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Capacitance Probe Study of Rotating-Head/Tape Interface

Abstract: A modified version of the capacitance probe technique is used to investigate the head-tape interface in a rotating head configuration. The relationship between air-bearing spacing and contour design is studied as a function of tape tension, head protrusion, and velocity; in addition, the effect of wave dynamics on flying height is examined.

Introduction

The measure of capacitance between adjacent surfaces has been used extensively to study the spacing of bearing surfaces separated by thin lubricant films. Crook [1, 2] used the technique to measure the spacing in the contact zone between oil-lubricated disks. Archard and Kirk [3] applied the method to study elastohydrodynamic lubrication of crossed cylinders and derived a simple empirical expression for the oil film thickness of the contact zone. In an application involving air-lubricated bearings, Ma [4] and Licht [5] studied the dynamics of self-acting foil bearings on a rotating circular drum using aluminized Mylar tape. Dynamic spacing variations were likewise investigated with the capacitance technique by Lin and Beye [6] and by Briggs and Herkart [7] in the study of the magnetic head-disk interface of magnetic recording disk files.

In the work reported in [4] through [7] the capacitance method was found especially useful because it furnished dynamic spacing information. This latter information is desirable in the design of magnetic recording devices, since a recording head has to maintain a stable and uniform transducer/medium spacing.

In this communication we use the capacitance probe technique to investigate the behavior of the magnetic head-medium interface in a rotating head configuration [8]. In particular, we have incorporated the capacitance probe in the magnetic head and have studied the head-tape flying behavior as a function of contour design, tape tension, and head velocity.

Experimental setup and measurement procedure

• *Measurement apparatus*

The experiments discussed in this paper were carried out on the vertically mounted rotating head device shown in Fig. 1, which consists of two sintered steel cylindrical mandrels of 44.5-mm radius. A removable rotor, mounted between the mandrels, carries a recording head in which a capacitance probe with circular cross section is glass-bonded. Clear Mylar tape with a 100 nm aluminum film on one side is wrapped through 360° around the pressurized mandrels which support the tape hydrostatically in the mandrel area but with the tape unsupported in the gap between mandrels. In the lower mandrel a stationary mercury bath is mounted concentrically to couple the capacitance probe signal from the rotating head to the capacitance meter. Conversion of capacitance into voltage output was accomplished with the arrangement shown schematically in Fig. 2.

Experimental procedures

• *Calibration*

In order to calibrate the capacitance data, stroboscopic white light interferometry as described by Talke and Tseng [8] was used. Since the aluminized tape is not transparent to light, replacement of this tape with a clear tape of identical mechanical properties is necessary for interferometric flying height measurements. To avoid possible ambiguities connected with measuring flying height on one tape and capacitance values on another, the following procedure was used, which allowed the use of the same tape for both the capacitance measurement and the white light interferometry.

First, the aluminized tape was wrapped around the stationary mandrels and the path of the rotating head on the tape was marked. Thereafter, a small "window" was etched into the aluminized layer approximately in the center of the track. At this location white light interferometry was used to measure the head-tape spacing, while

