The Effects of Unsteady Flow on the Slider Vibration in a Hard Disk Drive

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***Abstract*--In this work, air flow induced vibration of the slider in a hard disk drive has been investigated experimentally. Flow fluctuations were measured upstream and downstream of the slider with a single, constant temperature hot wire anemometer. Displacement of the slider was measured with a laser Doppler displacement meter. Two unsteady flow phenomena that can affect slider vibration in the plane of the disk were studied: the vortex shedding from the slider and periodic flow fluctuations caused by disk hub geometry. Vortex shedding of relatively low frequency from the slider is shown to occur in a range of the disk speeds and slider positions. The periodic pressure fluctuation caused by airflow over a particular geometry of disk hub was found and its influence on the slider vibration has been measured at various disk speeds and slider positions.**

I. INTRODUCTION

The demands for higher recording density and performance in hard disk drives (HDD) require highly accurate head positioning and increasing the number of tracks per inch (TPI) on disk surface. The track density of current commercial magnetic disk drives exceeds 10,000 TPI and is projected to exceed 25,000 TPI by the next century. Track misregistration errors of the heads

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must be reduced to achieve these very high track densities.

The airflow induced by rotation of a magnetic recording disk in HDD is of particular interest because the unsteady flow can excite vibration of the recording head-suspension assembly. Many contributions to the understanding of the airflow in HDD have been forthcoming. Early work on the characterization of the flow between corotating disks was conducted by Lennemann [1]. He observed the existence of an inner region of laminar flow with a polygonal boundary which rotated slightly slower than the disks. Abrahamson, Koga and Eaton found that the polygonal shape of the laminar region was related to two dimensional vortices in the outer region of the disks [2]. The effects of disk speed and disk spacing on the number of vortices and mean radius of the laminar region was studied in this report. It was found that fluctuation of the tangential air velocity in corotating disks has a local maximum near the boundary of the laminar region [3]. The effects of suspension arm, located between disks in a disk stack, on the flow have been investigated experimentally and numerically [4]-[7]. Although their studies on the flow in corotating disks contributed to the problems of heat transport and contaminants removal, the explicit effect of the air flow pressure fluctuation on the vibration of the slider / head suspension assembly was not addressed. The effect of air flow in a hard disk drive on the vibration of suspension was investigated [8]. They found that the vibration amplitude of the suspension was proportional to the square of the approaching air velocity. In their subsequent studies, flow fluctuation in the wake of the suspension was measured using hot wire techniques and its effect has been studied [9],[10]. They also proposed a numerical, pseudo three dimensional, flow model describing the flow around the suspension to aid the evaluation of flying height fluctuation and positioning error. It was found from their work that the suspension vibrates at its natural frequencies, even though the frequency spectrum of flow pressure has different dominant frequencies. It is also found from their work that the flying height fluctuation can be reduced by using aerofoil type suspension. However, the flow in the boundary layer of the rotating disk near slider in a HDD, and its effect on the slider vibration, have not been investigated.

This work first addresses vortex shedding from the slider. Vortex shedding is a well-known cause of structural vibration and is especially important when a natural frequency of the structure is close to the vortex shedding frequency. Vortex shedding has been found over a range of disk speeds and slider positions on the disk, and its effects have been observed. Periodic flow fluctuation was observed emanating from bolts on the hub clamping the disk stack together. Flow near the disk hub and its influence on the slider vibration have been investigated by measuring the displacement amplitude of the slider at harmonics of the runout frequency. This was accomplished at different locations of the slider and at different disk speeds. The experimental observations show that vortex shedding from the slider has little affect on slider vibration because of the de-tuning of the shedding frequencies and natural frequencies of the suspension. However, the periodic flow fluctuations emanating from flow over the clamping bolts on the hub can excite significantly the slider near the hub.

