UVP MEASUREMENT OF TAYLOR-COUETTE VORTEX FLOW WITH SMALL ASPECT RATIO

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ABSTRACT

In this study, experiment was carried out for Taylor-Couette vortex flow. Taylor-Couette vortex flow with small aspect ratio can be generated by two concentric rotating cylinders; a rotating inner cylinder and a fixed outer cylinder. Two test section sizes with radial ratio of 0.375 and 0.667 were applied. Aspect ratio and gap between inner and outer cylinder were kept constant 3 and 25 mm respectively. Successive instantaneous and mean velocity profiles were obtained by using an ultrasonic velocity profiler (UVP). The spatiotemporal velocity field was analysed by two dimensional Fourier transform. In this case, the characteristics of Modulated Wavy Vortex Flow (MVF) and Wavy Vortex Flow (WVF) transition are confirmed. Furthermore, the bifurcations between each cell modes namely the N-2Cell, N-4Cell, A-3Cell and A-4Cell modes are clarified.

Keywords: Taylor-couette vortex flow, small aspect ratio, UVP

INTRODUCTION

Taylor-couette flow can be observed usually in between two concentric rotating cylinders and applied intensively for bioindustry and medical field [1]. The study of flow pattern and bifurcation in the finite boundary (end-wall) with small aspect ratio become great interest. Nakamura [2] studies the flow pattern with the variation of aspect ratio (1-8). Benjamin [3] studied the mutation of primary flow at the length of comparatively short annulus was changed. Mullin [4] investigated the evolution of primary flow and the transition from N-cell mode to (N+2)-cell mode by flow visualization. However the dfficulty is to understand the mode bifurcation measuring the spatiotemporal internal flow completely. For this reason, the direct measurement of the internal velocity field is nessesary.

Recently, in a series of research by Takeda using an ultrasonic velocity profiler (UVP), the spatiotemporal velocity field was measured. The flow fields were analysed by using two dimensional Fourier transform and the orthogonal decomposition technique, and intensities of coherent structual modes were quantitatively obtained. The variation of the intensities of various modes with respect to Reynolds number clearly shows a transition behaviour of the quasi-periodic state resulting from the wavy vortex mode and the modulating waves, which is found to disappear suddenly [5].

The purpose of this study is to perform a direct measurement of velocity field in the Taylor-Couette vortex flow structure with small aspect ratio by using an ultrasonic velocity profiler (UVP) and a visualization by laser sheet. Furthermore, the characteristics of the vortex flow such as vortex mode bifurcation, vortex intensity and spectrum transition in each vortex mode are investigated by Fourier transform analysis.

