An experimental comparison of the head/disk interface dynamics in 5¼- and 8-inch disk drives

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A laser Doppler vibrometer is used to measure the head/disk interface dynamics in computer disk drives. The stability of the head under steady operating conditions is compared between a 5¼-inch and two different 8-inch "Winchester" drives. In the larger drives, high-frequency vibrations (between 5 and 10 kHz) are detected on the slider which are not present in the smaller drive. These vibrations have amplitudes on the order of magnitude of the head/disk spacing and are related to the rolling and pitching modes of the slider. The vibrations of the disk, suspension, and actuator arm are also investigated and correlated with the results obtained on the slider.

Introduction

The storage density of magnetic disk drives has increased by four orders of magnitude since the introduction of the first model in 1957. This progress has paralleled the reduction of the spacing between the magnetic medium of the disk and the read/write head. Recent disk drives have slider bearings that maintain a head-to-disk spacing (or flying height) as small as 0.3 μm, as opposed to 20 μm for the earlier models.

Such close head-to-disk spacings require a thorough understanding of the dynamics of these slider bearings since the spacing must be maintained without head-disk contact. A contact can result in damage to the magnetic coating of the disk, in the loss of the stored information, and in the required replacement of the head-disk assembly. This problem, also known as "head crashing," has been one of the main concerns of the disk drive industry. Many experimental investigations have been undertaken to understand the dynamic behavior of these slider bearings and to verify the results of numerical simulations [1]. White light interferometry, very useful for static flying height measurements, is limited to very low frequencies for dynamic studies. Capacitive methods present a wide-frequency bandwidth but require a physical alteration of the slider. Another interferometric method, laser Doppler vibrometry, was recently applied to this problem [2]. This technique allows detection of transient motions of the slider in an unmodified disk drive.

As a consequence of the dramatic increase of the areal density of storage, the recent trend has been to reduce the

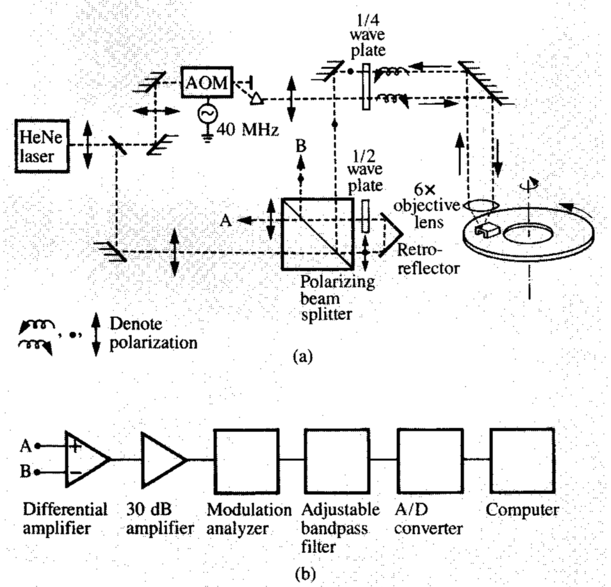

Figure 1

Optical (a) and electrical (b) components of the LDV.

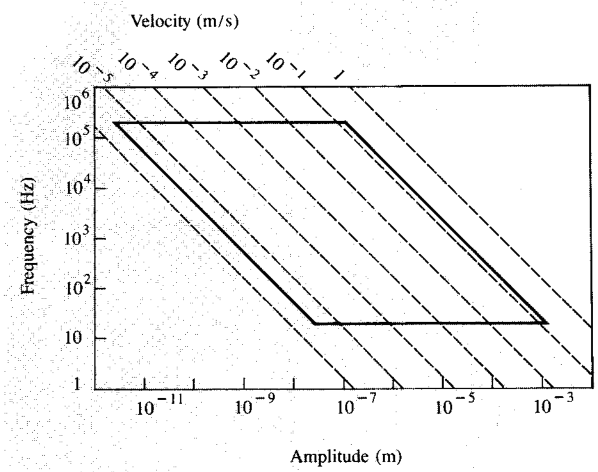

Figure 2

Usable range of the LDV.