II. EXPERIMENTAL SETUP

To measure the flow fluctuation near slider in a HDD, a hot wire anemometer was used. A single, constant temperature tungsten hot wire sensor of diameter 0.0038mm and sensor length 1.25mm, was used for the measurement. The experimental setup is shown in Fig. 1. A hard disk drive with three - disk stack was used in this experiment. The flow fluctuation was measured at different locations on the upper most disk surface in HDD with the change of disk speed. A special motor driver board (PMDM SKA90030) was used for controlling the disk speed. The hot wire was located at various positions downstream of the slider for the experiment of vortex shedding phenomena. For the experiment of periodic flow in HDD the hot wire was positioned in between the disk hub and the slider.

The lateral vibration of the slider was measured at specific disk speeds and slider positions. A rectangular 3×3 mm hole in the cover allows laser transmission for measurement of the vibration of the slider in the radial direction as shown in Fig. 2. Labview was used to collect the data of frequency spectra and the data was processed in PC.

III. VORTEX SHEDDING FROM SLIDER

A. Hot wire measurement downstream of the slider

Flow fluctuation downstream of the slider on the uppermost disk surface of a three - disk stack was measured using a hot wire anemometer. The hot wire was located at various positions downstream of the slider. The peak in the flow fluctuation due to vortex shedding was then found at different disk speeds and at different, radial positions of the slider from the disk center, $R_{s.}$

The flow fluctuation spectra downstream of the slider, under the change of the height of hot wire from the disk surface, *h* are shown in Fig. 3. (R_s = 34mm, disk speed = 6,000 rpm, slider height = 0.017 inch). It is observed that the vortex shedding occur at 1080Hz. When the hot wire was located at very close to the disk surface (*h* = 0.005 inch), there was negligibly small peak from vortex shedding appeared and the peak from runout frequency (100 Hz) of the disk was dominant. As the hot wire vertically traversed from the disk surface, the peak amplitude from the vortex shedding gradually increases and reaches its maximum at *h* = 0.012 inch. As the hot wire moves from the disk surface further, the peak decreases and disappears when *h* = 0.022 inch.

The effect of disk speed on the vortex shedding was also tested. The spectra of the flow fluctuation past the slider at the mid point of the slider vertical height (*h* = 0.008 inch), is shown in Fig. 4 as the disk speed varied from 4800 rpm to 7800 rpm (R_s = 34mm). The frequency of vortex shedding, denoted by the peak in the spectrum, increases with disk speed and the magnitude reaches its maximum at 6000 rpm (vortex shedding frequency = 1080Hz at this disk speed). Subsequently, the peak disappears for all intents and purposes when the disk speed exceeds 7800 rpm. The Strouhal number based on the speed of the disk surface ($S = {f_s D}/{U}$, f_s : vortex shedding frequency, D : slider width, U : speed of the disk surface at R_s) in this speed range (4800 ~ 7800 rpm) was found to be 0.08.

The translation of the vortex downstream from the leading edge of the slider has been confirmed by measuring the magnitude of the peak as hot wire traverses in the *x-y* plane shown in Fig. 5(a) (disk speed : 6000rpm). The peak magnitudes measured at each point in the *x-y* plane at the mid point of the slider height are shown in Fig. 5(b). The direction of vortex translation has been found to be 23 ° from the θ-axis by tracing the points of maximum magnitudes of the peak from vortex shedding. (See Fig. 5.(a),(b))

B. *Effect of vortex shedding on slider motion*

To evaluate the effect of vortex shedding on the slider motion, the lateral, in-plane, slider vibration was measured using a Laser Doppler Displacement Meter (LDDM). The spectrum of the slider vibration when the disk is rotated at 6000 rpm without a cover (R_s = 34 mm) is shown in Fig. 6. A peak of insignificant amplitude was observed at the frequency of vortex shedding

(1080Hz). No peak was found at the vortex shedding frequency at other disk speeds as well. It appears that the pressure fluctuation from the vortex shedding is not sufficient to excite the slider motion in the frequency range measured in this experiment. This result is similar to that of Tokuyama and Yamaguchi who observed that the effect of the wake behind the suspension on its dynamics was negligible [10]. From this result, it is observed that excitation by vortex shedding from the slider is negligibly small for this disk drive even though a prominent peak in the flow fluctuation exists in the wake of slider. However, it may become an important factor if the shedding frequency approaches one of the natural frequencies of the actuator system.