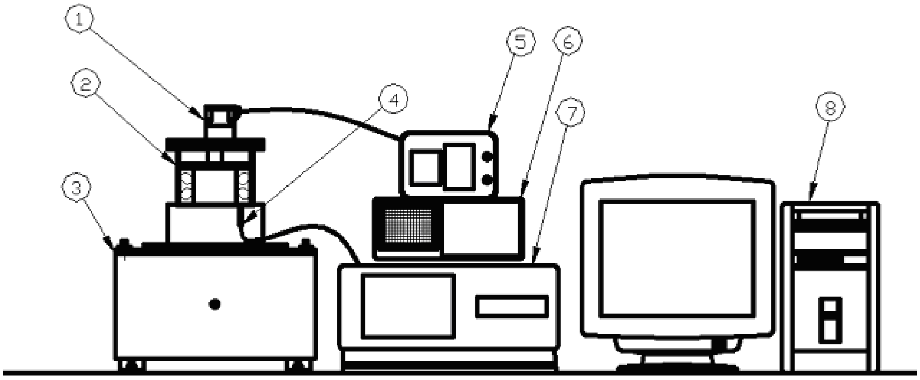
EXPERIMENTAL METHOD

Fig. 1 shows the set up of UVP measurement system, and Fig. 2 shows the test section. Test section consists of concentric cylinders made of Plexiglas. The inner cylinder was rotated, being direct driven by electric motor and the outer cylinder was stationary. To isolate the external vibration transmission, the appliance was held at the special isolator of resonance frequency of 0.5Hz. The length of the cylinder was H=75mm. In this experiment, two sizes of test section were utilized. The first one has R_1=15mm and R_2=40mm corresponding to $\eta=R_1/R_2=0.375$. The second one has R_1= 50mm and R_2= 75mm corresponding to $\eta=R_1/R_2=0.667$. Both types has the same gap of $\Delta r=R_2-R_1$=25mm and the aspect ratio, H/d=3. The working fluid was 68wt% glycerol water. The Reynolds number is given by $Re=\Omega R_1 d/\nu$ (Ω is rotation frequency of the inner cylinder, ν is kinematic viscosity).The number of generated vortex cell can be controlled by acceleration and deboost of motor frequency.

The applied measuring system for velocity profile measurements was UVP (MetFlow, Model X3-PSi) with a personal computer for data analysis. The principle of the ultrasonic Doppler method is based on the echography for position information and Doppler shift relationships for velocity detection. For more details about the UVP measuring system, see Takeda 1995.

Table 1. UVP parameters

Basic frequency	8MHz
Ultrasonic beam diameter	2.5mm
Channel distance	0.87mm
Measurement points	128(82)
Number of profiles	1024



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

Fig. 1 Setup of UVP measurement

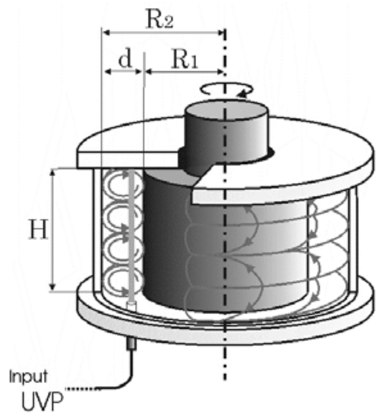
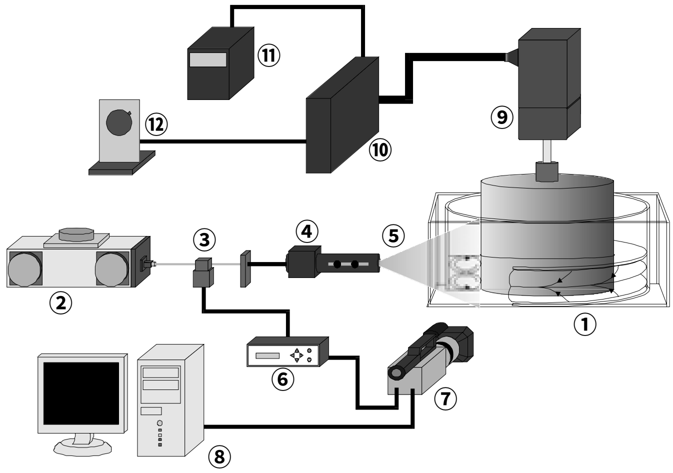


Fig. 2 Test section

In the present investigation, the ultrasound transducer was located at the outer wall of the end plates. The transducer was placed at the upper plate for η=0.667 and lower plate for η=0.375. The axial velocity components were measured in between the gap at the distance of 7 mm from the inner cylinder. The parameters of UVP measurement are shown Table 1. The ultrasound transducer was operated with a basic frequency of 8MHz. Then the sound velocity at 68wt% glycerol water was 1800m/s. In order to obtain the different vortex mode and bifurcation of vortex intensity, the Re was varied in the range of 0-2800.

Fig. 3 shows the set up of visualization. The conditions of each cell modes were visualized by using an Argon laser sheet. Static and moving images were obtained by digital camera and Hi-vision video camera, and edited by the personal computer.