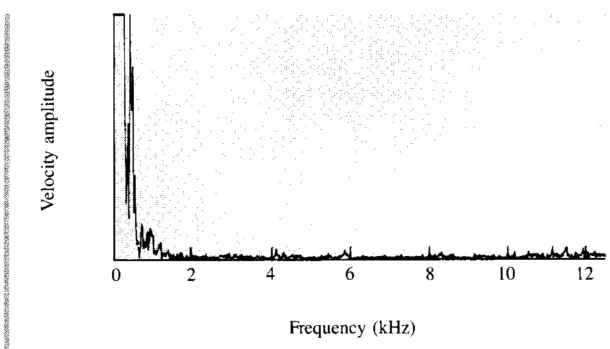

Figure 3

Frequency spectrum of the slider velocity in the 5¼-inch drive.

size of disk drive units, and "rigid disk" products have become available for smaller computer systems. New disk diameter standards have been introduced, and current products utilize disks with diameters of 14, 8, 5¼, and 3½ inches. In a previous paper [3], we studied in detail the slider dynamics in 5¼-inch disk drives by using laser Doppler vibrometry. It was expected that the larger drives would have different operating conditions for the slider bearings that might adversely affect their dynamic behavior. In this paper, we present results obtained for two different 8-inch disk drive designs using the same instrumentation as before, and we compare these results with those obtained earlier for the 5¼-inch drives. We first examine the motion of the slider in terms of its frequency content, and then we attempt to relate these results to the observed dynamics of the disk, the suspension system, and the actuator. All of the disk drives under consideration use the same "Winchester" technology.

Experimental apparatus

The core of our experimental apparatus is the Laser Doppler Vibrometer (LDV) shown in **Figure 1**. The optical section in Fig. 1(a) is modified from a commercially available LDV made by DISA Electronics. The system is based on the principle that light reflected from a moving surface is shifted in frequency, this shift being proportional to the surface velocity component parallel to the laser beam. This is a particular case of the well-known Doppler effect, and the proportionality constant is half the wavelength of the light. The measurement beam is first shifted in frequency by 40 MHz in a Bragg cell (or AOM) before being focused on the target surface, so that after it is recombined with the reference beam on the photodiodes, we obtain a 40-MHz FM signal with a modulation proportional to the surface velocity. Note that the measurement surface can be any component of the drive which is optically accessible to the laser beam, i.e., the slider, the disk, the suspension system, the actuator, etc. As shown in Fig. 1(b), the signal is then demodulated by a modulation analyzer (HP 8901A), digitized in a high-speed A/D converter (Biomation 8100), and sent to an IBM PC computer for analysis. The usable range of this system is presented in **Figure 2**.

The disk drives used in our present experiments are two commercially available 8-inch drives and one standard 5¼-

