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PRESSURE-SENSITIVE PAINT MEASUREMENT ON CO-ROTATING DISKS

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ABSTRACT

There appears fluttering phenomena in a hard disk drive system with high-speed disks rotating inside a closed space, leading to degrade of reading and writing performance. The precise pressure distribution on the disk may improve the performance, but there has been no report because it is very hard to measure the surface pressure using conventional techniques, such as pressure taps. While pressure sensitive paint (PSP) seems to be suitable for the pressure measurement on the disk, we have to compensate its highly temperature-sensitive characteristics of PSP, because the temperature distribution on the disk is not assumed to be uniform. We employed $PySO_3H$ based PSP, which has small temperature sensitivity, and have obtained the pressure distribution on the disk rotated at various speeds (10000-20000 rpm) successfully. The result showed that the pressure is higher at the disk outside than at the center, and forms a concentric circle distribution. Moreover, we found that the pressure difference between the inner and outer region of the disk increases as a square of disk rotation speed.

INTRODUCTION

Recently, a hard disk drive (HDD) is installed in many devices like a personal computer, a car navigation system and so on. In a HDD, data are read from/written to a rotating magnetic disk with a magnetic head. Therefore, high-speed and stable disk rotation holds the key to improve performance of a HDD such as high-speed access and high reliability. It is well known that high-speed disk rotation causes disk flutter and there has been a great discussion on this fluttering phenomenon [1–6]. For example, Abrahamson et. al. [1] researched on the structure of flow fields between disks by changing the disk rotation speed in water. Schuler et. al. [2] investigated the flow structures at relatively low Reynolds number ($Re_R \equiv \omega R^2/\nu < 10^5$). However, in view of the fact that the flutter phenomenon is a coupled problem between fluids and structures, the problem is still controversial. This is why we measure the pressure on a rotating disk in HDD. Pressure taps are usually used to measure the pressure on a solid surface. However, the method is unsuitable for a hard disk because it is difficult to install pressure taps in thin objects and to apply them to rotating objects owing to the wirings. Therefore, we focused on the measuring technique using pressure-sensitive paint (PSP) [7–10]. This is one of non-contact methods based on the interaction between luminophore and oxygen molecules. We have to compensate temperature dependency of PSP because the temperature distribution on a rotating disk cannot be assumed uniform. In this paper, by using $PySO_3H$ based PSP, which has small temperature dependency, we obtain the time-averaged pressure distribution on a rotation disk and consider the effect of the disk rotation speed on pressure distribution.

NOMENCLATURE

A,B,C	Stern-Volmer coefficients
P	pressure
I	luminescent intensity
$Re \equiv \omega Rh/\nu$	Reynolds number
ω	angular velocity
R	disk radius
h	disk-to-disk spacing
ν	kinematic viscosity
subscriptions:	
ref	reference conditions of PSP

PHOTOPHYSICAL PROPERTY OF PSP

The pressure measurement technique using PSP is based on oxygen quenching of luminescent molecules. When the PSP layer applied to a surface is illuminated with light of a proper wavelength, light of a longer wavelength emitted from PSP. Since the luminescence is quenched by oxygen molecules, the luminescent intensity decreases as an increase in partial pressure of oxygen. Pressure on the solid surface can be derived from the relation between the pressure and the luminescence intensity (Stern-Volmer plot) [11].

$$\frac{I_{ref}}{I} = A(T) + B(T)\left(\frac{P}{P_{ref}}\right) + C(T)\left(\frac{P}{P_{ref}}\right)^2 \quad . \qquad (1)$$

The Stern-Volmer coefficients have temperature dependence, because the radiationless deactivation and the oxygen coverage on the PSP surface are temperature-dependent. Hence, the calibration test has to take into account of the temperature dependence

TEMPERATURE DISTRIBUTION ON A ROTATING DISK

We measure the temperature distribution on a rotating disk. Figure 1 and Table 1 show the cross-sectional view and the detail size of our HDD, respectively. Three disks were set to the HDD concentrically. By using a quartz disk as the top disk, we have obtained the temperature distribution on the middle disk by an IR camera (NEC Avio Infrared Technologies, TVS-8502). We kept the ambient temperature 293 K during the experiment. The temperature distribution on the middle disk rotating at 20000 rpm is shown in Fig. 2. This figure shows that the temperature exhibits a concentric circle distribution and the temperature difference on the disk is ca. 2 K. Because this temperature difference causes critical error in PSP measurement, we need to exclude the effect for high accuracy pressure measurement.

