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Visualized Numerical Three-Dimensional Flow Development between Very Short Rotating Cylinders

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The experimental (Benjamin, 1981) and numerical (Pfister, 1988) investigation showed that Taylor vortex flow between two concentric cylinders has variety of flow modes which depend on the length of cylinders and the angular velocity of the inner cylinder. When the aspect ratio defined by the fraction of the gap width between cylinders and the height of cylinders is order of unity, Nakamura et al. (Nakamura, 1996) showed that various flow modes appear. The axisymmetric numerical calculation of Furukawa et al. (Furukawa, 2002) confirmed the unsteady flow found by Nakamura et al. and it also showed the existence of an unsteady mode. However, the fully developed flow is mainly investigated in these studies. In this numerical study, three-dimensional mode formation processes and their final flow modes are predicted.

The governing equations are the three-dimensional Navier-Stokes equations and the equation of continuity represented in the cylindrical coordinate system (r, θ, z). The radius ratio given by (radius of the inner cylinder) / (radius of the outer cylinder) is 0.667, and the outer cylinder is rest and the inner cylinder is suddenly accelerated to a constant angular velocity. The steady and unsteady flows are defined by the profile of torque acting on the outer cylinder, and the variance of the circumferential velocity component is used to determine whether the flow is axisymmetric or not. Volume-averaged enstrophy and energy are used to show the details of the time variations of unsteady flows.

The fully developed flows have the normal 2-cell mode, anomalous 1-cell mode, twin-cell mode and alternate mode. The latter three modes develop via the normal 2-cell modes. The anomalous 1-cell mode with a dominant cell is formed by the collapsing of other cell, and the flow during and after the mode formation process is axisymmetric. The twin-cell mode has two cells in the radial direction, and it appears after one cell of the normal 2-cell mode collapses other cell and the outer cell of the collapsed cells grows once again. The alternate mode has time-dependent variation of flow patterns in the meridional section. At lower Reynolds numbers, the flow changes to wavy after the alternative-mode emerges, and at higher Reynolds numbers, the flow becomes wavy during the collapsing of cells in the normal 2-cell mode. The flow of the alternate mode is the unsteady flow in which the splitting and merging of cells are continued during the collapsing of cells with each other, and it becomes wavy just after the mode formation at entire Reynolds numbers.

The alternate mode has four types. In the first type, the quasi-periodic variation of the enstrophy and energy forms, and a rapid reduction in the variation appears in the type second type. The third type has variations with beats, and the fourth type shows irregular variations. In each type of the alternative mode, the flow has tends to have cells aligned in the axial direction at the maxima of the variation, and cells aligned in the radial direction at the minima.

References

Benjamin, T.B., Mullin, T., 1981, “Anomalous mode in the Taylor experiment,” Proc. Royal Soc. Lnd., A, Vol. 377, 221.

Pfister, G., Schmidt, H., Cliffe, K.A., Mullin, T., 1988, “Bifurication phenomena in Taylor-Couette flow in a very short annulus,” J. Fluid Mech., Vol. 191, 1.

Nakamura, I., Toya, Y., 1996, “Existance of extra vortex and twin vortex of anomalous mode in Taylor vortex flow with a small aspect ratio,” Acta Mechanica, Vol. 117, 33.

Furukawa, H., Watanabe, T., Toya, Y., Nakamura, I., 2002, “Flow pattern exchange in the Taylor-Couette system with a very small aspect ratio,” Phys. Rev. E, Vol. 65.