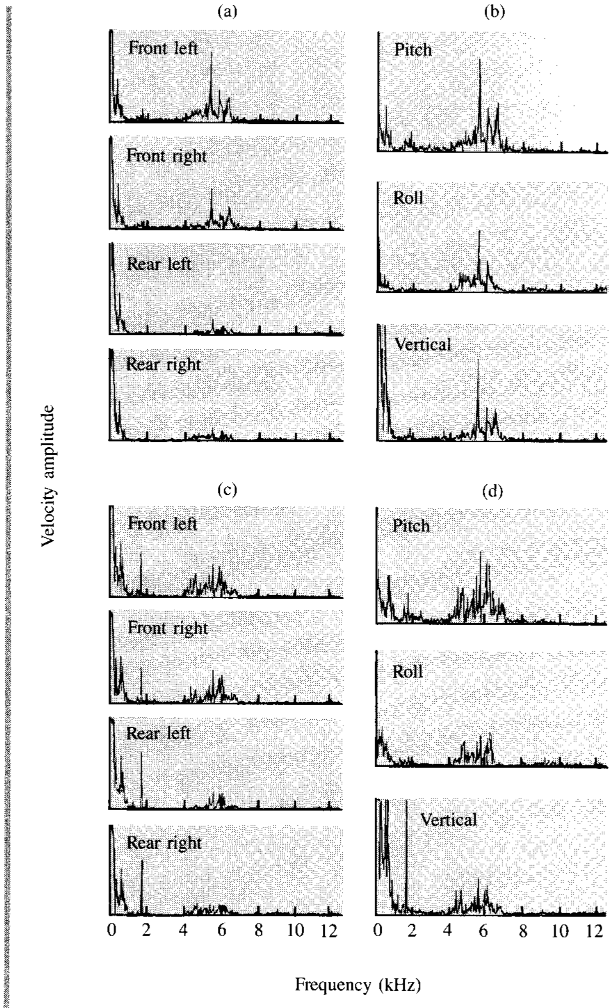

Figure 4

First 8-inch drive: (a) spectra of the four corner velocities when the slider is on track 0 (ID); (b) spectra of the pitch, roll, and vertical velocities, track 0; (c) spectra of the four corner velocities when the slider is on track 445 (OD); (d) spectra of the pitch, roll, and vertical velocities, track 445.

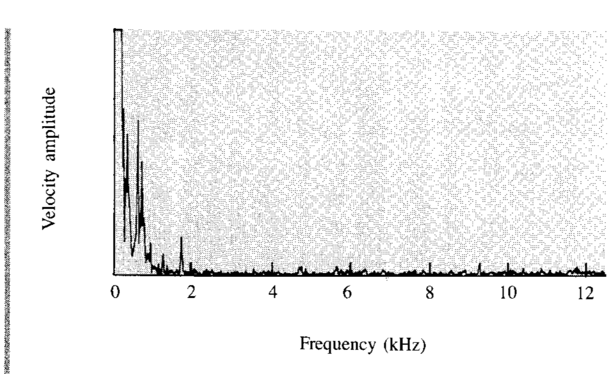

Figure 5

First 8-inch drive: spectrum of the disk vertical velocity.

inch drive. The first 8-inch drive has two disks storing 30M bytes of information. This drive utilizes 3340-type Winchester sliders and suspensions mounted on a linear actuator; each disk has 445 data tracks. The second model has six disks storing 60M bytes of data and uses similar sliders and flexures mounted on a rotary actuator; each disk has 359 data tracks. The 5¼-inch drive is used for comparison; it also has 3340-type sliders and suspensions.

Experimental results

- *Results for 5¼-inch drive*

In [3], a mechanical defect was artificially introduced on the disk surface in order to excite the air-bearing resonance frequencies, which were the primary concern of that paper. However, without such a defect, the slider follows the disk runout motion very closely, and frequency components above 1.5 kHz are absent in the slider velocity signal. This is illustrated in **Figure 3**, where the frequency spectrum was obtained by Fast Fourier Transform of the digitized time history data. The vertical scale is linear and shows normalized amplitude. The disk has a surface velocity of 24 m/s at the track where the head is positioned.

- *Results for first 8-inch drive*

As with the 5¼-inch drive, we examined the slider motion in the first 8-inch drive during steady operating conditions. A complete description of this motion was obtained by recording the vertical velocities of the slider at its four corners, and by calculating the pitch, roll, and vertical (at the geometric center) velocities. **Figure 4(a)** displays the frequency spectra of the velocities at the four corners when the head is at the ID (inside diameter, track 0), while the spectra of the calculated pitch, roll, and vertical velocities appear in **Figure 4(b)**. Similar results obtained when the slider is flying at the OD (outside diameter, track 445) are presented in **Figures 4(c)** and **4(d)**, respectively. Contrary to what was observed on the 5¼-inch drive, a high-frequency component around 6 kHz clearly appears in the slider motions. The amplitude of this vibration decreases from ID to OD, where the surface velocities are 23 m/s and 33 m/s, respectively. From Figs. 4(a) and 4(c), we notice that the 6-kHz vibration is very pronounced at the front of the slider, where its amplitude is on the order of 0.15 μm, while the rear is almost unaffected. A strong frequency component at 1.73 kHz is also detected on the vertical excursion of the head at the outer track.