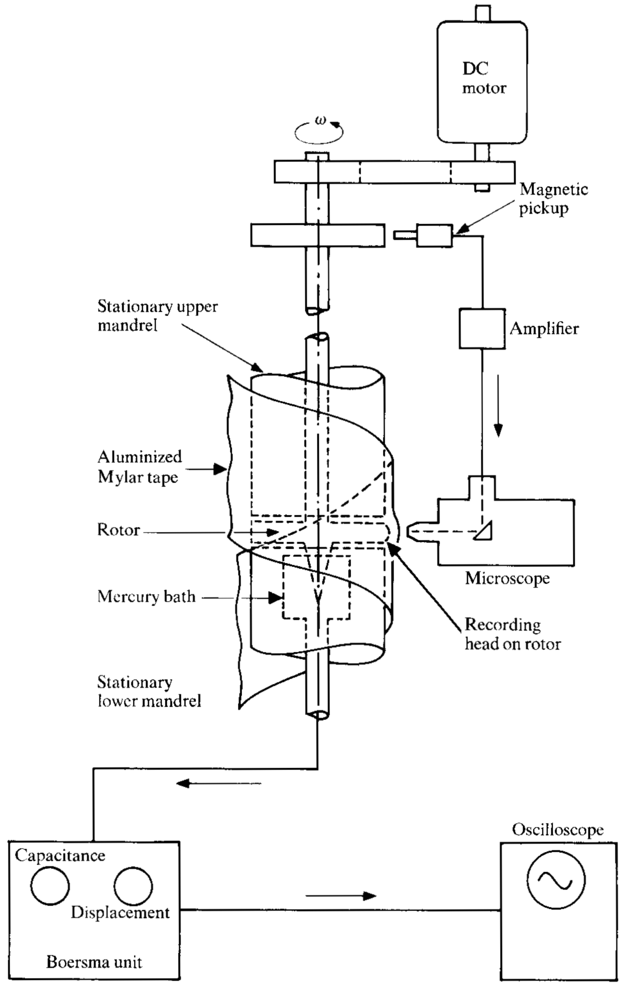


Figure 1 Experimental setup for capacitance measurement.

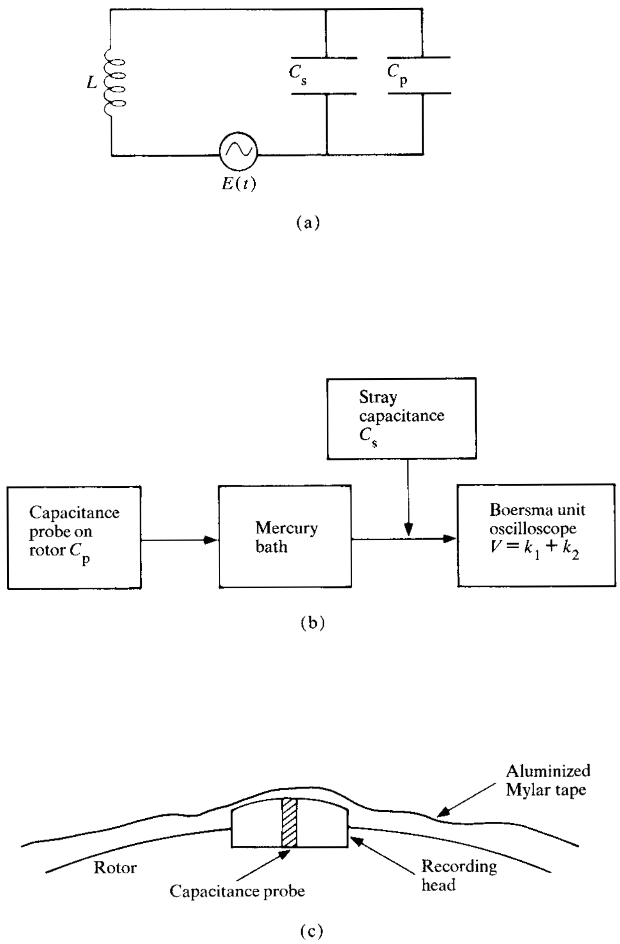


Figure 2 Schematic of capacitance probe measurement. (a) Resonance circuit. (b) Capacitance measurement. (c) Physical arrangement.

capacitance data were obtained everywhere else along the track. By equating the average capacitance output from both ends of the window to the interferometrically measured flying height in the window, we were able to establish a direct calibration of capacitance output in terms of spacing on the same tape. To extend the calibration to other flying heights, we varied head velocity and tape tension in small increments. It should be emphasized that removal of the aluminized layer in the small window area does not seem to affect the mechanical tape properties since the aluminized coating is only 100 nm thick, as compared to the tape thickness of 0.037 mm.

Throughout the calibration and experiments the uncoated side of the tape was chosen to be the surface that is adjacent to the head, i.e., capacitance variations were measured through the thickness of the tape. This may appear undesirable, since one would obtain higher resolution if the metallized surface were placed directly adjacent to the head. However, whenever this was done, catastrophic failure occurred due to intermittent contacts between the head and the aluminized tape during start-up. These intermittent contacts, on the other hand, were of little consequence if the uncoated side of the tape was adjacent to the head; hence, all tests were conducted with this latter arrangement.

Whenever the metallized side of the tape is chosen to be the back side of the tape, there are two capacitances in series, one due to the air gap and one due to the thickness of the Mylar tape (0.037 mm). Clearly, care must now be taken in interpreting capacitance variations in terms of flying-height variations because changes in tape thickness or tape dielectric constant influence the capacitance measurement. To account for this latter effect, we measured the dc-capacitance variations prior to each experiment along each track at near-zero velocity, when no air bearing existed between head and tape, and we referenced all dynamic flying-height data to this zeroreference line. In most cases it was found that the dc variations at low head velocities along a track were so small that corrections due to tape thickness or tape dielectric constant variations were insignificant; i.e., the variations were generally equal to or less than the resolution limit of white light interferometry (0.025 μm).

