FLOW INSTABILITY BETWEEN SHROUDED COROTATING DISKS

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Abstract

As a simplified model of a magnetic disk drive for a micro-computer, a body force instability of flows between shrouded corotating disks has been investigated. The hot-wire measurements as well as the numerical simulation have been conducted. The measurement of disk vibration revealed the role of the feedback loop of elastic vibration and flow instability for establishing disk flutter.

Key Words: body force instability, hard disk drive, disk flutter, rotating disk

1. Introduction

As a simplified model of hard disk drives (HDDs), the flow instability between corotating disks within a stationary cylindrical enclosure has been investigated. With increasing access speed and truck density, the problems of flow-induced vibration are becoming crucial(1). Although the coupling of the elastic vibration of a rotating disk and the unsteady motion of the surrounding fluid via unsteady fluid dynamic force are essential for disk flutter problem, it has been usually treated as an elastic problem with paying little attention to the details of fluid motion.

In this paper, the flow instability and the disk vibration are discussed on the bases of the hot-wire measurements as well as the numerical simulations.

2. Geometry and Controlling Parameters

The flow geometry and coordinate system are given in figure 1. A number of disks of the outer radius R_2 are cramped co-axially onto the axis with constant spacing H and a small gap “a” between the shroud surface. The angular velocity of rotation are denoted by Ω. The controlling parameters are Reynolds number $\mathrm{Re} = \Omega R_2^{\,2}/\nu$ and geometrical parameters, H/R_2 and a/R_2.

For sufficiently high Reynolds number, the terms of $O(\mathrm{Re}^{-1/2})$ can be neglected, resulting in the inviscid equations. They admit two solutions(2), a) $v_r = v_z = 0$, $v_\theta = r$ (solid body rotation) and $v_r \neq 0,\ \ v_\theta = \dfrac{C}{r}\ \ v_z = 0$ (free-vortex like)

The base flow is constructed with the core region given by these inviscid solutions and thin viscous layers on the shroud and disk surfaces.

3. Results and Discussions

3.1 Mean velocity field

The measurements were performed by employing the large scale test rig as shown in figure 2. The specially designed double-sensor hot-wire probe was employed to obtain radial and tangential velocity components. The numerical simulations were based on the Reynolds averaged Navier-Stokes equation together with the Reynolds stress equation model of Gibson and Launder⁽⁶⁾.

Figure 3 shows the tangential velocity component at the center plane between the disks for five different rotational speeds. The solid body rotation in the inner region($r/R_2 < 0.7$) as well as the free-vortex like flow in the outer region($r/R_2 \geq 0.7$) can be recognized.

Numerically simulated streamlines given in figure 4 indicate a pair of counter rotating closed streamlines of the toroidal vortices in accordance with the hot-wire measurements. This vortex system becomes unstable above certain Reynolds number and may exert velocity and pressure fluctuations.

3.2 Large scale vortical structure

The time traces of the velocity fluctuation at $z/H = 0.5$ and $r/R_2 = 0.84$. are given in figure 5. The periodic fluctuation at the high rotational speed inferres the establishment of large scale vortical structure proposed by Lennemann⁽³⁾ and Abrahamson et al.⁽⁴⁾.

Wave number of the vortical disturbance obtained from the two-point velocity correlation together with the previous investigations are compiled in figure 6. All the data sets show the common tendency of decreasing wave number with increasing Reynolds number. According to the flow regime proposed by Abrahamson et al.⁽⁴⁾, modern commercial 2.5in and 3.5in HDDs fall in the alternating or indeterminate regime in which the vortical structure is itself unstable. The instability has been found in some experiment at Reynolds number below 6000, while the DNS shows that it can not be found until Reynolds number exceeds 22000. The discrepancy may be partly due to the undefined disturbance in the experiment and partly due to the numerical diffusion in the DNS.

3.3 Flow instability and disk flutter

The velocity fluctuation as well as the disk vibration have been measured by employing the axisymmetric model of commercial 3.5in ten-decker disk drive. The power spectrum of the vibration signal given in figure 7 shows five broadband peaks corresponding to the disk vibration, which are coincident with the eigen frequency of elastic vibration obtained by the FEM analysis. Figure 8 is the corresponding spectrum of velocity fluctuation. The peak frequencies coincide almost exactly with the first four eigen frequencies of the disk vibration.

Since the velocity of the surface movement is negligibly small, it is clear that the velocity fluctuation is not a simple consequence of mass continuity and change of volume. 3.5in HDD lies out of stable vortex regime and the flow instability may accept disturbances of wide range of frequency. Assuming that the wave number lies between 6 to 8 and rotational speed lies between 60 to 70% of Ω, the frequency of the instability can be estimated in the range of 430 to 670Hz. It may be inferred that the flow instability accepts the infinitesimal disturbance due to disk vibration, attains energy and grows to significant amplitude. Resulting fluctuation exerts unsteady fluid dynamic forces on the disk and acts as the external forcing of elastic vibration. This feedback loop may be essential for establishing disk flutter.