The above results were next compared with measurements made on the disk itself. **Figure 5** presents the typical frequency content of the disk vertical runout velocity. Contrary to the results from the slider, this spectrum does not show any component above 2 kHz. It illustrates a major difference between this drive and the 5¼-inch drive previously examined: In the present case, the slider does not follow the disk exactly; i.e., the motions of the slider and the disk differ by the high-frequency terms. The amplitude of the differential motion is substantial, since it represents almost half the flying height.

A very peculiar phenomenon can be observed on the disk motion: The 1.73-kHz vibration is present in the frequency spectra of the disk vertical velocity, but its amplitude is dependent upon the location of the slider. This is illustrated in **Figure 6**: The disk runout velocity is recorded at the same place when the head is on three different tracks (0, 150, and 300). The corresponding spectra show important amplitude variations for the 1.73-kHz vibration, which can be as large as 0.2 μm peak-to-peak at the sharpest resonances. Note that these resonances are very sensitive to the position of the slider; they are affected by a single track change. For a given position of the slider, the amplitude of this component is decreasing on the disk from ID to OD. Also, this phenomenon is observable only after the drive has been running for some time (at least 30 minutes), indicating that it may somehow be associated with thermal effects.

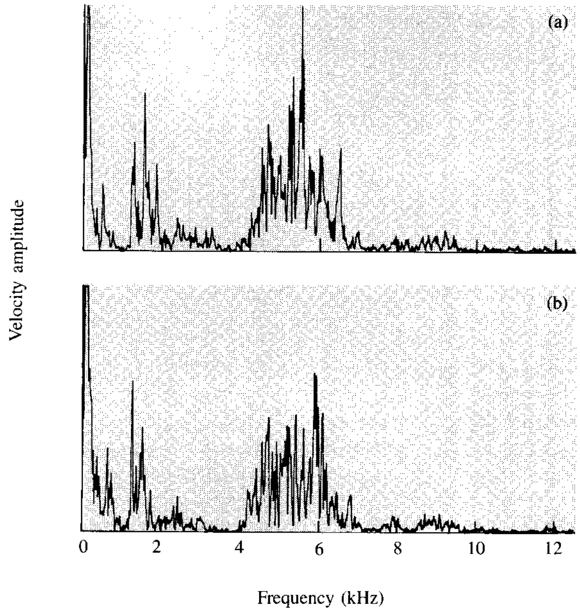

Figure 7

First 8-inch drive: spectra of the load beam vibration at its tip for the head on tracks 0 (a) and 445 (b).

