Bead-like Vortex and Sickle-like Vortex Found around a Thick Rotating Disk in a Casing

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Introduction

Analytical, experimental and numerical studies have been carried out on the flows around a rotating disk and the flows between two rotating disks [1, 2]. These flows are classified into several types. The first type is the flow between a narrow axial gap and the second type is the flow between a wide axial gap. The third type is the flow in the cylindrical casing and the annular cavity, and the fourth type is the flow with bifurcation. The fifth type flow is the rotating flow around the disk in the casing with a radial gap as well as the axial gap.

We numerically study the fifth type of flows. The flow around a disk with a radial gap has been considered by Schouveiler et al. [3], and it is shown the effect of the radial gap is not small. Al-Shannag et al. [4] studied the model of the hard disk drive. They used rotating a hub and attached two disks and assumed the periodicity in the axial direction. The result shows the time-dependent flow. More realistic flow of the hard disk drive has been simulated by Hendriks [5]. The result found that an outward jet flow appears on the rotating disks and Taylor vortices formed between the disk rim and the outer casing are confined by the jet flow.

We have been investigated numerically and experimentally the effect of the radial gap at the low and the middle Reynolds numbers [6, 7]. The disk has a finite thickness. Therefore, Taylor-Couette type vortex flow appear between the disk rim and the side wall of the cylindrical outer casing. When the rotation speed is not small, Taylor-vortex in the radial gap flow makes disturbances at the radial gap. When the axial gap between the disk surfaces and the end walls of the casing are wide, these disturbances are carried out by the inward flow on the stationary end walls of the casing. When the axial gap is narrow, the disturbances are apt to be confined in the radial gap, and a chain of vortices appear around the disk rim.

In this paper, we especially evaluate the flow with narrow axial gaps and investigate the transition of the chain-like vortex flow as the Reynolds number changes.

Formulation
The rough sketch of the flow field investigated is shown in Fig. 1. In this figure, the cylindrical coordinate is \((r, \theta, z)\) and the origin is located at the center of the bottom end wall of the casing. The disk radius and its thickness are \(r_c\) and \(h_d\), and the inner radius and the height of the casing is \(r_c\) and \(h_d\), respectively. The disk is placed at the center of the casing and it is driven by the shaft with the radius \(r_s\). The velocity components in the \(r, \theta, z\) directions are \(u, v, w\), respectively. The reference length is the disk radius and the reference velocity is the azimuthal velocity at the rim of the disk. All physical quantities are made dimensionless by these reference values. The geometrical size investigated in this paper is given by \(h_d = 0.236, h_l = h_u = 0.0394, r_c = 1.118, h_c = 0.315, r_s = 0.0787\) and \(r_d = 1.0\).

The governing equation is the time-dependent incompressible three-dimensional Navier-Stokes equations and the equation of the continuity. The boundary condition is no-slip condition, and the flow is at rest in the initial state. The finite difference method and the fractional step method are used to solve these equations. The grid points in the \(r, \theta, z\) directions are 265, 338 and 81, respectively. We have confirmed that well converged results are obtained by these grid points.

**Results**

When the Reynolds number is small, steady Taylor vortex flow is formed between the radial gap, and no disturbance is found in the flow field.

![Figure 1: Flow field and cylindrical coordinate.](image1)

![Figure 2: Contour of the axial velocity component \(w\) in the \(z\)-plane (Re = 7000, \(z = 0.0984\)).](image2)
Figures 2 and 3 show the contours of the axial velocity component in the $z$-plane and $r$-plane, respectively. At the dimensionless time $t = 70$, vortices about 30 appear around the disk rim. We call this vortex flow a bead-like vortex. After the appearance of the bead-like vortex, the vortices begin to merge and fewer and longer vortices are formed at $t = 230$. Because the shape of the vortex is like a sickle, we call this flow a sickle-like vortex. Figure 3 says that the flow is not symmetric in the axial direction. The time variations of the total energy of $u$ and the torque on the disk surface are shown in Fig. 4. When the flow is bead-like vortex, the variations of the energy and the torque are not large. However, the time variation enlarges when the sickle-like vortex appears.

The contour of the axial velocity component at $Re = 8000$ is shown in Fig. 5. The flow is symmetric in the axial direction and no transition to the sickle-like vortex is observed.

The diagram of flow transition is shown in Fig. 6. In this figure, the gray region shows no vortex flow, the yellow region shows a flow that transits from the bead-like vortex to the sickle-
Figure 6: Transition of the flow patterns with the Reynolds number.

like vortex, the red region shows the bead-like vortex appearing symmetrically in the axial direction. The green region represents the flow in which the spiral rolls with negative front angle near the disk rim, as well as the bead-like vortex, appear. The blue region and the violet region shows the spiral rolls and the turbulent flow. The numbers shown in the figure denotes the number of beads, sickles or spiral rolls found in the flow. In the yellow region, the upper is the number of beads and the lower is the number of sickles, and in the green region, the upper and lower show the numbers of beads and spiral rolls, respectively. From this diagram, we can say that some critical Reynolds numbers exist, that divide the appearance of the flow transiting to the sickle-like vortex, bead-like vortex, and the flow with spiral rolls.

References