IV. PERIODIC FLOW NEAR THE DISK HUB

A. Hot wire measurement near disk hub

The flow fluctuation upstream of the slider resulting from the hub design has been found to have an important influence on the slider vibration. To identify the variation of the flow at different locations on the disk, flow fluctuation was measured using a hot wire positioned from inner radius to outer radius of the disk. The spectra of the flow fluctuation upstream of the slider over the uppermost disk surface at different R_h (radial distance of the hot wire position measured from the disk center) are shown in Fig. 7, when the disk is rotated without a cover. This figure shows a dominant peak in fluctuation at the 4th harmonic of run out frequency, $4\omega_o$ = 400Hz. The maximum magnitude of the fluctuation appears near the disk hub and decreases in magnitude as hot wire traverses from the clamping collar to the rim of the disk. This flow fluctuation is caused by the flow over the four clamping bolts located on the top of the disk hub.

In commercial hard disk drives the actuator servo system positions the head precisely on a particular track. Because of the characteristics of the sensitivity function, noise at particular frequencies is amplified while noise at other frequencies can be controlled. Typically, disturbances from sources above 350 Hz can be amplified by the servo control system. Thus, noise at $4\omega_o$ = 360 Hz for a disk speed of 5400 rpm, is of primary concern.

B. Effect of periodic flow on slider motion

To examine the influence of the flow near the disk hub on the slider, the lateral vibration of the slider was measured at specific disk speeds and slider positions. The amplitude of this vibration was compared to that measured under identical conditions after flattening the top of the disk hub (See Fig. 8) and also to those in the uncovered case.

Typical spectra of the lateral vibration of the slider on the uppermost disk are plotted in Fig. 9. Note that the magnitude of vibration at frequencies less than 350Hz can be controlled through the servo system with feedforward cancellation even though the magnitudes of vibration are large. Thus, they are not of principal concern here. The large amplitudes above 350Hz, say at $4\omega_o$, can be important because peaks at these frequencies are amplified. In Fig. 9, the amplitudes at $4\omega_o$ are substantially reduced when the hub has a flat-top, implying that there is a significant influence on the periodic flow from the hub geometry on the slider motion.

To confirm this effect, the displacement amplitudes of slider vibrations are compared at $4\omega_o$ for disk speeds (5400 – 9900 rpm) and slider locations (21 – 26 mm) when: 1) the normal hub is used, 2) the flat–top hub is used, 3) the cover is not used with a normal hub. The results are shown in Fig. 10 and the effect of using a flat–top hub on the amplitude at $4\omega_o$ are readily apparent. That amplitude is substantially reduced from those with normal hub at all speeds in the range tested when Rs = 21, 22, 24 mm.

The differences in the amplitude of vibration when using the normal hub and flat–top hub increase as the slider position moves radially inward. This phenomenon is explained by the hot wire measurement of flow fluctuation at different radii from the disk center as shown in Fig. 7. Periodic flow excitation amplitude in the inner region exceeds that in the outer region of the disk. It is also observed that use of the cover attenuates the periodic flow excitation except when Rs = 21mm, based on the magnitude of the slider vibration amplitude in the covered and uncovered cases (See case 1) and 3) in Fig. 10).

V. DISCUSSION

From these results, it is observed that the periodic flow excitation excites lateral slider vibration when the slider is within 26 mm from the disk center. By use of flat–top hub, the displacement amplitude of the slider vibration at $4\omega_o$ was reduced by 33 % when averaged over the speed range tested when R_s = 21mm.