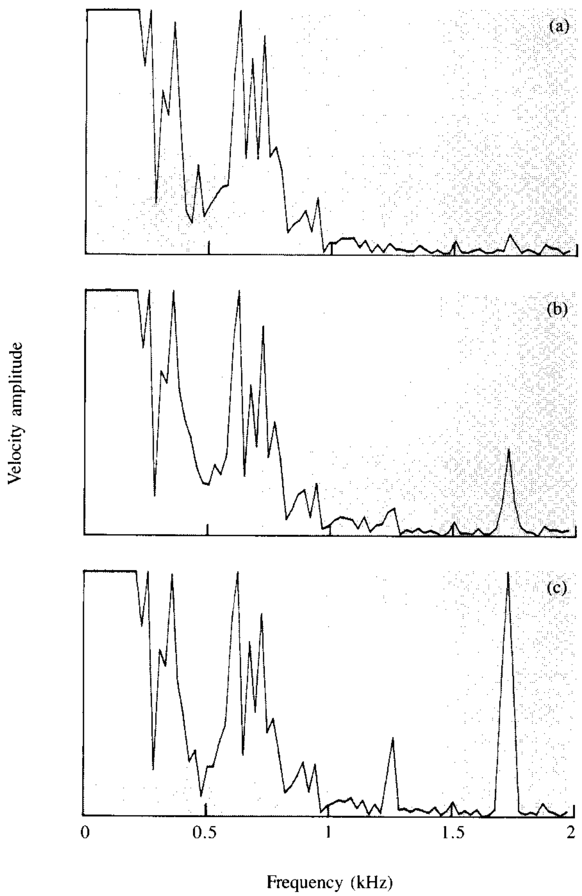

Figure 6

First 8-inch drive: spectra of the disk vertical velocity at the 9-cm radius for the slider on three different tracks (a) track 0, (b) track 150, (c) track 300.

Next, we examined the vibration of the load beam. The measurements were performed at the tip of the beam (just above its attachment to the head) for the slider on tracks 0 and 445. The frequency content of this vibration for both slider positions is shown in **Figures 7(a)** and **7(b)**. The 6-kHz vibration observed on the slider is also present here, its amplitude being about 0.2 μm. As on the slider, it has a larger magnitude at track 0 than at track 445. The 1.73-kHz component, on the other hand, is present in both graphs with approximately the same amplitude.

The motion of the actuator was then examined. Its spectrum, displayed in **Figure 8**, shows a dominant vibration at 1.73 kHz, with a maximum amplitude of 1 μm. This vibration, like all those described previously, is synchronized with the rotation of the disk; i.e., the time history appears stable on the oscilloscope when it is triggered with the index signal of the drive. It presents some nodes which are also synchronized with the disk rotation.

To confirm these results, the same experiments were repeated with another drive of the same model, but with slightly different air flow and actuator designs. The slider vibration at 6 kHz was also observed on this drive, with a maximum amplitude of 0.1 μm. This is significantly smaller than on the other drive, possibly because of the difference between the air flows of the two drives. The first drive has

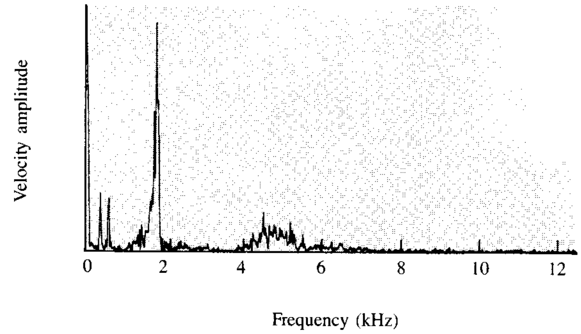

Figure 8

First 8-inch drive: spectrum of the actuator vibration.

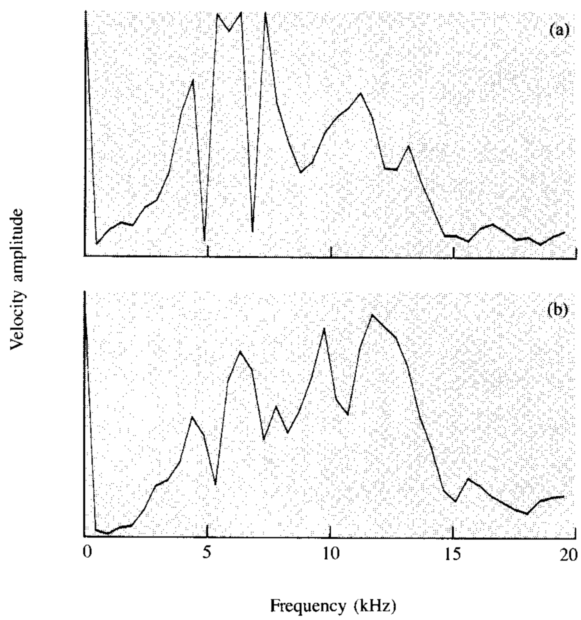

Figure 9

First 8-inch drive: spectra of the front (a) and rear (b) slider velocities at the defect.

fanlike wings mounted on the spindle to recirculate the air through a filter, and the second one does not have this feature. We also observed that the 1.73-kHz vibration did not clearly appear in the slider motion nor on the disk. In fact, the vibration of the actuator was much smaller in amplitude for this drive, on the order of 0.3 μm.