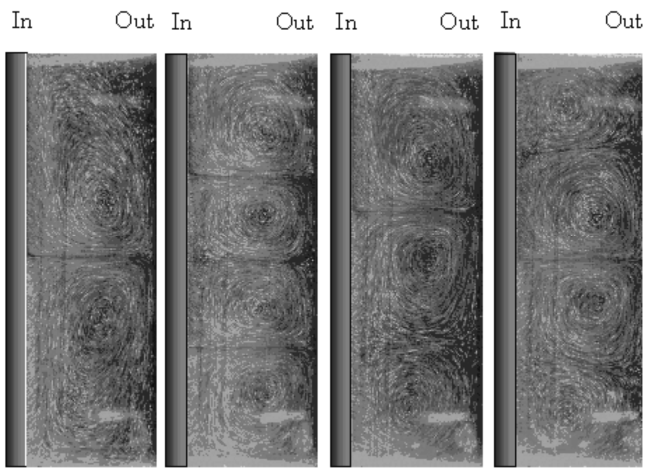
1. Taylor-Couette Vessel 2.Argon laser 3.AOM 4.Cylindrical lens 5.Laser sheet 6.PIV driver 7. Camera 8.PC 9.Motor 10.Controller 11.Tachometer 12.Speed converter

Fig. 3 Setup of visualization

RESULTS AND DISCUSSION

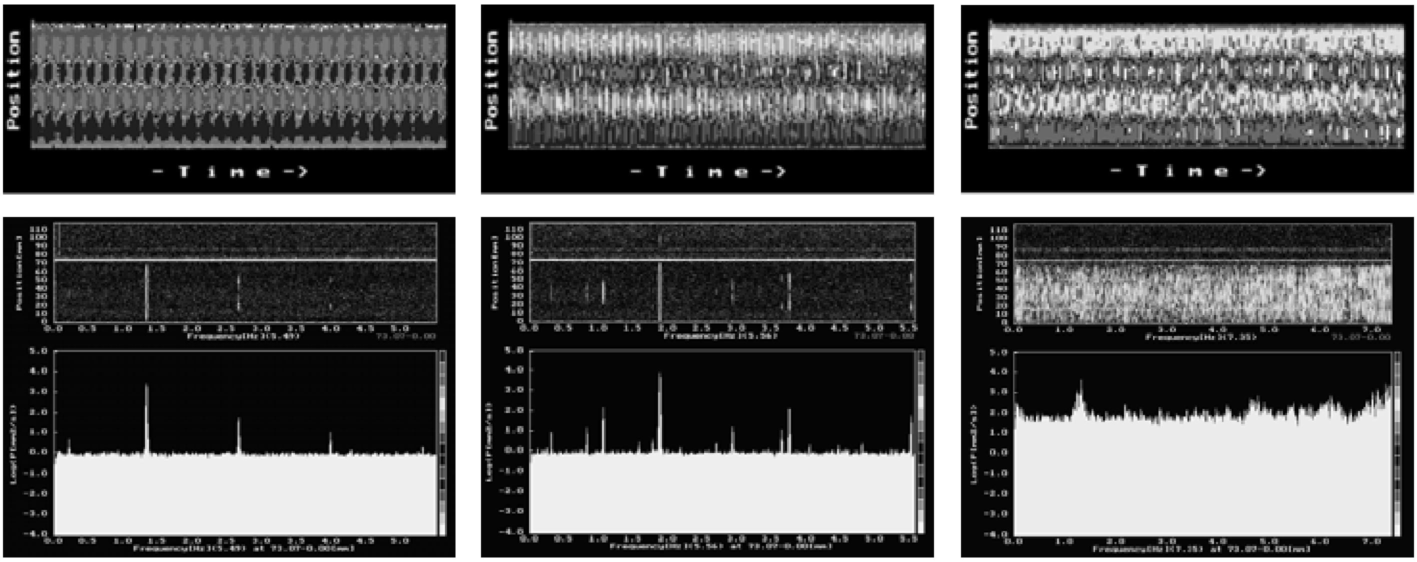
For the lower critical Reynolds numbers, the two-dimensional Couette flow is generated. In this case, the tangential velocity depends only on the radius position, $\boldsymbol{V}=(0,V_\theta(r),0)$. At the critical Reynolds number, the Couette flow becomes unstable and be transformed to the three dimensional Taylor vortex flow (TVF). In this case, the vortical structure called "counter-rotating toroidal vortices" was generated. In Taylor vortex flow at small aspect ratio, various flow patterns appear.