4. Conclusions

(1)Flow regions proposed previously have been confirmed by experiment and numerical simulation.

(2)Wave number and phase velocity of the large scale vortical structure decreases with increasing disk speed.

(3)Spectrum of disk vibration and velocity fluctuation coincide well, suggesting the importance of the feedback loop of elastic vibration and flow instability.

5. Literature

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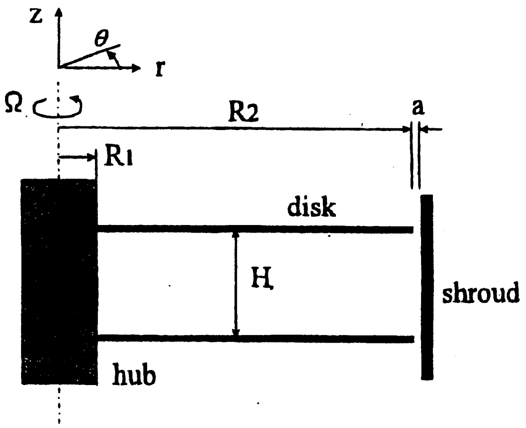

Fig.1 Geometry and coordinate system.

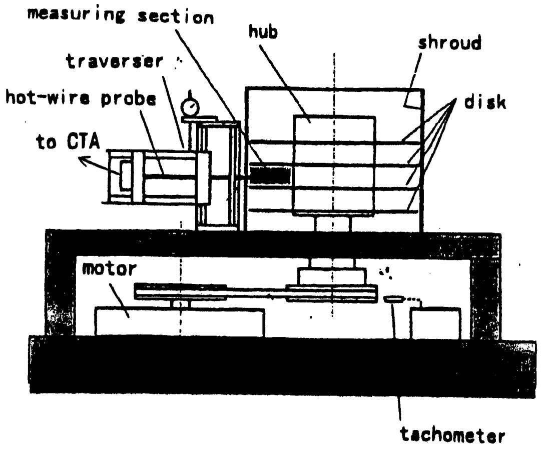

Fig.2 Large scale test rig.
$(R_2 = 178mm, H = 22.6mm, N = 300 - 2400rpm)$

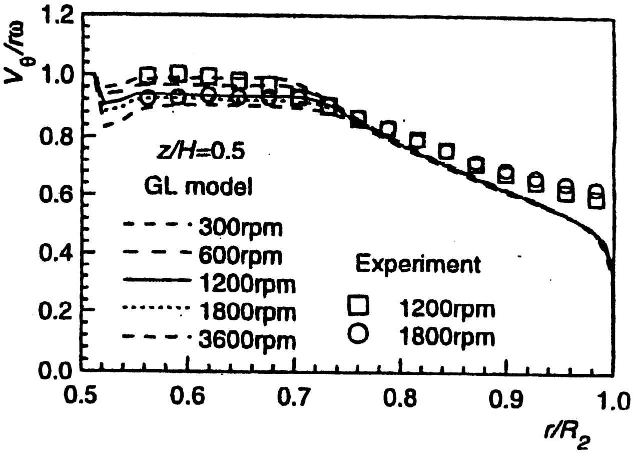

Fig.3 Tangential velocity component in center plane between disks.

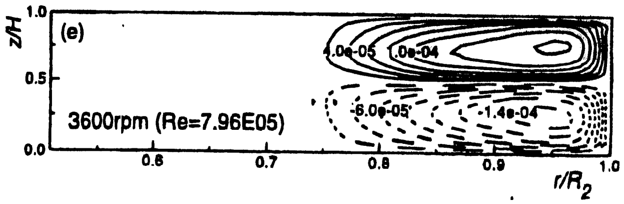

Fig.4 Numerically simulated streamlines of toroidal vortices projected onto the meridian plane.