Experimental results

In Fig. 3 the flying-height variation along a complete track is shown for spherical heads of radius 38.1, 25.4, 19.1, and 12.7 mm. In all figures we have denoted the entrance and exit of the head into the tape by symbols A and C, respectively, while the location of the window is indicated by W. All capacitance traces in Fig. 3 were obtained for the same conditions of velocity (20 m/s), load (5 N), and protrusion of the head into the tape (0.076 mm).

Several observations can be made from Fig. 3. First, we note that all heads fly under the given conditions in the submicrometer region, the region most desirable from a magnetic recording viewpoint. Second, we note that the flying height of the head is not constant along the trace in the probe region, but varies between ± 12 percent of the nominal flying height. This variation of the flying height in the probe region is due to both a lengthwise shifting of the air bearing on the head and dynamic flying-height variations resulting from head-tape compliance variations. Finally, we observe that the air-bearing spacing at the head-tape entry point A becomes smaller than the nominal spacing as the radius of the head diminishes. This close spacing, corresponding to the pronounced voltage spike at A, shows that the dynamic information of the capacitance measurement is very helpful in designing the head-tape interface, i.e., a head exhibiting a close approach at the tape-head entry is prone to wear even if the average flying height over most of the track is large enough to allow complete hydrodynamic flying.

This statement is well supported by our experimental wear results. Physical examination of a used tape often reveals evidence of head-tape contact, generally starting in the entry region, but with little sign of wear along the remainder of the track. Furthermore, tapes that show wear along the center section of the track almost always show more severe wear and material transfer at the leading portion of the track.

The effect of contour changes on flying behavior is shown in Fig. 4 for a spherical head of 19.1-mm radius modified by two 0.13-mm-wide parallel "bleed" grooves in the longitudinal direction approximately 0.76 mm apart. Comparing the trace in Fig. 4 with that of the complete spherical head, Fig. 3(c), we notice a slight decrease in the circumferential flying-height variation, coupled with a 20 to 30 percent decrease in the average