Fig. 4 shows the flow patterns obtained from visualization at the aspect ratio of 3. At a constant aspect ratio, the flow is classified as a primary mode and secondary modes. For the primary mode flow, the normal-2cell mode (N-2Cell, Fig. 4(a)) is formed smoothly from Couette flow by a gradual increase in Re. For the secondary mode, the normal-4cell mode (N-4Cell, Fig.4(b)) appears when the Re is increased abruptly at a certain value. The number of vortices in the secondary mode is different from those in the primary mode. From the results, normal mode can be observed only for the primary mode, while both normal and anomalous mode are observed for the secondary 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 flow of the anomalous modes have an anomalous cell, which gives one or two outward flow near the end wall. In this case, the anomalous modes are anomalous-3cell mode (A-3Cell, Fig. 4(c)) and anomalous-4cell mode (A-4Cell, Fig. 4(d)).



(a) N-2Cell (b) N-4Cell (c) A-3Cell (d) A-4Cell

Fig. 4 Vortex mode at η=0.375 (Re=370)

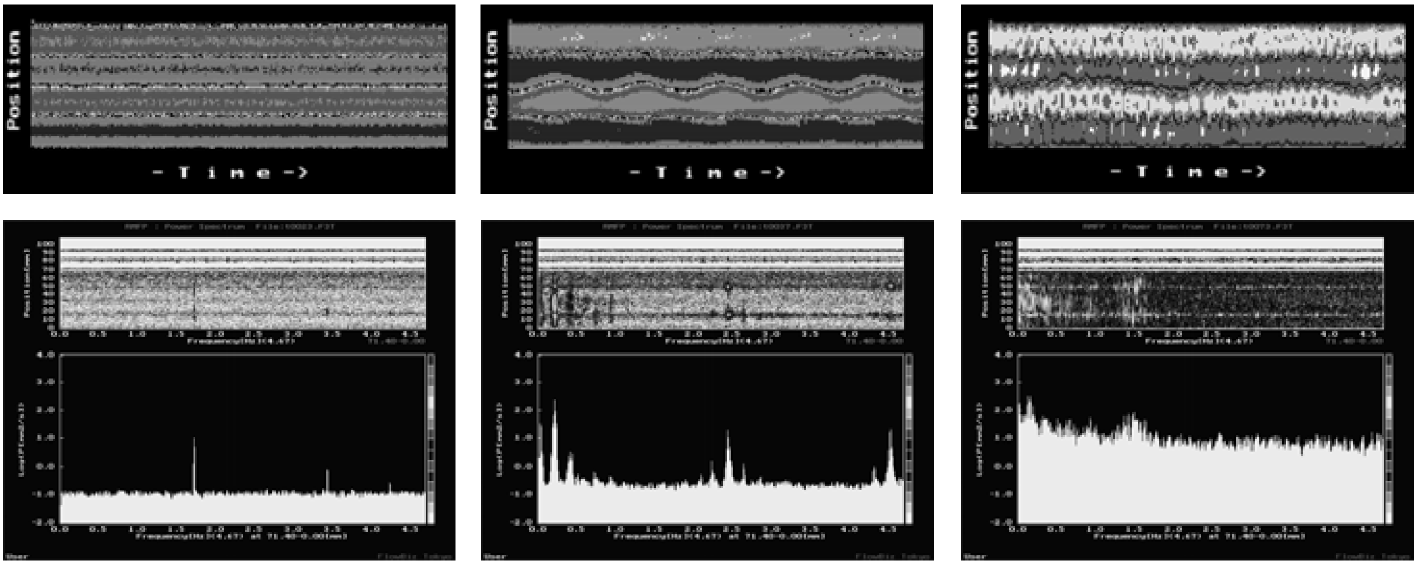


(a) N-4Cell mode, Re=640
(Wavy Vortex Flow)

(b) N-4Cell mode, Re=900
(Modulated Wavy Vortex Flow)

(c) N-4Cell mode, Re=2800
(Turbulence Flow)

Fig. 5 Velocity fields and the corresponding space-averaged power spectra at η=0.667



(a) N-4Cell mode, Re=870
(Wavy Vortex Flow)

(b) N-4Cell mode, Re=1230
(Modulated Wavy Vortex Flow)

(c) N-4Cell mode, Re=2360
(Turbulence Flow)

Fig. 6 Velocity fields and the corresponding space-averaged power spectra at η=0.375

With the increase in Re, the flow instability occurs and deforms the Taylor vortex to produce a time-dependent non-axisymmetric flow called the wavy vortex flow (WVF). With further increasing the Re, an additional wave mode appears which modulates the WVF; this flow is called the modulated wavy vortex flow (MWF).