It is also noted that the amplitude of slider vibration at $4\omega_o$ was found to decrease with increasing R_s in all 3 cases mentioned above. To find the source of this result, disk vibration was measured in the same range of disk speeds and slider positions. The disk vibration was measured by LDDM viewing through 2 mm diameter access holes drilled at each corresponding position from the disk center on the cover. The excitation appears essentially unchanged from that observed in normal operation. The 4th run out amplitudes of the disk vibration were divided by 40 and compared to the lateral slider vibrations when normal/flat-top hub is used; see Fig. 11. The disk vibration illustrated the same trend of decreasing amplitude of slider vibration with increasing the radial position of the slider, R_s. From these results, the slider motion in normal operation, in the ranges of the slider position and the disk speed tested, is shown to be excited by the disk vibration as well as the periodic flow. The effect of disk vibration on the track misregistration was studied experimentally by McAllister [11]. However, the relationship between the disk vibration normal to the disk surface and the lateral slider vibration were not investigated rigorously.

VI. CONCLUSION

Two types of air flow induced vibration of the slider have been investigated. Vortex shedding from the slider occurs over a range of disk speeds but its effect on slider motion is negligible for the disk drive tested even though prominent peaks are observed in the frequency domain in the wake of slider. On the other hand, the periodic pressure fluctuation in the flow caused by flow over the geometry of the disk hub excites slider motion. Its effect is more prominent near the disk hub than near the periphery. The amplitude of slider vibration can be reduced significantly by using a hub with flat surface and possibly by other hub designs though none have been investigated.

VII. REFERENCES

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Fig. 1. Set up for flow measurement by hot wire.

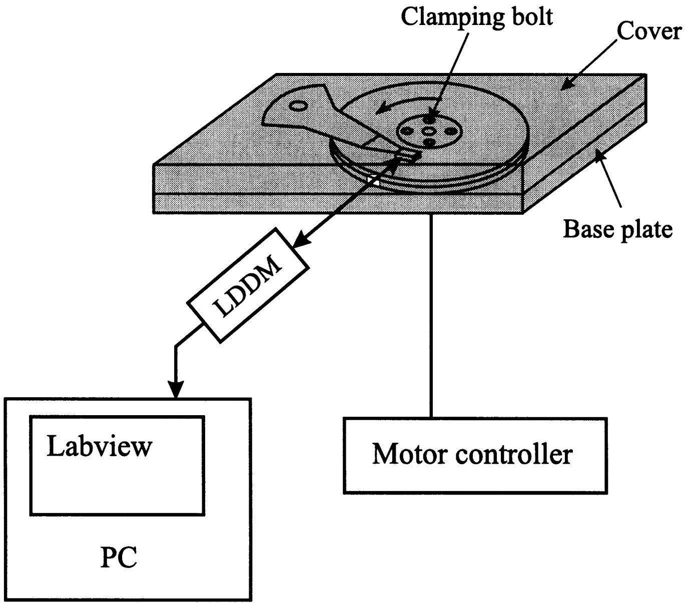


Fig. 2. Experimental setup for the vibration measurement of lateral slider vibration.

