents the laser-light from penetrating the flow fields. In order to investigate the flow fields of liquids with optically non-transparent media, the Ultrasound Velocity Profile method (UVP method) has been developed [1][2]. Recently, the velocity information obtained from liquid-metal flows are available, i.e. measurements in mercury [3] and measurements in sodium [4]. Hence, the method for investigating the flow fields in the magnetic fluids has also been available [5] [6].

Taylor-Couette flow with small aspect ratio, which has the effect at the end of annulus, is an interesting physical phenomenon, typical to non-linear dynamics. Many researchers have carried out the investigations on mode bifurcation and flow pattern, applying laser Doppler anemometry, flow visualization or other methods. Benjamin [7] studied the change in mutation of primary flow at the length of comparatively short annulus. Mullin [8] investigated the evolution of primary flow and the transition from N-cell mode to (N+2)-cell mode by flow visualization. If we use a magnetic fluid as a test liquid, it is suggested the possibility of mode control by using an external magnetic field.

Some experimental investigations by mean of torque characteristics for cylindrical and spherical Couette flow on magnetic fluids had also been studied [9]-[11]. The UVP method was applied to the time-dependent Taylor-Couette flows obtained between two concentric rotating cylinders to measure time-dependent flow dynamics of a magnetic fluid by Kikura, et al.[12]. They found that under a non-uniform magnetic field, there is an angular dependence of the flow and the maximum velocity depends on the intensity of the magnetic field and is influenced by the level of the upstream velocity.

Thus, the aim of the present paper is to measure the internal flow of a magnetic fluid on Taylor-Couette flow with small aspect ratio using UVP method and to discuss the influence of an applied magnetic field on the flow mode bifurcation control.

SOUND PROPERTY OF MAGNETIC FLUID

Since the ultrasound properties, especially sound velocity, were unknown for the magnetic fluid used in this investigation, and its value is essential in the ultrasonic Doppler method, we measured the sound velocity [12]. In Fig. 1, the results are given for a magnetic fluid. The based test fluid W-40 is a water-based magnetic fluid and the weight concentration w% of fine magnetite particles is controlled by dilution. From Fig.1 we found that the velocity of sound in magnetic fluids decreases with the increase in weight concentration of magnetite particles. In the present study, we used the magnetic fluid of 23.35w% having a sound velocity of 1450 m/s.

Even though the magnetic fluids are composed of solid, magnetic, single domain particles coated with molecular layer

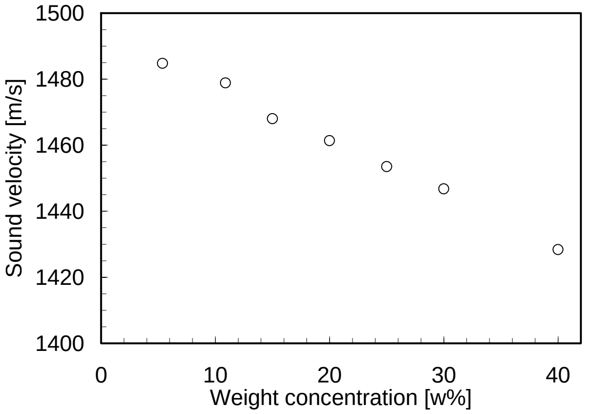


Fig. 1 Sound velocity of a water-based magnetic fluid

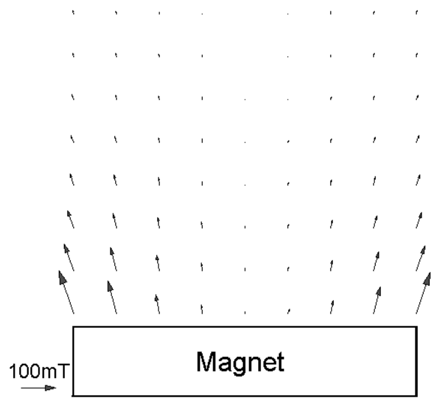
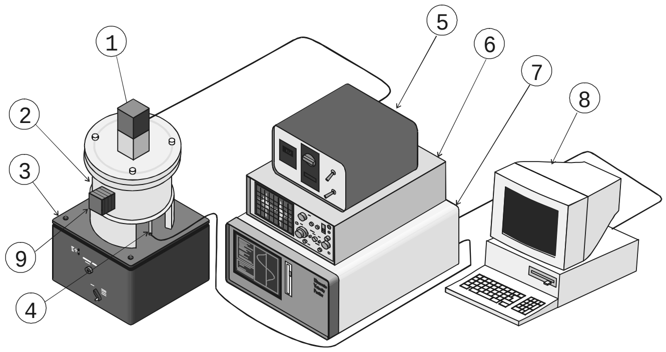