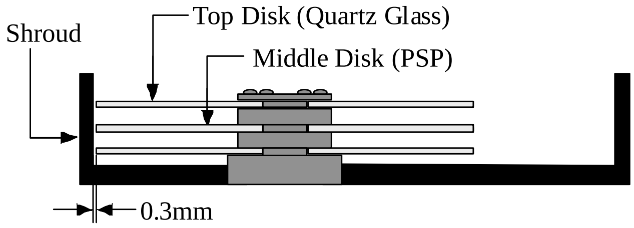

FIGURE 1: CROSS-SECTIONAL VIEW OF HDD

TABLE 1: GEOMETRIES OF HDD

Disk diameter		95 mm
Number of disks		3
Disk material	Top	Quartz glass
	Middle, Bottom	Aluminum
Disk thickness	Quartz glass disk	1.25 mm
	Aluminum disk	0.8 mm
Disk-to-disk spacing		2.65 mm
Disk-to shroud spacing		0.3 mm

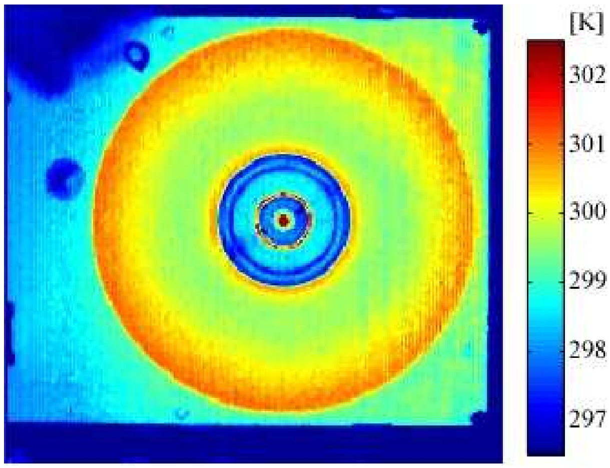

FIGURE 2: TEMPERATURE DISTRIBUTION ON THE MIDDLE DISK AT 20000 RPM

EXPERIMENTAL APPARATUS AND CALIBRATION

Formulation of PSP

We employed a pyrene sulfonic acid ($PySO_3H$) as a luminophore of PSP to eliminate the error due to the temperature distribution on the rotating disk. $PySO_3H$ based PSP is known to have two luminescent peaks (a monomer and an eximer peak) which have an opposite temperature dependency. When we measure at an appropriate wavelength band, luminescent intensity is independent of temperature [12]. We adopted a TLC (Thin Layer Chromatography) plate as a

