An experiment on the flow in a hard disk drive

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ABSTRACT

The authors attempt flow and thermo visualizations on a real HDD. Additionally, the authors attempt measurements based on UDM (Ultrasonic Doppler Method), using a geometrically-symplified model. Thermo visualizations shows no obvious increase of disk-surface temperature during first 60[min.]. We confirm the existence of the solid-rotation core with some obstructed flows. But, there is no core at higher brockage ratio of the obstruction. The comparison between LDV and UDM shows the effectivity of UDM. Using UDM, the authors showed the disk flow, qualitatively.

Keywords: HDD, UDM, UVP, Disk flow, Rotating disk, Flow visualization, and Thermal image

1. INTRODUCTION

Hard-disk drives are the most popular storage devices in modern PCs. Recently, for higher speed and higher capacity, the accurate positioning operation of read/write magnetic heads becomes required. As the inside flow often causes pressure and velocity fluctuations, more accurate research have been needed.

Our present interest is the flow between two disks. Namely, we consider a pair of disks of the same radius in a stationary cylindrical enclosure. Disk spacing is much narrower than disk radius. Disks are connected with a common shaft, and corotate. Such a flow is often non-axisymmetric, and consists of two regions, that is, the region in solid-body rotation and the region of secondary flow. Until now, various studies have been carried out in order to resolve the flow. For example, Gor et al. (1994) measured the combined effect of an obstruction which is inserted from the enclosure, using a laser Doppler anemometry. Recently, Suzuki and Humphrey (1997) have performed three-dimensional numerical simulations for corotating-disks flow with two types of obstructions, such as a magnetic head arm support and an air lock.

There have been no experiments on real devices. So, in the present work, the authors attempt flow and thermo visualizations on a real HDD. Additionally, because there have been less experiments (for example, hot-wire, LDV and flow visualization), the authors attempt measurements based on UDM (Ultrasonic Doppler Method), using a geometrically-symplified model.

2. REAL DISK-DRIVE UNIT TEST

2-1. EXPERIMENTAL METHOD

2-1-1. Apparatus

Configuration of experimental apparatus is shown in Fig.1. Flow visualizations are performed with an obstructed or an unobstructed configuration. A real hard-disk drive used in the present work rotates at 7,200rpm (Re=1.13 × 10^5, $\delta = G/R_d$=0.0423 and $\lambda = R_w/R_d$=1.0. For definitions, see below.). An original enclosure wall and rotating disks are replaced by acrylic ones, for observation. An obstruction is simplified by removing fine parts such as magnetic heads. The obstruction is joined with adhesive on the enclosure-wall. A high-speed video camera is used.

2-1-2. Parameters

Important parameters are as follows (see Fig.2).
Reynolds number based on the disk radius is

$$Re = \frac{\omega R_d^2}{\nu}. \quad (1)$$

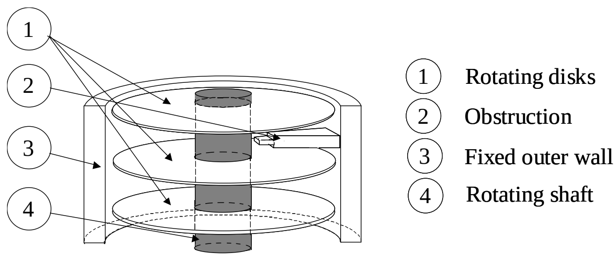
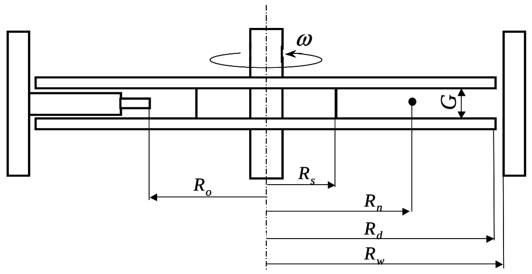
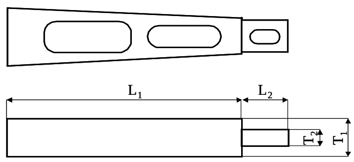


Fig.1. Schematic diagram of HDD.



G : gap
R_d : radius of rotating disk
R_s : radius of shaft
R_w : radius of fixed outer wall
R_o : radius to an obstruction tip
R_n : radius to a nichrome smoke wire
ω : angular velocity

Fig.2. Definitions of experimental parameters.



(a) top view

(b) side view

Fig.3. Parameters of obstruction.

The ratio of gap to disk radius is

$$\delta = \frac{G}{R_d}. \quad (2)$$

In this work, δ=4.23×10^{-2}.

Dimensionless radius of the enclosure-wall is

$$\lambda = \frac{R_w}{R_d}. \quad (3)$$

In this work, λ 1 and $(R_w-R_d)/R_d$=0.004.