Fig. 3 Magnetic field and



1. Motor, 2. Taylor-Couette Vessel, 3. Isolator, 4. US transducer, 5. Controller, 6. Oscilloscope, 7. UVP monitor, 8. PC, 9. Magnet

Fig. 2 Experimental apparatus

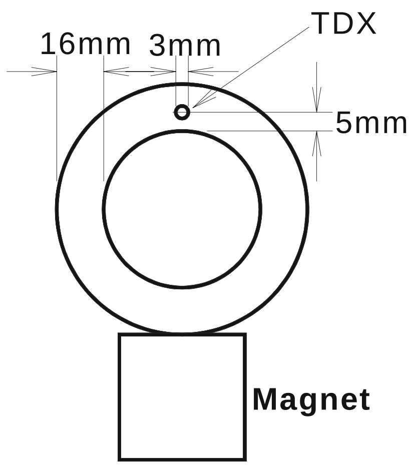


Fig.4 Measuring position

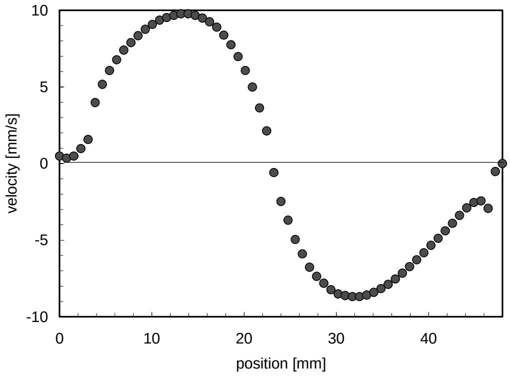
of a dispersant, the diameter of particles in the size range of 5 to 15 nm is too small to emit strong ultrasound signals. Furthermore, the present investigations are based on the propagation of ultrasound waves in magnetic fluids possessing a large absorption of ultrasound. To acquire such a strong ultrasound signal, tracer particles (Micro Sphericalfeather: MSF10) were added to the flows. The tracer particles are made of a SiO2-shell having a spherical shape, uniform diameter particle of 0.9 mm with low effectiveness and specific gravity. Although these particles are much smaller than the wavelength of the ultrasound, the reflected-power is efficient to produce significant signal-to-noise ratio of the detected ultrasound wave and the measuring length in the magnetic fluid is 60 mm in the present case. The propagation of ultrasound in magnetic fluids was investigated by Gogosov et al [13]. They found out that the sound velocity in a magnetic fluid was smaller than that in the solvent. Additionally, the sound velocity changed when a magnetic field was applied. However, in the present configuration we had not found any deflectable change in the sound velocity due to the present magnetic field.

EXPERIMENTAL SET-UP

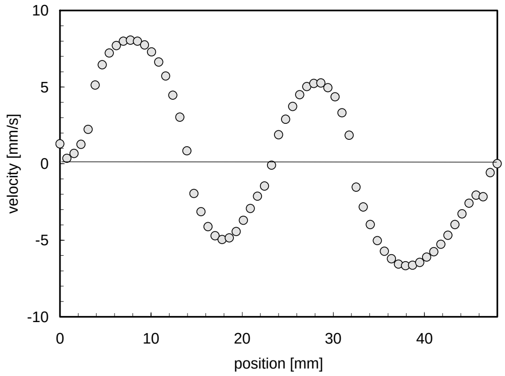
The schematic of experimental apparatus is shown in Fig. 2. The apparatus consists of two concentric cylinders, which are made of Plexiglas. The length of the cylinders are 48mm, the outer radius of the inner cylinder is R_i = 24mm and the inner radius of the outer cylinder is R_o = 40mm. They are positioned vertically adjacent and the gap between the two cylinders is filled with a magnetic fluid. The UVP transducer (8K3I, INS 570, Japan Probe Co.)is installed from the bottom of container to measure the axial velocity distributions. In a system with fixed outer cylinder, the fluid in the annular gap moves in a plane perpendicular to the cylinder axis for small Reynolds number ($Re=\Omega R_i(R_o-R_i)/\nu$). Here, Ω is rotation rate of inner cylinder, and ν is kinematic viscosity of a magnetic fluid. The UVP monitor used in this work is the X-3 PSi model (MetFlow SA) with basic ultrasound frequency of 8MHz..

The non-uniform magnetic field was applied perpendicularly to the cylinder axis using a 40-mm×40-mm×45-mm permanent magnet, positioned outside the cylinders. Typical magnetic field distribution (B_0 = 62mT) around the cylinder is shown in Fig. 3a and the locations of ultrasonic transducer for measurements are shown in Fig. 3b. Here B_0 is mean magnetic field intensity on the surface of the magnet. The Hall-effect Gauss meter measured the vertical and horizontal magnetic inductions; hence the vector field of the magnetic field was obtained. We applied the magnetic fields with following two ways, one is that the magnet applied when the rotation of the cylinder Ω=0, and after the start of rotation the magnet was released from the cylinders (case-1). The other way is that after the rotation of the cylinder, the magnet was placed at the outer cylinder. Subsequently, the magnet was released from the cylinders (case-2).