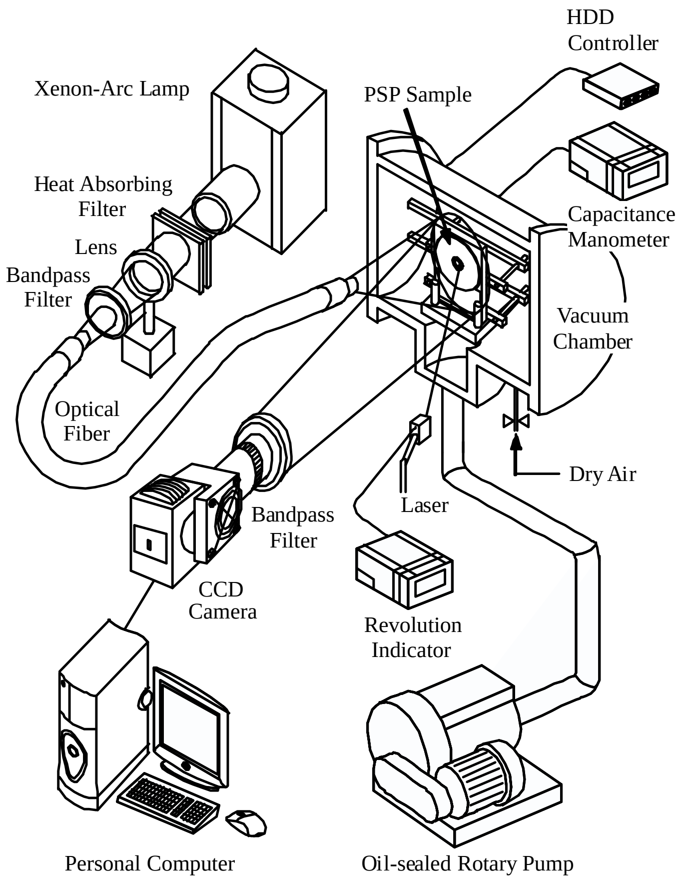

FIGURE 3: EXPERIMENTAL APPARATUS

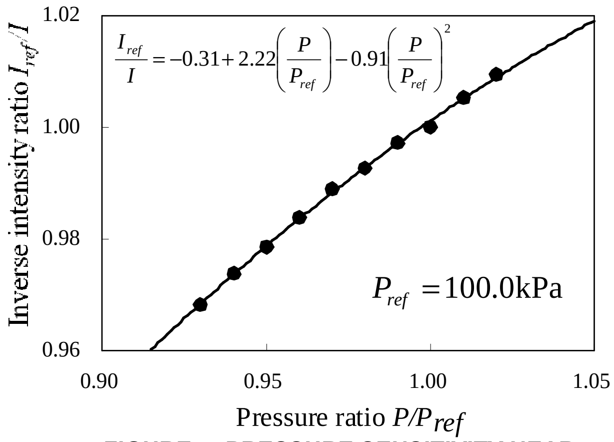

FIGURE 4: PRESSURE SENSITIVITY NEAR ATMOSPHERIC PRESSURE

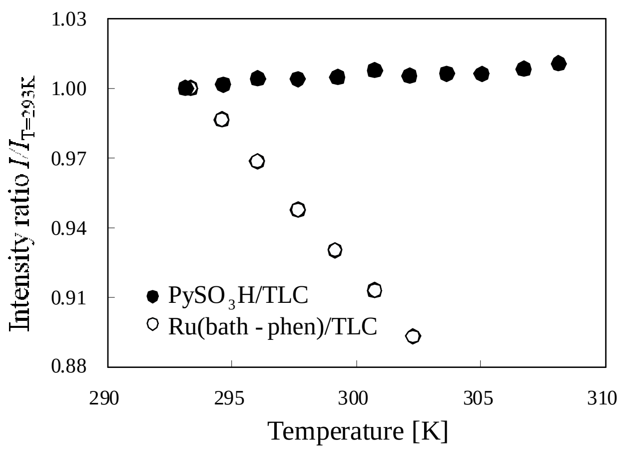

FIGURE 5: TEMPERATURE CHARACTERISTIC NEAR ROOM TEMPERATURE

binder. After bonding $PySO_3H$ on it by dipping in $PySO_3H$−acetone solution for 5 min, we pasted it on an aluminum disk.

Experimental Apparatus

Figure 3 shows a schematic image of the experimental apparatus composed for this study. The PSP sample was set inside a vacuum chamber. The air in the vacuum chamber was evacuated by an oil-sealed rotary pump. After that, monitoring by a capacitance manometer, the pressure in the vacuum chamber was controlled by supplying dry air (O_2 21%, N_2 79%). A xenon arc lamp (Ushio, UI-502Q) with a band-pass filter (350±20 nm) was used as an excitation light source illuminating the sample via an optical fiber. The luminescence from PSP was filtered by a band-pass filter (470±20 nm) to eliminate the light from the xenon lamp and was detected by a CCD camera (BITRAN, BU-52LN-F). The temperature of CCD was cooled to 253 K and the exposure time was 2.0 sec. Disk rotation speed was controlled by a motor driver with measuring by a photoelectric sensor.