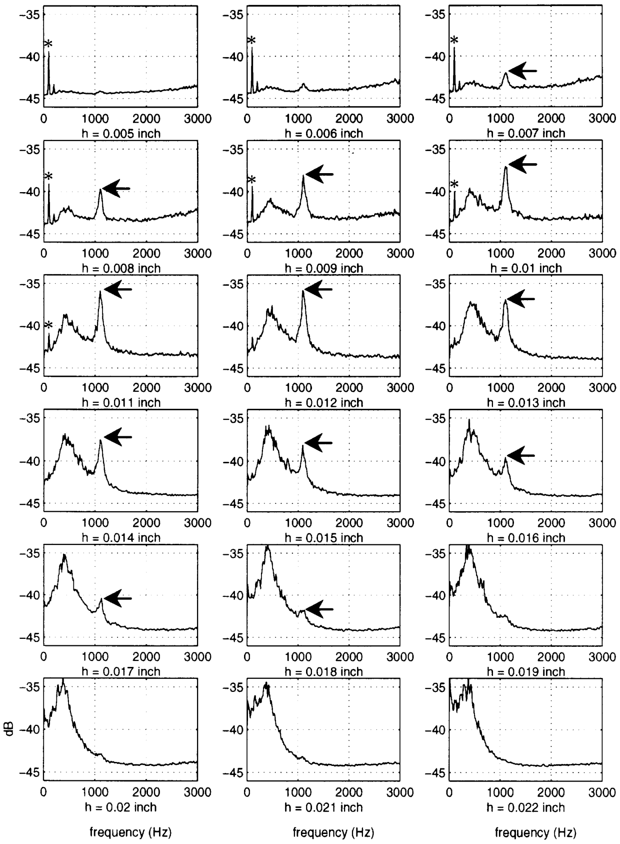


Fig. 3. Wake spectra past slider with height from disk surface.
(Rs = 34mm, disk speed = 6,000 rpm,
✳: peak from disk runout, ← : peak form vortex shedding)

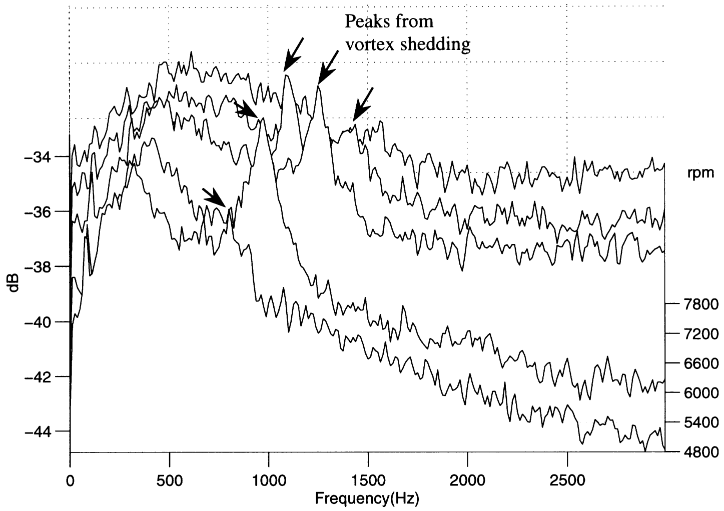
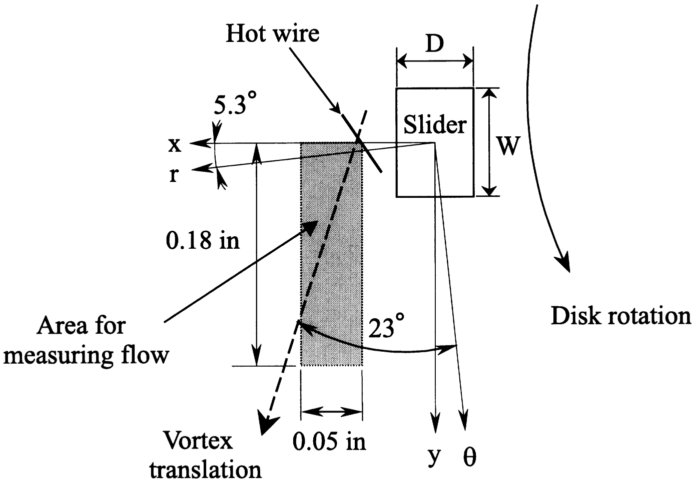
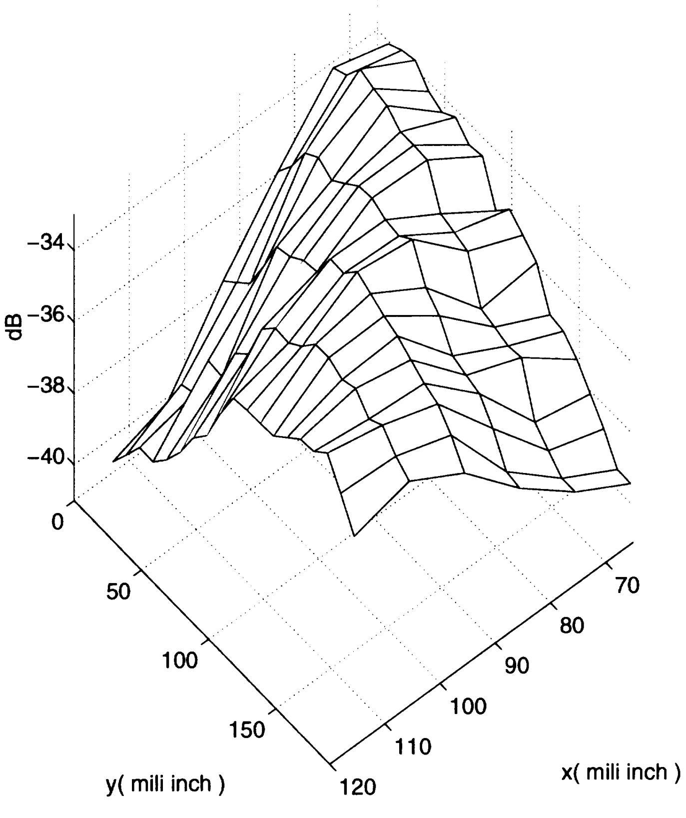