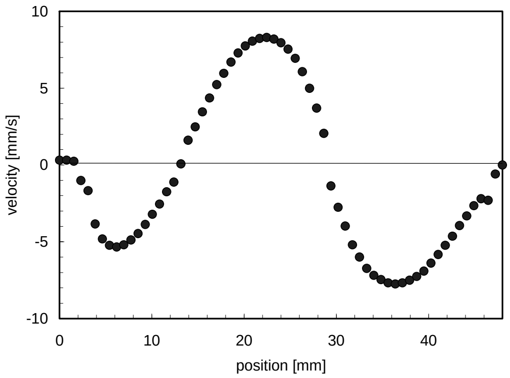
RESULTS AND DISCUSSION



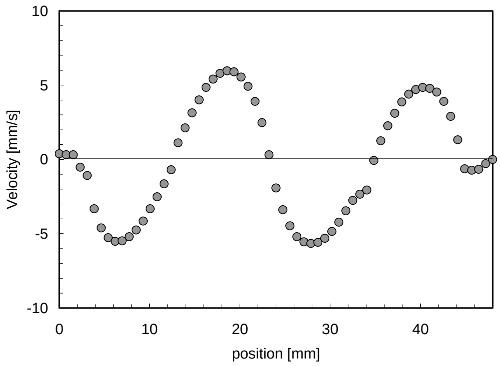
(a) N-2Cell Mode



(b) N-4Cell Mode

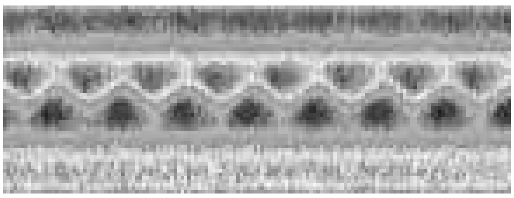


(c) A-3Cell Mode

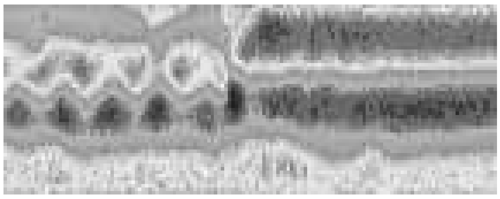


(d) A-4 Cell Mode

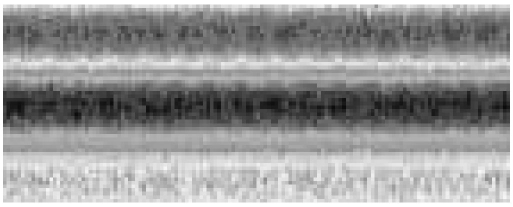
Fig. 4 Axial mean velocity profiles (Re=350, B_0=0)



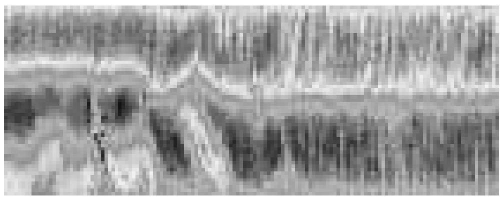
(a) A-4 Cell (Re=420)



(B) A-4 to A3 Cell (Re=580)



(c) A3 Cell (Re=1080)

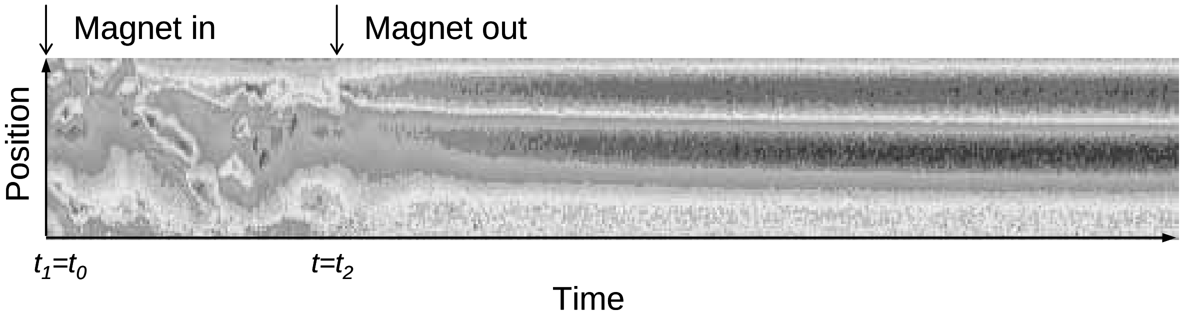


(d) A3 to N2 Cell (Re=1250)

