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TAYLOR VORTEX FLOW OF A MAGNETIC FLUID

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ABSTRACT

Flows of magnetic fluids are increasing importance in a number of fields of engineering and this has increased the interest in studying flows of this kind. For such flow investigations conventional methods, such has hot wire anemometry, cannot be applied because of the special properties of magnetic fluids. In addition, the dark coloured liquid dose not permit laser-Doppler-techniques to be used to locally study the flow fields. In order to investigate fluid flow fields of liquids with optically non-transparent media, the Ultrasound Velocity Profile Method (UVP-method) has been developed. Recently velocity information obtained in liquid metal flows have become available, i.e. meaurements in mercury[1] and measurements in natrium[2]. Hence, a method has become available that can be applied to also investigate flow fields of magnetic fluids.

The UVP-method employs the instantaneously mesured frequency of pulsed ultrasound wave, backscattered from small tracer particles suspended in a flowing fluid which is transparent to ultrasound, although it might not be tranparent to light. In spite of the fact, that magnetic fluids are composed of solid, magnetic, single domain particles coated with the molecular layer of a dispersant, the diameter of these particles lying in the size range of 5 to 15 nm is too small to yield good ultrasound signals. To yield such signals, tracer particles have been added (Micro Sphricalfeather: MSF) made of a SiO_2-shell yielding a spherical, uniform diameter particle(0.9 μm) of low effective, specific gravity. Although these particles are much smaller than the wavelength of the ultrasound, the reflected power is efficient for good signal-to-noise ratio of the detected ultrasound wave. This will explained in the presentation.

The present investigations are based on the propagation of ultrasound waves in magnetic fluids which possesses a large absorption of ultrasound. Thus the measuring length in the magnetic fluid was only 100 mm in the present case. The propagation of ultrasound in magentic fluids was investigated by Gogosov et al.[3]. They showed that the sound velocity in a magnetic fluid was smaller than in the solvent, and also that the sound velocity changed when a magnetic field was applied. They also found that the sound velocity did not depend on the frequency of ultrasound and did not change monotonically with the temperature of the magnetic fluid.

To consider the differences in sound velocity in defferent magnetic fluids, it is also investigated the velocity of ultrasound in the present magnetic fluid. Test liquid is a magnetic fluid with 40% weight concentration of fine magnetite(Fe_3O_4) particles in a water carrier. The sound velocity 1410m/s at 22°C is measured. Since the intensity of the magnetic field is small, no defifference in sound velocity under the magnetic field is obtained.

The UVP method is applied to time-dependent Taylor vortex flows obtained between two concentric rotating cylinders to measure time-dependent dynamics of the flow of a magnetic fluid. Some experimental investigations by mean of torque characteristics for cylindrical and spherical Couette flow on magnetic fluids were studied[4],[5]. Niklas[6] solved the ferrohydrodynamic equation for Taylor vortex flow and obtained the changes in the critical Taylor number T_c and wave number k_c which characterize the instability of the flow.

Taylor vortex flow is typically studied for flow transition from laminar to turbulent flow[7]. The aim of the present paper is to measure the internal flow of a magnetic fluid on Taylor vortex flow. Two concentric cylinders were made of transparent acrylic (Fig.1). The length of the cylinders are 160mm, the outside radius of the inner cylinder R_i=15mm and the inside radius of the outer cylinder R_o=23mm. They were placed vertically and the UVP transducer was located in order to measure the axial velocity distributions. In a system with the outer cylinder fixed, the fluid in the annular gap moves in a plane perpendicular to the cylinder axis for small Reynolds number ($Re = \Omega R_i(R_o - R_i)/\nu$). The nonuniform magnetic field was applied horizontally using a 70mm × 70mm × 15mm magnet from outside of cylinders. Three different intensity of magnetic fields at the surface of outer cylinder are 36mT, 57mT and 79mT which are measured by changing the distance between the cylinders and the magnet. The UVP monitor is X-1 PS in 4MHz.