Fig. 5 and Fig. 6 show the velocity fields and the corresponding space-averaged power spectra in the WVF and MWF and turbulence flow for N-4Cell mode at η=0.667 and η=0.375, respectively. The velocity levels in those figures are represented by the color contour. For WVF, oscillation with basic wave frequency of 1.32Hz is appeared clearly from both velocity field and its power spectra in Fig. 5(a), while the basic wave frequency of 1.6 Hz is observed only from power spectra in Fig. 6(a). With increasing of Re, the basic wave frequency is shifted to higher level. At η=0.667 in Fig. 5(b), the additional frequency of 1.05Hz is appeared together with the existing basic wave frequency of 1.87Hz for Re=900. At η=0.375 in Fig.6(b), the broader shape of power spectra is appeared with increasing of Re upto 1230. Further increasing of Re, flow field become complete turbulence as illustrated in Fig. 5(c) and 6(c). Thus, the characteristics of vortex flow can be obtained by FFT analysis.

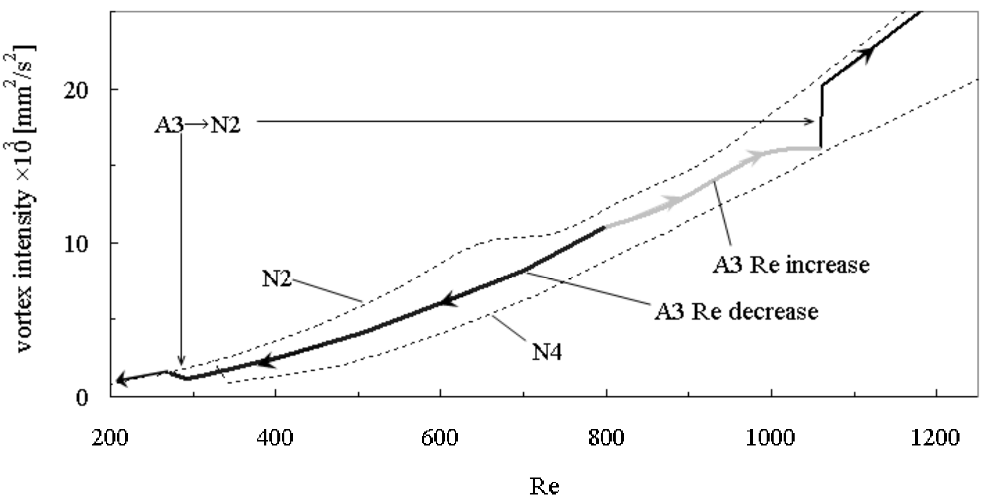


Fig. 7 Influence of bifurcation of Vortex intensity to Reynolds number at η=0.667

Using an ultrasonic velocity profiler, successive instantaneous and mean velocity profiles were obtained.

At N-2Cell mode, there is no significant difference of vortex intensity in the transition with the variation of Re. However the dependency of Re on vortex intensity is observed for N-4Cell and A-3Cell case. For example, Fig. 7 shows the bifurcation of vortex intensity for A-3Cell in term of Re. An upper and lower dotted lines represent vortex intensity for N-2Cell and N-4Cell respectively. With the increase of Re from Re=800, the characteristic of vortex intensity for A-3Cell approaches to the behavior for N-4Cell at Re=1060, then it switches to the behavior for N-2Cell when further increase of Re. During the increasing of Re from 800 to 1060, vortex intensity is departed from the original path at Re =1000. This can be explained by the influence of instability. In the other hand, the vortex intensity for A-3Cell approaches to behavior for N-2Cell when Re decreases. This bifurcation is the irreverible process.

CONCLUDING REMARKS

Spatio-temporal velocity profile of Taylor-couette flow at small aspect ratio was obtained by UVP measurement. Furthermore, the characteristic of each cell modes and spectrum transition of bifurcation were confirmed. Finally, bifurcation in term of Re was clarified by considering the measured vortex intensity.

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