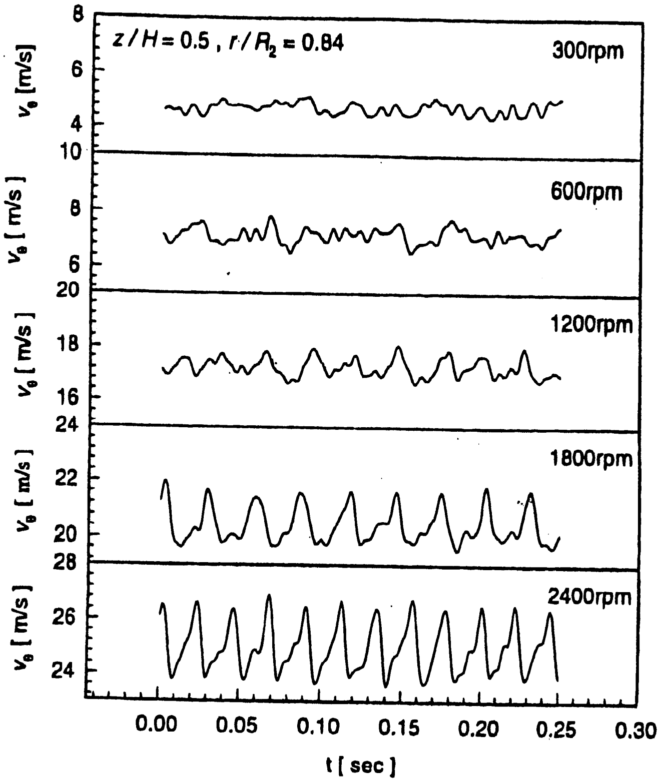

Fig.5 Time traces of velocity fluctuation in the center plane

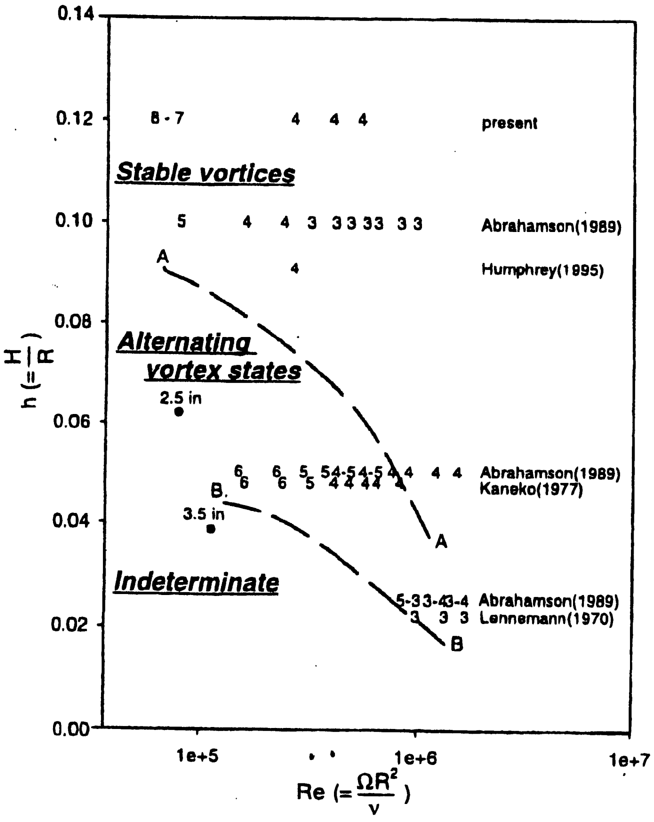

Fig.6 Circumferential wave number of the large scale vortical structure.

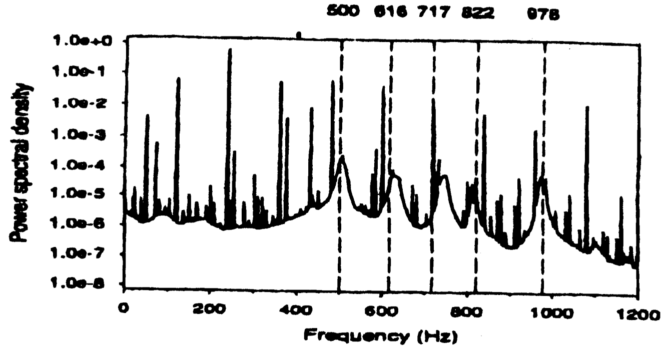

Fig.7 Spectrum of disk vibration of 3.5in HDD

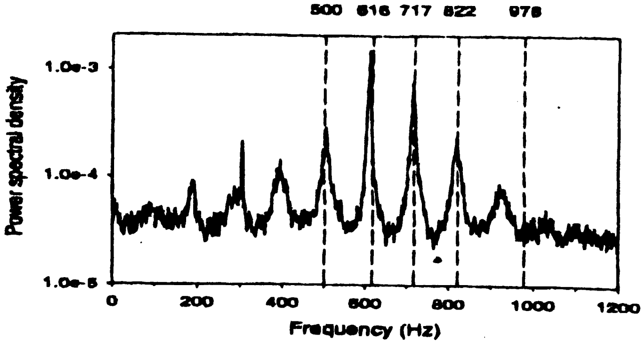

Fig.8 Spectrum of velocity fluctuation between disks of 3.5in HDD.