Steady-state velocity distributions at $Re/Re_c = 1.72$ are given in figure 2. This shows the time-averaged velocity profiles of the axial component at the inner wall position. Since the data set consists of 128 times series of 1024 data points, the temporal characteristics of the flow were studied using a Fourier transform in the space domain[8]. This is an energy spectral density in wavenumber with sufficient data points and resolution. Figure 3 shows the time-averaged energy spectral density(ESD). The wavelength of the roll structure can be readily obtained for the profile and was estimated for steady state data as an average of 6 rolls(3 vortex pairs) which are influenced with the magnetic field. A decreasing tendency is seen on maximum ESD and wavelength along with a decline in the intensity of the magnetic field(Figure 4). From approaching to zero value of multiply by the maximum velocity($A^2 = Vx^2_{MAX}$), it is possible to determine the critical Reynolds number as shown in figure 5. The critical Reynolds number under the non magnetic field is Re_c=75 which is in good agreement with the analytical value of the radial ratio η=0.65[9]. This suggests that the magnetic fluid shows relatively good Newtonian fluid behavior on present flow without the magnetic field. However the data with the magnetic field show different trend. Increasing the intensity of magnetic field, the line shift toward a higher value and the critical Reynolds number also shift up. This shows that the apparent viscosity of magnetic fluid under the magnetic field is increased.

Reference

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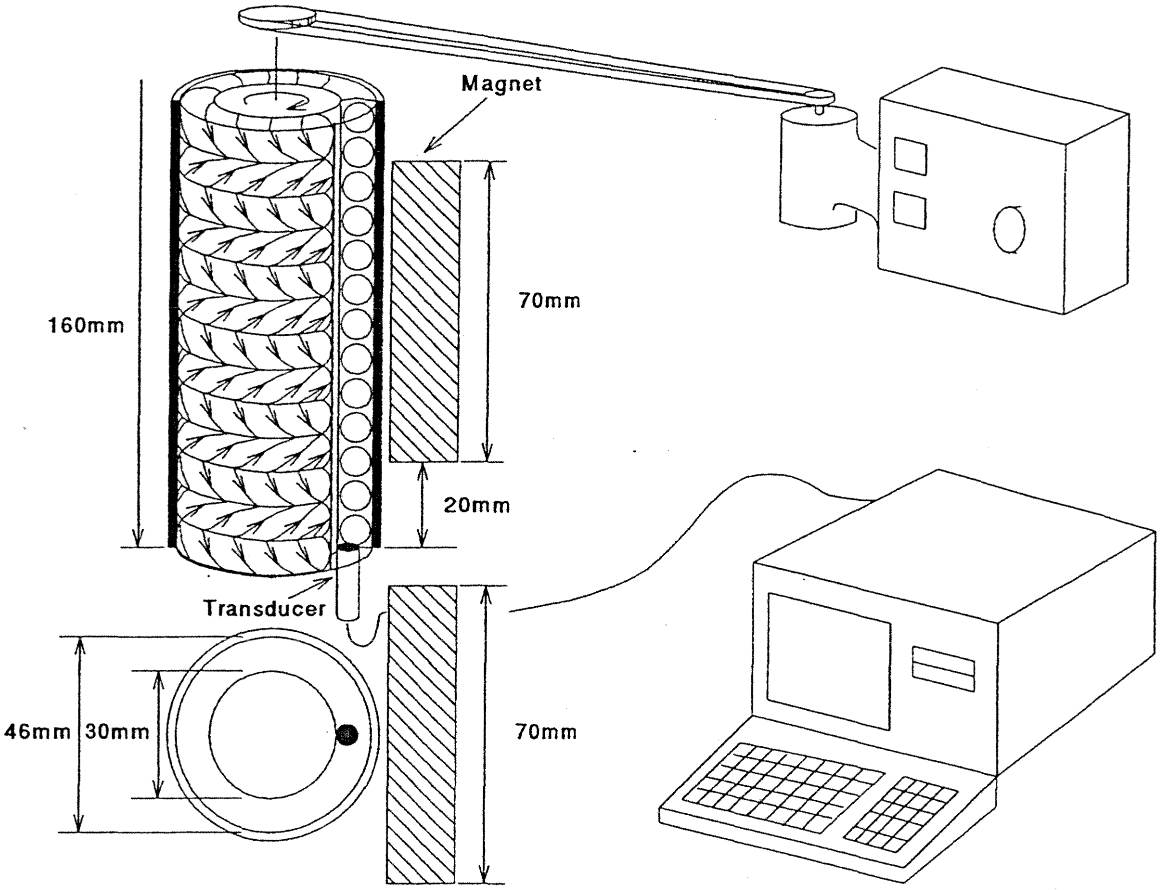