In order to identify the air-bearing resonance frequencies for this drive, an experiment similar to the one presented in [3] was performed; i.e., a small mechanical defect was introduced on the surface of the disk, and the slider response to this excitation was recorded. **Figure 9** presents the spectra of the front and rear slider velocities. The small defect is traveling under the left rail of the slider. The front mostly vibrates at the same 6-kHz frequency observed previously without the defect, while the rear exhibits a new frequency component at 12 kHz. Therefore, it appears that the vibration observed in the steady-state running conditions is related to the front resonance of the slider bearing.

- *Results for second 8-inch drive*

As in the preceding section, we recorded the slider motion in this drive during steady operating conditions and examined their frequency content. **Figures 10(a)** and **10(c)** present the results from the four corners of the slider when it flies on two different tracks: track 256 (middle of the disk) and track 359 (outside diameter). The calculated pitch, roll, and vertical velocities at these tracks have the frequency spectra shown respectively in **Figures 10(b)** and **10(d)**. The vibration of the slider exhibits some high-frequency terms not related to the runout of the disk, since a typical disk runout vertical velocity would present a frequency spectrum very similar to the one previously presented in Fig. 6. Here, two main frequencies appear in the kilohertz range: 7.5 kHz and 9.5 kHz; there is also a minor component around 5 kHz. The first of these frequencies appears to be related to the pitching of the slider, while the other is associated with its rolling. Both of them contribute little to the vertical motion. Note also that these high-frequency motions are present not only at the front of the slider but also at the rear. Their amplitude can be as large as 0.1 μm at the front and 0.05 μm at the rear, as compared to the 0.3-μm steady-state flying height.

At the inside tracks (from 0 to 190), the head is partially covered by a metal plate, and only the rear of the slider is optically accessible. The frequency spectra of the rear corner velocities are shown in **Figure 11**. The high-frequency dynamics are significantly smaller in this region, which points out the possible importance of the air flow in their amplitude. The drive has a forced air recirculation and filtering system using a fan on the spindle (similar to the one described previously for the other drive design). When the head is under the metal plate, it is partially protected from the air flow drawn by this system, which apparently results in the reduced head vibrations.

The vibrations of the suspension and actuator were then examined. **Figure 12** presents the frequency content of the load beam velocity measured at its tip. Three main components appear, which are the same as those detected on the slider: 5, 7.5, and 9.5 kHz. However, their relative magnitudes are different from those on the head. The 7.5-kHz term seems to be dominant, and a study of its mode shape shows that it is related to the torsion of the beam. This is not surprising, as the torsion of the beam is coupled with the pitching of the slider. Another element of the suspension system is the gimbal assembly. Measurement of its vibrations