Pressure Sensitivity and Temperature Dependency

Figures 4 and 5 show the pressure sensitivity near an atmospheric pressure and the temperature dependency of the luminescent intensity near room temperature of $PySO_3H$/TLC, respectively. For comparison, the characteristic of bathophen ruthenium (Ru(bath-phen)) based PSP, which is widely used, is also shown in Fig. 5 . The luminescent intensity was well fitted by Eqn.(1) near an atmospheric pressure as shown in Fig. 4. Figure 5 shows that luminescent intensity change caused by temperature was about 0.07 %/K at the temperature range from 293 to 303 K.

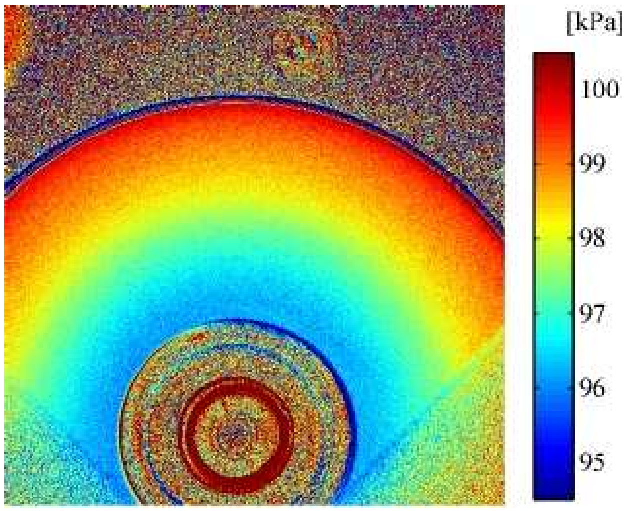

FIGURE 6: PRESSURE DISTRIBUTION ON THE MIDDLE DISK AT 20000 RPM

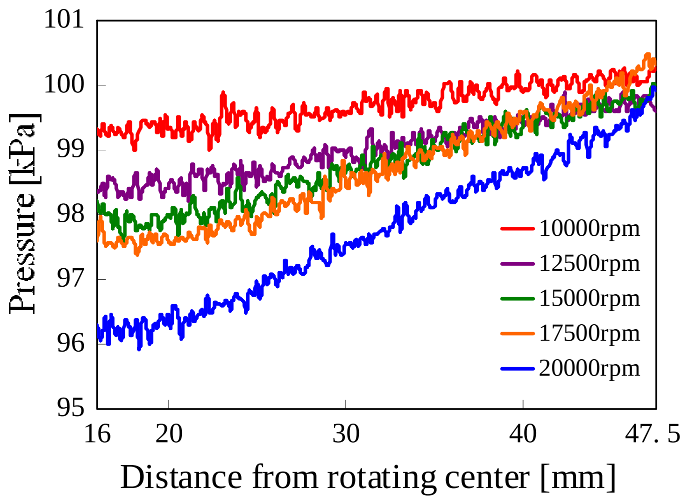

FIGURE 7: RADIAL PRESSURE PROFILES AT VARIOUS DISK ROTATION SPEEDS

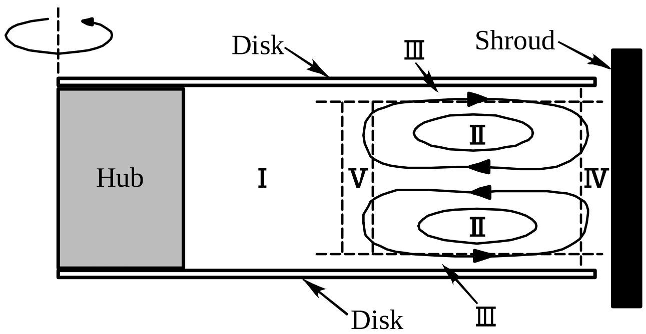

FIGURE 8: SCHEMATIC OF FLOW BETWEEN DISKS [3]. (I)SOLID-BODY ROTATION REGION; (II)THREE-DIMENSIONAL FRICTIONLESS POTENTIAL CORE; (III)EKMAN BOUNDARY LAYERS; (IV)SHEARED LAYER ALONG SHROUD; (V)FREE SHEAR LAYER.