Fig.1 Experimental Apparatus

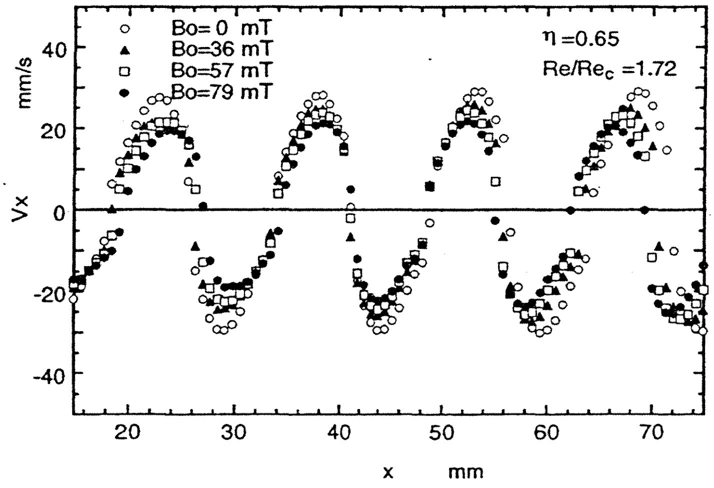

Fig.2 Mean Velocity Profiles

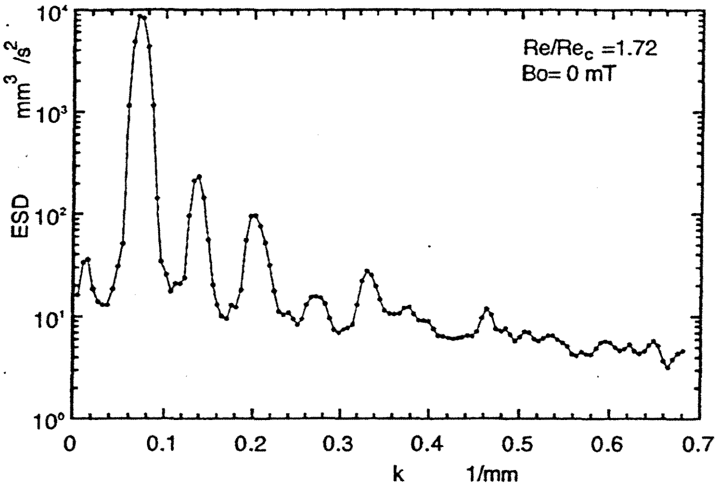

Fig.3 Time-Averaged Enery Spectral Density

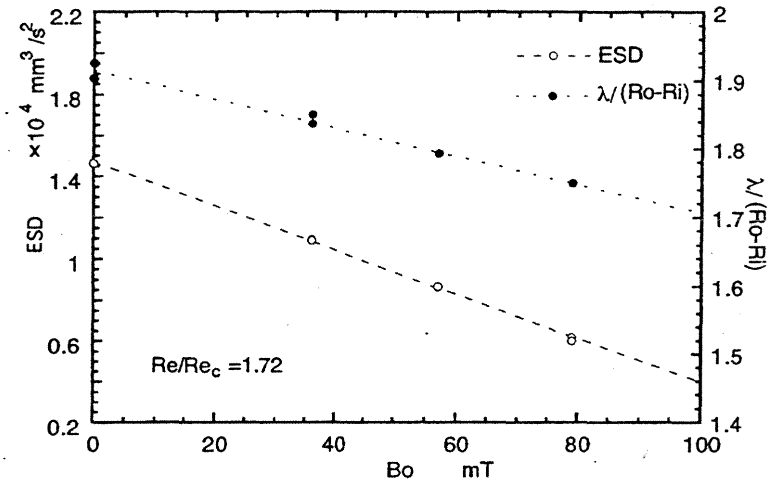

Fig.4 Maximum ESD and Wave Length

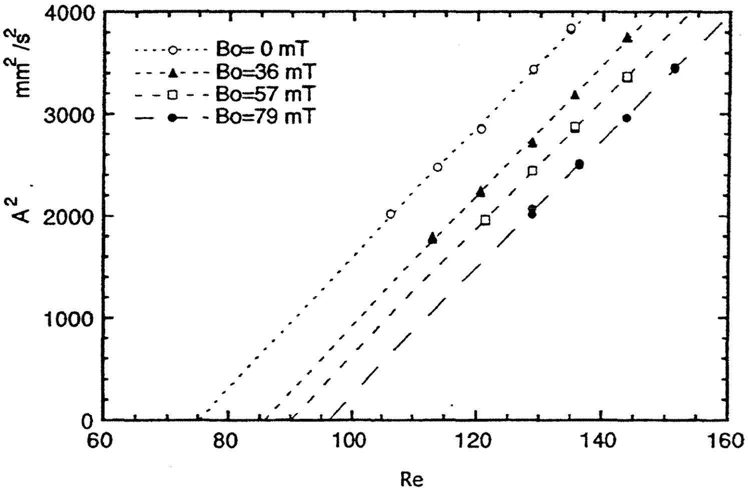

Fig.5 Critical Reynolds Number