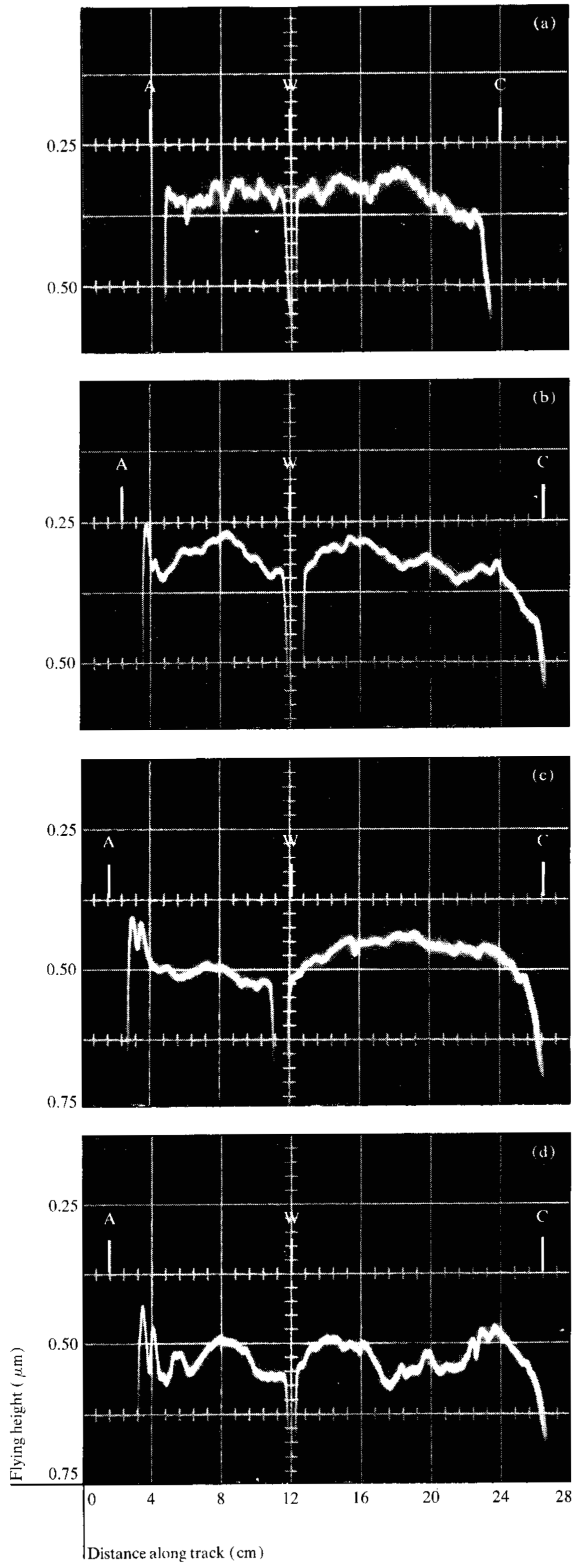


Figure 3 Circumferential flying-height variation as a function of head radius R (head velocity $U = 20$ m/s, tension $T = 5$ N, protrusion $\delta = 0.076$ mm). The values of R: in (a), 38.1 mm; in (b), 25.1 mm; in (c), 19.1 mm; and in (d) 12.7 mm.

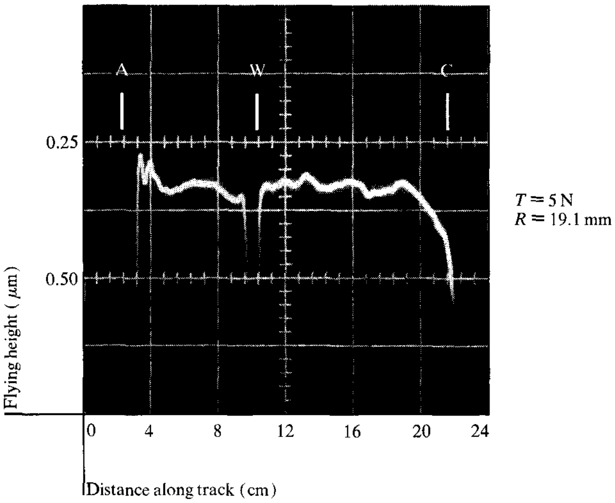
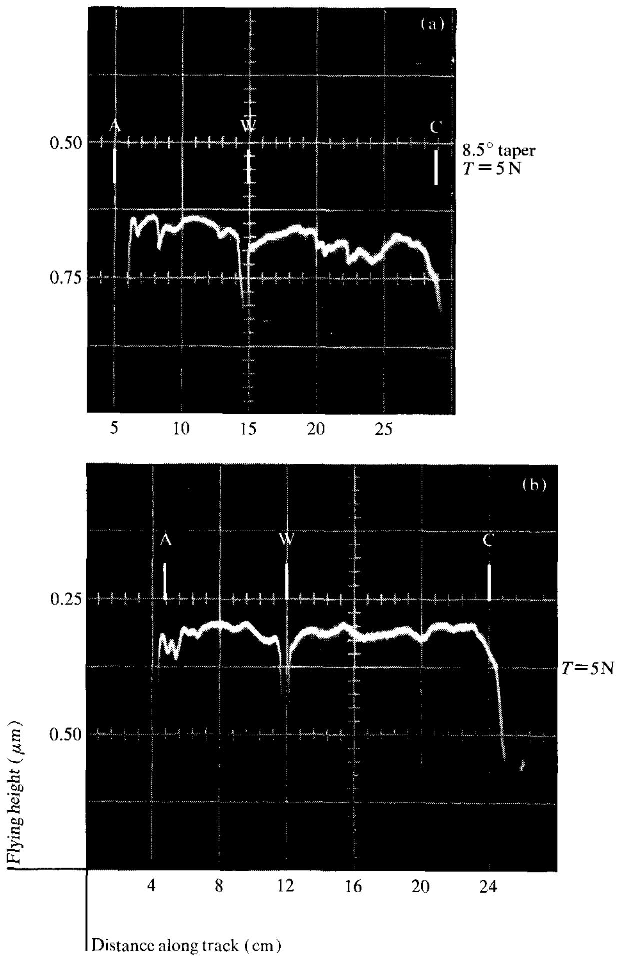


Figure 4 Capacitance trace showing the effect of "bleed" slots in the spherical bearing ($U = 20$ m/s).

Figure 5 Capacitance trace showing the effect of front taper on flying behavior ($U = 20$ m/s). (a) Spherical head with front taper, $R = 31.8$ mm; (b) spherical head without front taper, $R = 31.8$ mm.



flying height. The latter result apparently is due to the increase of side leakage caused by the slots.