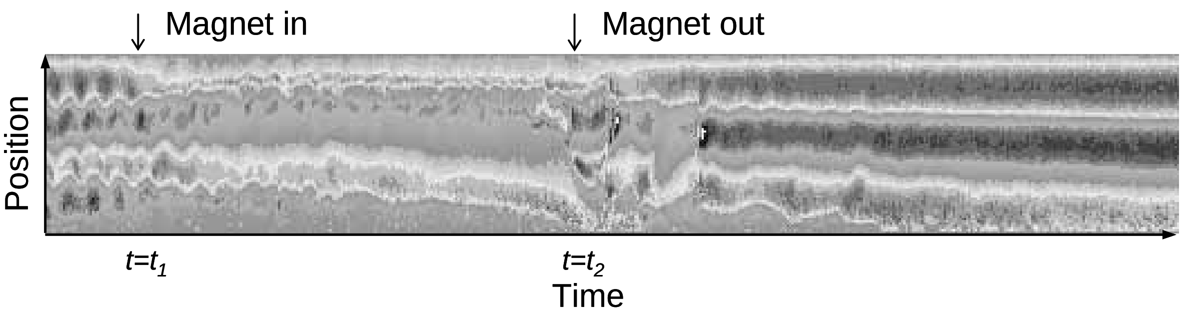
Fig. 5 Mode bifurcation from A-4Cell mode to N-2 Cell mode (B_0=0)

The velocity profile was obtained by setting up the ultrasound transducer on the outer wall of the end plate at the inner wall position, as illustrated in Fig. 3b. At very low Reynolds numbers in a rotating Taylor-Couette system, the flow is a two-dimensional circular Couette flow having the velocity profile $V=(0,V_\theta(r),0)$. At critical Reynolds number, Couette flow becomes unstable to Taylor-vortex flow (TVF), which has three dimensional, axisymmetric counter-rotating toroidal vortices. Taylor vortex flow occurs with small aspect ratio on various flow patterns. Fig. 4 shows the mean velocity distributions in different flow mode at same Reynolds number (Re = 350) without magnetic field. In Taylor-Couette flow with small aspect ratio, the flow is classified as primary mode and secondary modes. The primary mode flow (N-2Cell) is formed smoothly from Couette flow by a gradual increase in Re. The secondary mode (N-4Cell) occurs when the Re was abruptly increased until reaching a certain value. The number of vortices in the secondary mode is different from one in the primary mode. The primary mode and secondary mode are distinguished into normal mode and anomalous mode. On each end wall, the flow in the normal mode has a normal cell which gives an inward flow in the region adjacent to the end wall. The flows of the anomalous modes (A-3Cell and A-4 Cell) have anomalous cells, which give an outward flow near the end wall. Using UVP method we can obtain the instantaneous velocity profiles and understand the each mode from instantaneous and mean velocity profiles.

Mode bifurcation occurred depending upon the increase of Reynolds number. Fig 5 shows mode bifurcation of the anomalous 4-cell mode (A-4 Cell) for the measured velocity profiles. In each display, the ordinate represents position (64 data points for 0.74mm in width) and the abscissa is time (256



(a) Case 1



(b) Case 2

Fig. 6 Measured velocity profiles (Re=600, B_0=62mT)

points for 29s). The velocity values are color-coded: yellow and red being positive; green and blue, negative. The full-scales are of ±20mm/s, ±30mm/s, ±40mm/s and ±50mm/s, respectively.

Fig. 6 shows the measured velocity profiles for mode control using a magnetic field. In case-1, the magnetic field was applied from rotating start and the final flow mode was anomalous 3-cell mode. In the case 2, the magnetic field was applied during normal 4-cell mode; the final flow mode was also anomalous 3-cell mode. From each one of them, reliable control to 3-cell mode was obtained. The study clarified that the UVP method was capable to provide the information on the structure of Taylor vortex flow with small aspect ratio, in a magnetic fluid.

CONCLUDING REMARKS

The flow structure of the Taylor-Couette flow with small aspect ratio of a magnetic fluid has been investigated using the ultrasonic velocity profile (UVP) method. For checking the ultrasound properties of the magnetic fluid, the dependence of sound velocity on the weight concentration was studied. The velocity of sound in magnetic fluids decreases with increase in weight concentration of magnetite particles. However, in the present configuration we found no deflectable change in the sound velocity due to the magnetic field. From the experimental results on the Taylor-Couette flow with aspect ratio of 3 in a magnetic fluid under the no external field, 4 type of flow modes(N-2cell, N-4Cell, A-3Cell and A-4Cell mode) have been understood from instantaneous and mean velocity profiles. Mode bifurcation occurred depending upon the increase of Reynolds number. Influence of an applied magnetic field on the flow has been carried out and we found that the possibility of mode bifurcation control using magnetic field.

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