Fig. 4. Wake spectra past slider with disk speed.



(a)



(b)

Fig. 5. (a) Hot wire locations for flow fluctuations measurement.
(b) Peak magnitudes at vortex shedding frequency in x-y plane.
(disk speed : 6000rpm)

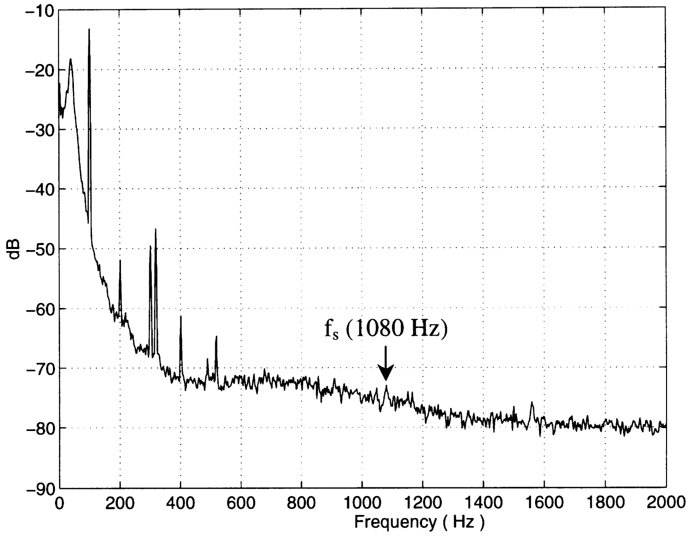


Fig. 6. Slider vibration (Rs : 34mm, Disk speed : 6000 rpm).