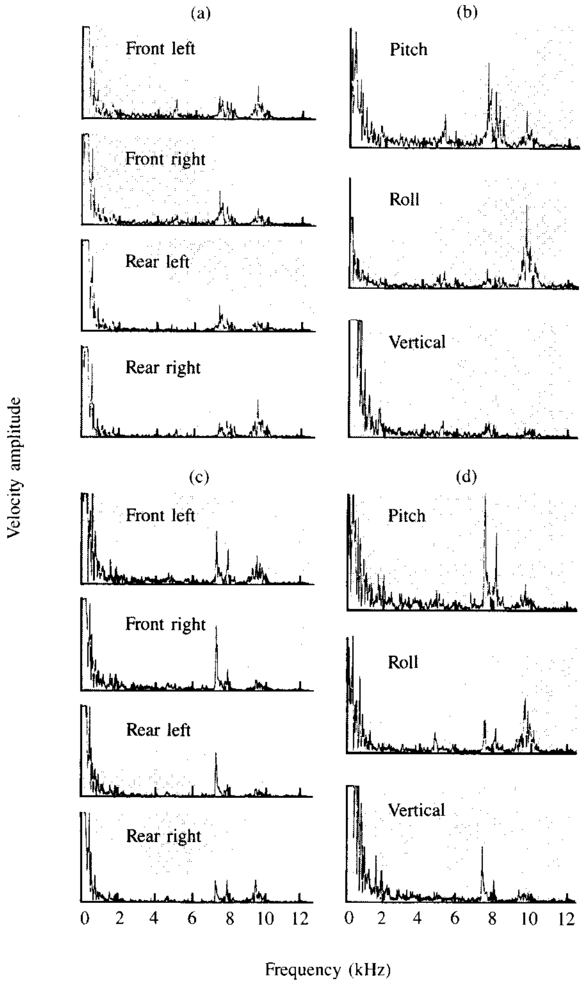

Figure 10

Second 8-inch drive: (a) spectra of the four corner velocities when the slider is on track 256; (b) spectra of the pitch, roll, and vertical velocities, track 256; (c) spectra of the four corner velocities when the slider is on track 359; (d) spectra of the pitch, roll, and vertical velocities, track 359.

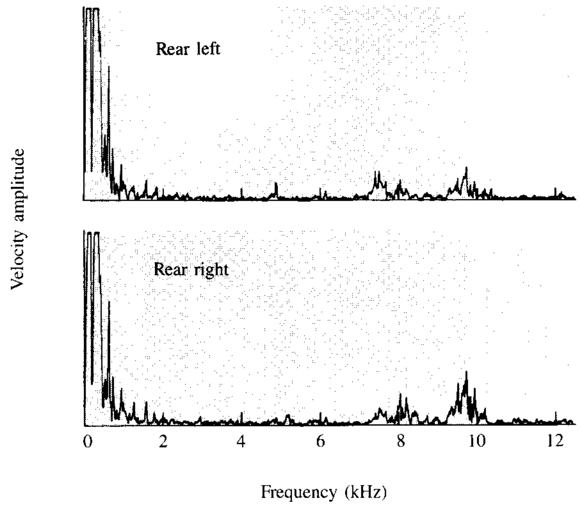

Figure 11

Second 8-inch drive: spectra of the rear left and rear right slider velocities for track 112.

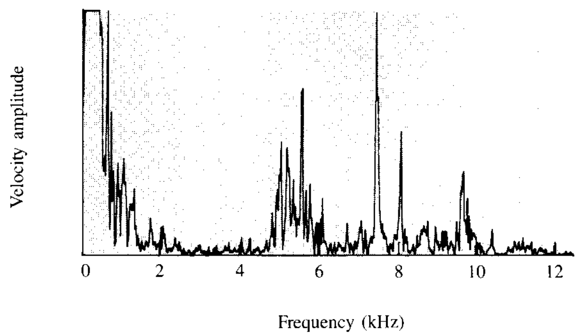

Figure 12

Second 8-inch drive: spectrum of the load beam vibration at its tip.

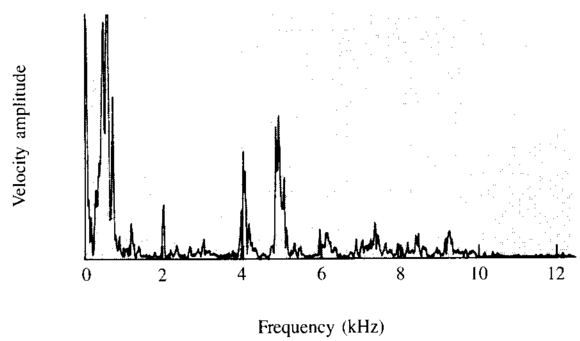

Figure 13

Second 8-inch drive: spectrum of the actuator vibration.

shows some low-frequency, high-amplitude terms which are not synchronized with the disk rotation. The frequency spectrum of the actuator vibration was also recorded. As seen in **Figure 13**, it displays one principal frequency at 586 Hz (not synchronized with the disk), and two smaller components at 4.1 kHz and 4.9 kHz. In this drive, no influence of the actuator vibration on the disk motion is observed.