The obstruction is shown in Fig.3. Dimensionless length of the obstruction is

$$\alpha = \frac{L_1 + L_2}{R_d}. \quad (4)$$

Blockage ratio of the obstruction is

$$\beta = \frac{L_1T_1 + L_2T_2}{R_wG}. \quad (5)$$

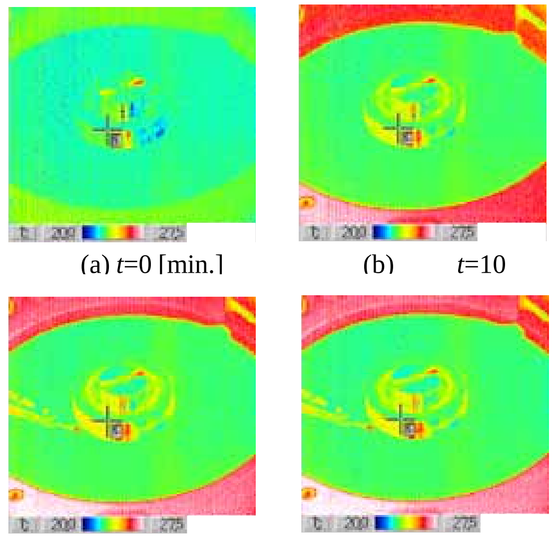
2-1-3. Thermo-visualization procedure

In order to observe the surface temperature on the real disk unit, we try thermal-image measurements. Pictures are taken at a frame rate of 120[fps]. We remove a top plate covering the device interior, and replace the special glass plate through which infrared rays pass efficiently.

2-1-4. Flow-visualization procedure

We lighted up by a halogen lamp, which is fixed as to prevent the reflection. The device has three disks. So, we have painted a middle disk black, and visualized an upper disk space. Flame rate of the camera is 6,000[fps]. In order to confirm the accuracy of the frame rate, we have checked the position of a mark on the disk.

The smoke-wire method is adapted, using liquid paraffin. We used a pair of nichrome wires twisted (diameter: 0.2mm), for more smoke. We take pictures at the time enough after the starting up.



(a) t=0 [min.] (b) t=10

(c) t=30 (d) t=60 [min.]

Fig.4. Surface temperature on a rotating disk of a

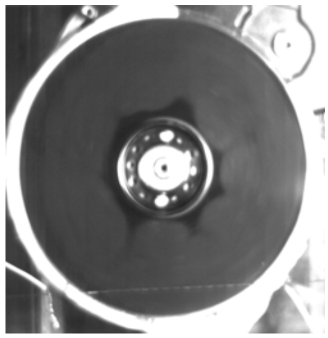


Fig.5. Visualization without obstruction (Re=1.13×10^5).

We drilled two 0.5mm holes on the enclosure wall, for the nichrome wire. The position of the nichrome wire is at R_n/R_d=80%.

2-2. RESULTS AND DISCUSSION

2-2-1. Disk-surface temperature

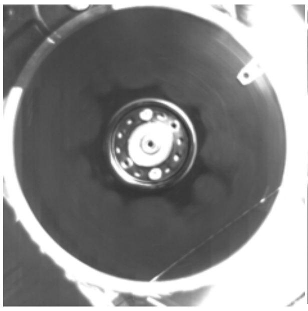
We observed disk-surface temperarure during 1 hour after the starting up. Results are shown in Fig.4. Here, temperature is not absolutely but relatively, in exact meaning. The enclosure-wall temperature increases by about 3 degrees after 30 minutes later. But, we can observe no clear increase of disk-surface temperature during 60[min.].

2-2-2. Unobstructed Flow

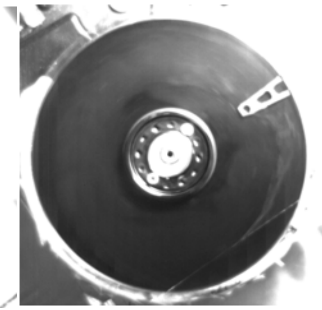
Fig.5 shows a steady state at the time enough after the starting up. We are able to confirm the existence of a solid-body-rotation core. The core is almost polygonal with 6 to 7 apexes (circumferencial mode 6 to 7).

2-2-3. Obstructed Flow

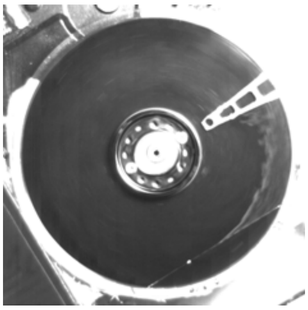
Fig.6 shows obstructed flows with the obstructing length α=20, 40 and 60%. The obstruction is about 90° downstream from a nichrome wire. The core size in Fig.6(a) (α=20%) is roughly the same as that in Fig.5.



(a) α=20%, β=11%



(b) α=40%, β=31%



(c) α=60%, β=50%

Fig.6. Visualization with obstruction (Re=1.13×10^5).