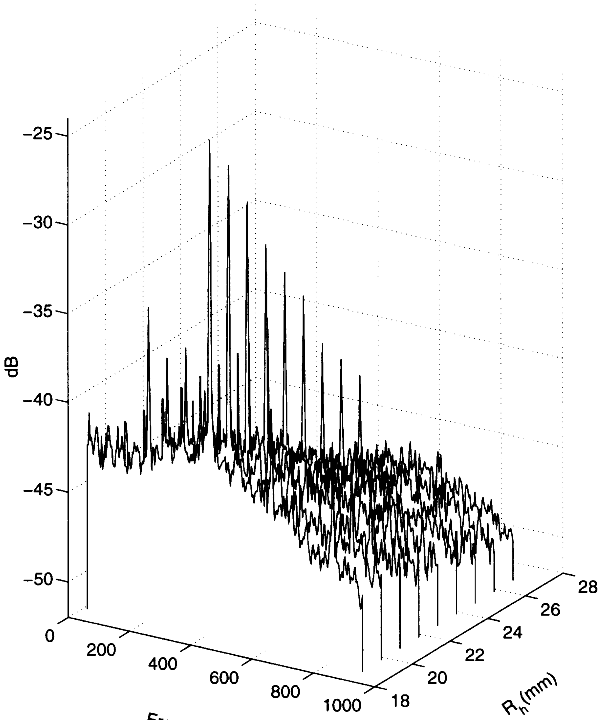


Fig. 7. Flow fluctuation spectra in the upstream of slider
(disk speed : 6000rpm, $4\omega_o$ = 400Hz)

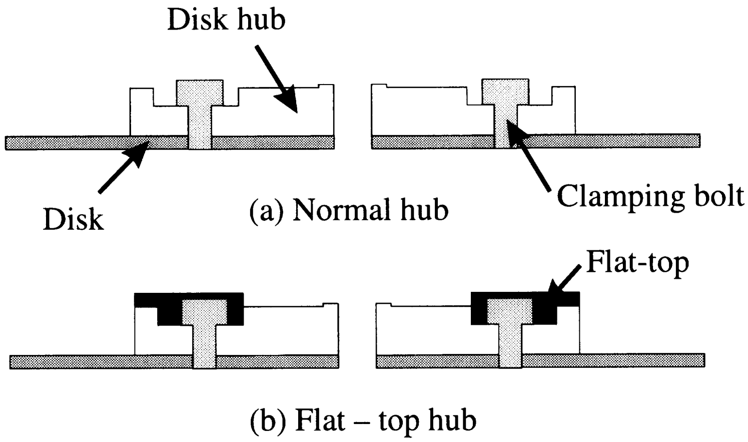
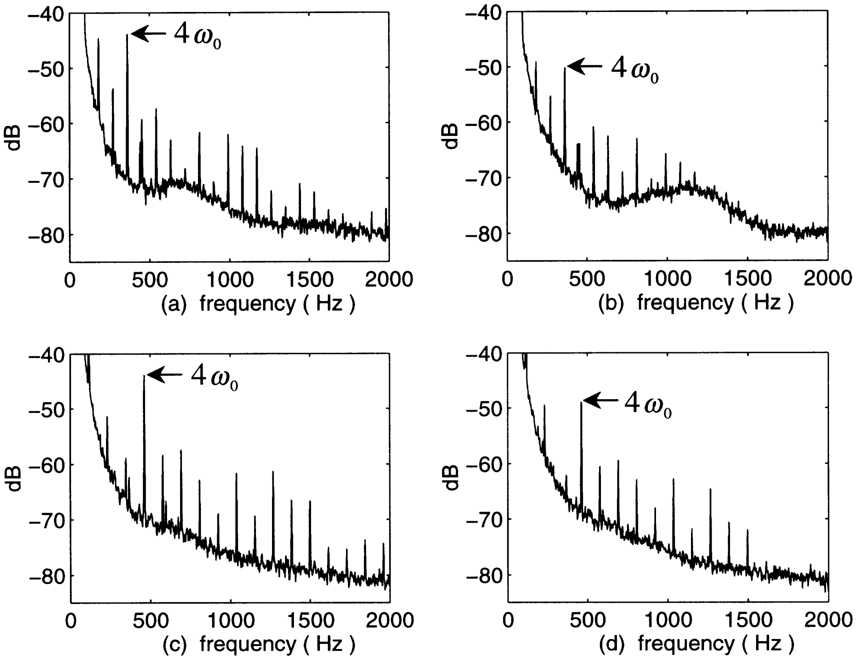


Fig. 8. Geometry of the flat top.