Finally, the reaction of the slider to an artificial defect on the disk surface was investigated. The frequency spectra of the front and rear slider velocities are presented in **Figure 14**. At the rear, the 9.5-kHz component does not appear, while a strong 12-kHz peak and a smaller 15-kHz peak are visible. At the front, the main peaks are still at 7.5 kHz and 9.5 kHz,

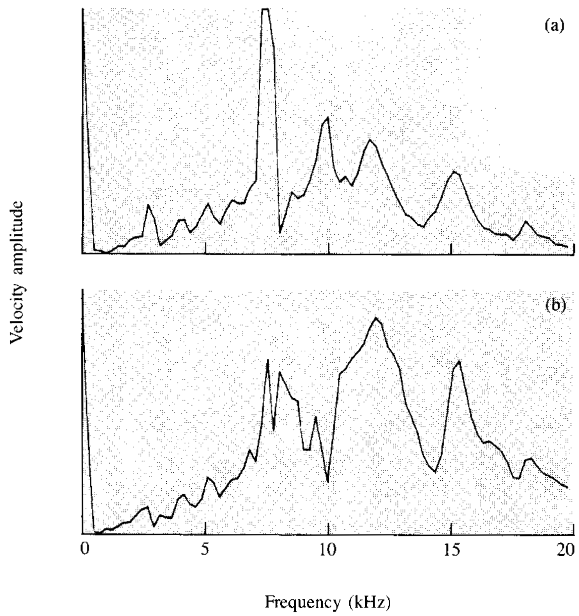

Figure 14

Second 8-inch drive: spectra of the front (a) and rear (b) slider velocities at the defect.

but the first one is more prominent here compared to the experiment conducted without a defect. This identifies the 7.5-kHz frequency as the front bearing resonance and the 12-kHz peak as the rear bearing resonance.

Conclusions

The results presented in this paper show some major differences in the slider dynamics between the two different 8-inch drive designs and the 5¼-inch drive examined in [3]. In the 5¼-inch drive, the slider follows the disk runout motion very closely and presents no detectable high-frequency vibration. In the 8-inch drives, on the other hand, there are steady-state slider vibrations in the kilohertz range which have no counterpart on the disk. The amplitudes of these vibrations are not negligible compared to the flying height. One of these modes is related to the resonance of the front of the air-bearing and is observed in both types of drives: at 6 kHz for the first one and at 8 kHz for the other one. This mode of vibration can be viewed as the first pitching mode, the second one being associated with the resonance of the rear of the air-bearing, which is at a higher frequency (12 kHz for both drives) and is not excited unless an artificial perturbation is introduced. On the second 8-inch drive, however, another mode at 9.5 kHz is detected which is related to the roll of the slider. The presence of these vibrations is obviously undesirable, since they can seriously affect the head stability. Note, however, that the rear of the slider, which is the closest to the disk and carries the read/write element, is more stable than the front.

More generally, the measurements performed show that the head/disk interface problem in an actual disk drive cannot be reduced to the single air-bearing problem. The drive must be considered as a system that includes the head suspension, the actuator, the disk, the air flow, and the slider-bearing in order to predict the behavior observed here, i.e., the presence of high-frequency dynamics in a supposedly steady-state situation. This type of approach is also necessary to avoid undesirable phenomena such as the excitation of a disk mode by the actuator (as observed in one of our drives), or resonances of the suspension system. In studying these dynamical systems, laser Doppler vibrometry is a powerful tool, since it can detect vibrations of all components of the drive that are optically accessible.

Acknowledgment

This research was sponsored by the Center for Magnetic Recording at the University of California, San Diego, under Contract UCB ENG-5730 with the University of California, Berkeley. Also, F. E. Talke acknowledges the sabbatical support by the IBM Corporation.

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Received October 15, 1984

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