In Fig.6 (b) (α=40%), we can see the core, but the core dimension is much smaller than those in Fig.5 and Fig.6(a). It is difficult to determine the circumferential mode, because the apexies disappear just downstream the obstruction.

In Fig.6(c) (α=60%), we can not see the core. On the upstream of a thick part of the obstruction, smoke stagnates. On the other hand, there is no smoke on the upstream of a thin part of the obstruction. Humphrey et al. (1997) reported that there exists a reversed flow region on the immediate downstream of the obstruction. However, we couldn't confirm the reversed flow.

3. MODEL TEST

3-1. Experimental Method

For UDM measurements (Takeda, 1986), we use a geometrically simplified apparatus, which is made of acrylic resin. We use three UDM transducers in order to measure three velocity components u_r, u_θ and u_z. As particles to reflect ultrasonic waves, we use polyethyrene beads, whose specific gravity is 0.918, and whose mean diameter is 12µm. To measure the radial velocity u_r, one transducer is fixed outside the enclosure-wall toward the centre. To measure the circumferencial velocity u_θ, another transducer is fixed outside the enclosure wall eccentrically. To measure the axial velocity u_z, the other transducer is above the rotational disk.

3-2. RESULTS AND DISCUSSION

We conducted LDV (Laser Doppler Velocimetry) measurements and UDM measurements, simultaneously, in order to check UDM accuracy. We measured the circumferential velocity u_θ (shown in Fig.7). Vertical axis is dimensionless time-mean circumferencial velocity. Horizontal axis is dimensionless radial position. UDM results agree well with LDV results.

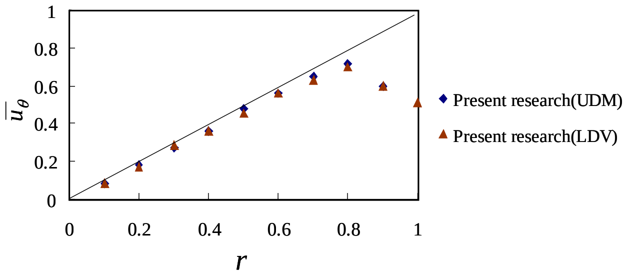


Fig.7. Comparison UDM with LDV at z=0.5 (Re=1.0×10^5, λ=1.0, δ=0.3, mode4).

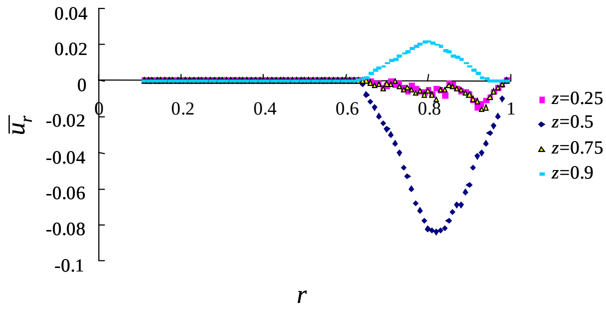


Fig.8. Velocity u_r by UDM at z=0.25~0.9 (Re=5.0×10^4, λ=1.0, δ=0.2, mode5 to 6).

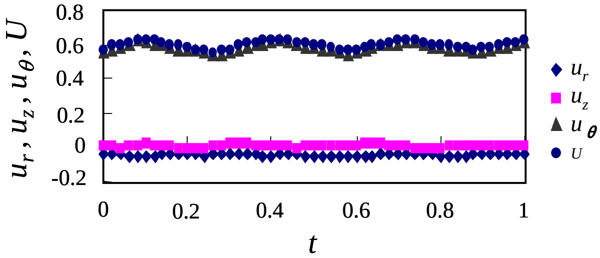


Fig.9. Time histories of velocity components by UDM at r=0.9, z=0.5 (Re=1.0×10^5, λ=1.0, δ=0.3, mode4).

Fig.8 shows radial velocity profiles at several vertical positions. Vertical axis is dimensionless mean radial velocity. Horizontal axis is dimensionless radial position. It is confirmed that centripetal flow exists near a midplane between disks, and centrifugal flow exists near disk-surfaces.

Fig.9 shows radial, axial and circumferencial velocities at r=0.9 and z=0.5. Vertical axis is instantaneous dimensionless velocities. Hrizontal axis is dimensionless time. We can confirm that periodic fluctuations correspond with the circumferencial mode.

4. CONCLUDING REMARKS

The following conclusions are obtained.

1. We can observe no obvious increase of disk-surface temperature during first 60[min.].
2. We confirm the existence of the solid-rotation core at α=0, 20 and 40% (at β=0, 11 and 31%, respectively). But, there is no core at α=60% (at β=50%).
3. The comparison between LDV and UDM shows the effectivity of UDM. Using UDM, we observed the disk flow qualitatively.

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