(a) frequency (Hz)
(b) frequency (Hz)
(c) frequency (Hz)
(d) frequency (Hz)

Fig. 9. Lateral slider vibrations at ;
(a) 5400 rpm, (b) 5400 rpm with flat-top hub
(c) 6900 rpm, (d) 6900 rpm with flat-top hub

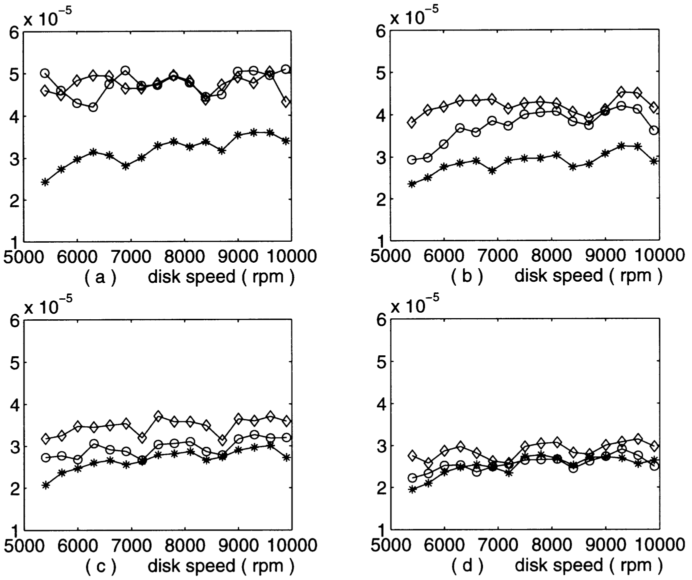


Fig. 10. Amplitudes of slider vibration at $4\omega_0$ with disk speed.;
ï : 1) normal hub, ✳ : 2) Flat-top hub used, ◊ : 3) uncovered,
(a) Rs = 21 mm, (b) Rs = 22 mm, (c) Rs = 24 mm, (d) Rs = 26 mm
(Displacements are nondimensionalized with slider width D)

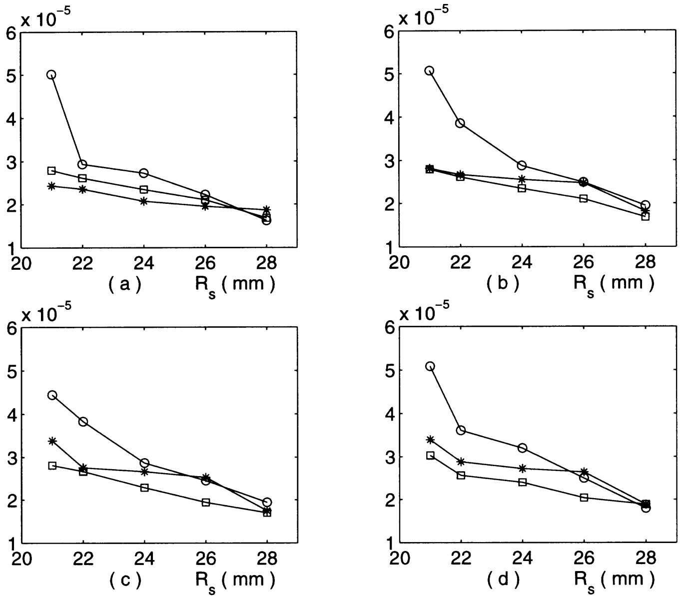


Fig. 11. Vibration amplitudes at $4\omega_0$ with Rs:
ï : slider (with normal hub), ✳ : slider (with flat-top hub),
□: disk vibration amplitude divided by 40,
(a) 5400 rpm, (b) 6900 rpm, (c) 8400 rpm, (d) 9900 rpm
(Displacements are nondimensionalized with slider width D)