If the effect of tension on the air bearing stability is studied, we note that the increase in tension generally causes a slight decrease in both the circumferential flying-height variation and the average flying height. The latter effect is small, however, since doubling of tension typically results in a flying-height decrease of less than 20 percent.

A typical flying-height trace for a 31.8-mm radius spherical head modified by an 8° taper of 0.25-mm length in the front section is shown in Fig. 5(a). We observe by comparison with Fig. 5(b) that the effect of the taper is to increase the average flying height from approximately 0.3 μm to 0.7 μm. The dynamic flying-height variation along the track is not substantially altered, however, and it appears that incorporation of a taper is an effective means of modifying the average flying height.

Discussion

The observed flying-height variations along a track as a function of speed, tension, and head design indicate that capacitance traces contain important dynamic information not obtainable from white light interferometry. Of course, since the calibration of the capacitance output relies on white light interferometry, the capacitance probe technique becomes useful only in conjunction with the interferometry, and both methods should be looked upon as complementary laboratory techniques.

In examining the capacitance traces of Figs. 3 through 5, we may ask what the cause of the head-tape dynamics is and to what degree these flying-height variations could be minimized. The answers to both questions seem related to the fact that the head causes a time-dependent deflection in the tape which is a function of head protrusion, head velocity, and head-mandrel design.

In Figs. 6(a) and (b) the time-dependent tape deflection, obtained by placing a stationary capacitance probe adjacent to the tape along the path of the head, is shown for a spherical head at velocities of 12.7 m/s and 25 m/s. We observe that the tape disturbance is wavelike in nature and strongly speed dependent, showing a drastic increase in amplitude and number of waves with increasing velocity [9].

It is apparent that these waves influence the flying behavior of the head since they change the angle of wrap of the tape over the head. In fact, the flying height-vs-speed behavior of a typical spherical head [Fig. 6(c)] shows that the flying height first increases with velocity, then reaches a maximum, and, finally, decreases as the velocity is increased further. This decrease in flying height with speed is in contrast to classical foil bearing theory [5], where a 2/3-power relation between flying height and speed is observed. It is apparent, however, that damping of the waves in the rotating head setup will influence the flying height-speed relationship observed in Fig. 6(c). In fact, it has been shown, by using a protruding rotor design, that damping of the waves may be achieved to such a degree that the flying-height decrease with velocity is eliminated.

One final point should be made. Due to the *in situ* calibration of the capacitance probe using stroboscopic white light interferometry, extension of the resolution and flying-height range of the capacitance probe was possible beyond that of prior studies. Because of its usefulness in the current work, it seems justifiable to suggest that the combination of white light interferometry and capacitance probe techniques should prove useful also in further applications related to elastohydrodynamic lubrication.

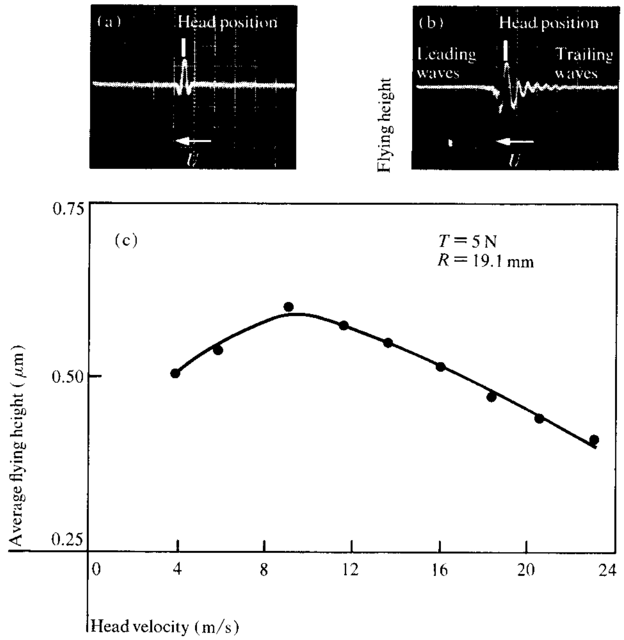


Figure 6 Head velocity effects. (a) and (b), time-dependent tape deflection as a function of head velocity ($T = 4$ N). In (a) $U = 12.7$ m/s. In (b), $U = 25$ m/s. (c) Effect of head velocity on head-tape spacing (protrusion $\delta = 0.076$ mm).

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Received May 3, 1976; revised December 9, 1976

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