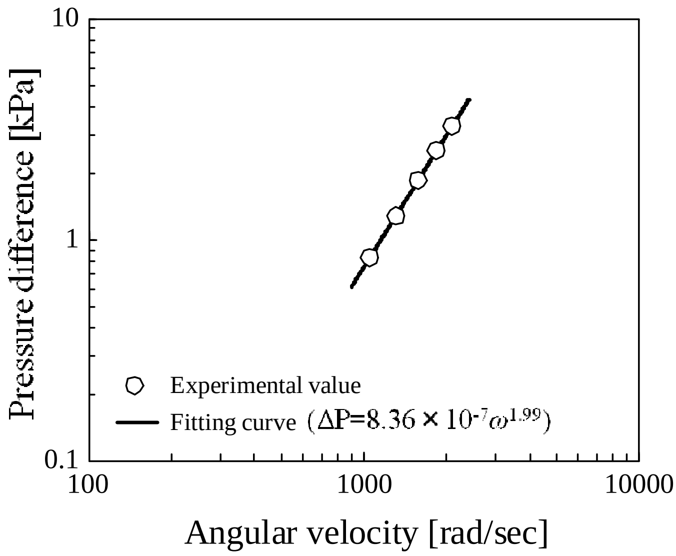

FIGURE 9: RELATION BETWEEN PRESSURE DIFFERENCE AND ANGULAR VELOCITY

PRESSURE DISTRIBUTION MEASUREMENT

When the disk rotated at 10000−20000 rpm, 64 images were taken. By averaging these images, we obtained the test image. With images taken under the constant pressure condition, the reference image was obtained in a similar way. With these two images and the Stern-Volmer coefficients obtained from the calibration experiment, pressure distributions were calculated from Eqn.(1).

The time-averaged pressure distribution on the middle disk at 20000 rpm is shown in Fig. 6. From this figure, we can see the pressure distribution forms a concentric circle distribution. Similar distributions are also observed at other rotation speeds. Moreover, Fig. 7 shows a radial pressure profile with various disk rotation speeds. As Fig. 7 shows, the pressure is higher at the disk outside than at the center. Pressure at outer region of the disk approaches to a surrounding pressure at any rotation speeds. Several studies revealed that the flow near the rotating disk is divided into two flow regions called the solid-body rotation region and Ekman layer ((I) and (III) in Fig. 8). According to the measurement by hot-wire probe [5] at $Re=3.4\times10^4$, 5.2×10^4 and by LDV (Laser Doppler Velocimetry) [13] at $Re=1.7\times10^3$, 3.3×10^3, the fluid near the disk rotated without radial velocity in the solid-body rotation region and with a little radial velocity in Ekman layer from the viewpoint of mean flow. Judging from these results, we can assume that the mean flow near the disk almost rotates with the disk in the Reynolds number range we treated (Re=8.7×10^3, 1.7×10^4). The pressure gradient is radically caused as a centripetal force. The rotation motion of the fluid was strengthen with an increase of a disk rotation speed and it followed that greater pressure gradient occurred.

We note the relation between the angular velocity and the pressure difference between the outer part and the inner part of the disk. We define a pressure difference as the averaged pressure difference between 44.5−47.5 mm and 16−19 mm to reduce the measuring error caused by the shadows of the top disk and the clump which fixes disks to HDD. In Fig. 9, we took the pressure difference and the angular velocity as a vertical and a horizontal scale in logarithmic display, respectively. Figure 9 shows that experimental values show a polynomial trend and the gradient was 1.99 calculated by least squares approximation. The result indicates that the pressure difference increases as a square of a disk rotation speed. This is valid because pressure difference has $[L^{-1}MT^{-1}]$ dimension and angular velocity has $[T^{-1}]$ dimension.

CONCLUSIONS

By applying PSP to a disk in HDD, we measured pressure distribution on the rotating disk. The following concluding remarks are obtained:

1. By using temperature low dependency PSP using $PySO_3H$ as luminophore, we have successfully obtained pressure distributions on the rotating disk in HDD at various rotation speeds
2. The pressure is higher at the disk outside than at the center, and forms a concentric circle distribution. At any rotation speeds, the pressure at outer region of the disk approaches to a surrounding pressure
3. The pressure difference between the inner and outer region of the disk increases as a square of a disk rotation speed.

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