Conclusion

It has been shown that the stress-induced demagnetization of a magnetic recording medium is attributed to the broadening of the magnetization transition zone by stresses under the demagnetizing field. The stress-induced demagnetization of the media is the net effect of the magnetization reversal of the individual magnetic particles dispersed in the magnetic layer. For an investigation of the magnetization reversal, both the magnetoelastic energy produced by three-dimensional stresses, and the magnetostatic energy produced by the demagnetizing field must be considered. It has been found that the magnetization reversal is possible by even small stresses if a large demagnetizing field exists.

This study also clarifies that materials with negative λ_{100} are more susceptible to stress-induced magnetization reversal than those with positive λ_{100}. As for λ_{111}, only the absolute value is significant.

Acknowledgment

The author wishes to thank Dr. T. Suzuki for his helpful discussions.

References

[1] T. Kitamoto *et al.*, "Pressure demagnetization of cobalt-containing ferromagnetic iron oxide" (in Japanese) presented IECE Tech. Group Meeting of Magnetic Recording, Japan, paper MR74-34, 1974.

[2] P. J. Flanders, "Changes in recording tape magnetization produced by stress," *IEEE Trans. Magn.*, vol. MAG-12, pp. 348–355, July 1976.

[3] S. Ogawa *et al.*, "Stress demagnetization in magnetic coated disk" (in Japanese) presented at IECE Tech. Group Meeting of Magnetic Recording, Japan, paper MR 76-28, 1976.

[4] S. Timoshenko and J. N. Goodier, *Theory of Elasticity*. Maple Press, 1951.

[5] S. Chikazumi, *Physics of Magnetism*. New York: Wiley, 1964.

[6] R. Muki, "Three-dimensional problem of elasticity for a semi-infinite solid with a tangential load on its surface" (in Japanese) *JSME*, Japan, vol. 22, no. 119, 1956.

Erase Profiles of Floppy Disk Heads

ERIC R. KATZ, MEMBER, IEEE

***Abstract*—An experimental method is described to measure the amplitude profiles across written tracks used in rigid and floppy disk drives. This method allows determination not only of read, write, and side-erasure widths associated with the heads, but also of the detailed shape of the written profiles. These profiles may be obtained for tracks in the as-written condition, or after modification by the write or erase functions of the head. This method was applied to floppy disk heads in order to determine the trim erase characteristics of straddle erase, tunnel erase, and the implicit side erase characteristic of the read/write core itself. A number of typical track profiles are shown, demonstrating the usefulness of this technique. It was found that the straddle erase elements exhibit erasure both under the air gap and under the poles straddling the read/write core; the tunnel erase elements exhibit uniform erasure across their erase gaps but are subject to azimuthal misalignment effects; and the read/write cores themselves exhibit an implicit erase function during normal writing which, in the case studied, extended about 360 μm (9 μm) to each side of the core. Applications of this method to evaluate heads for use at high track densities are also outlined.**

I. Introduction

Track densities in floppy disk drives are currently in the 96 TPI to 135 TPI range, limited primarily by the relative lack of dimensional stability of the substrate over the necessary operating environment and by the fact that track following techniques are not employed. By incorporating track following techniques, track densities of 200–300 TPI are becoming feasible. In rigid drives, where disk substrates are dimensionally more stable, and track following techniques are used, track densities of 800–1000 TPI are practical.

In both floppy and rigid disk drives, the performance at high track densities depends on the accuracy of head registration during writing and reading. If a guard band is present, a small degree of misregistration will result in a loss of signal, resulting in a corresponding increase in the error rate [1]. However, if the degree of misregistration is larger than the extent of the guard band, the head can pick up extraneous signals, either from the adjacent track or from previously recorded information on the same track. These extraneous signals act as "coherent" noise sources, with phase that is random with respect to that of the on-track signal. The resulting additional bit shift can greatly increase the bit error rate, causing a rapid degradation of the system performance.

To date, in rigid disk drives these effects are minimized by using dedicated servos for track following, while floppy disk drives, which do not employ this technique, rely on dc-erase elements to generate relatively wide guard bands between tracks.

As track densities become higher, it becomes increasingly important to determine the quantitative relationships between

Manuscript received May 9, 1983; revised March 7, 1984.

The author was with the Shugart Corporation, 475 Oakmead Parkway, Sunnyvale, CA 94086. He is now with Domain Technology, 302 Turquoise Street, Milpitas, CA 95035.

0018-9464/84/0700-0528$01.00

the physical dimensions of the head, the width of the resultant written track, the width of the response function of the readback head, and the details of the guardbands between the tracks. Some theoretical work in this area has already been published [2]-[6]. A novel experimental method of determining the "write" profile of a tape head has also been described [7] in which a signal is recorded on the edge of a tape which is oriented perpendicular to the face of the head. A more conventional experiment based on sweeping the read/write head across the written track has also been described [8].

We have refined this procedure to determine not only the effective read and write width of read/write heads, but also the actual track-average amplitude profiles across the width of the written tracks. We specifically used this method to determine erase profiles (degree of erasure versus position) in the floppy head/disk interface resulting from tunnel erase, straddle erase, as well as the intrinsic side erase characteristic of the read/write core itself. We are also able to measure the crosstalk response between the erase elements and the main read/write core.

Since this method is quite general, it may be applied to rigid disk drives using either ferrite or thin-film heads, to determine effective read widths, write widths, and the extent of any intrinsic side erasure effects which can be used as intertrack guard bands.

II. Procedure

A. Equipment

The tests were performed on a Dymek Model 852-A floppy head/disk for an 8 in format and a Model 852-1A tester for $5\frac{1}{4}$ in format disks. These testers provided the disk clamping and rotation hardware, head positioning mechanisms, write circuits, readback circuits, and signal amplitude measurement and digitizing capability. All of the major functions could be controlled externally via a computer interface.

The head positioning mechanism consists of two stepper motors connected in tandem to a precision ground lead screw preloaded to minimize backlash. Minimum step size is 50 μin ($\sim$1.25 μm), while backlash is held to less than this value. The write and erase circuits are selectable independently. Internal oscillators provide the standard $1F$ and $2F$ frequencies. Signal amplitudes are measured with a wide-band peak detector circuit which is coupled to an analog-to-digital converter with a $3\frac{1}{2}$ decimal digit resolution. A special amplifier with an additional gain of 30 can be switched in, to improve amplitude resolution at low signal levels. For noise reduction an "overwrite filter" which consists of a notch filter tuned to the $1F$ frequency can be switched into the readback channel.

The testers were interfaced to a Hewlett-Packard HP-85 desktop computer, which is used both as overall system controller and also as the data processing computer.

B. Experimental Procedure

The experimental procedure consists of the following: a single frequency pattern is written with a head at an accurately known radial position on the disk. The head is then moved completely off the written track, and then swept across the track in precisely controlled steps. At each position the signal amplitude is measured and stored in the computer, along with the head position data. The resulting plot of observed amplitude versus head position represents a convolution of the written track profile with the response function across the head during readback. However it is the written track profile itself which is of interest, i.e., track average signal amplitude recorded in the media versus distance from the track center. This information is extracted from the observed data using a straightforward procedure described in the following section.

A particularly useful variation of this procedure consists of modifying a previously written track by placing either the read/write gap or one of the erase elements at an accurately known position relative to the track and activating the head for one revolution of the disk. The resultant track is then rescanned as above, generating a new amplitude versus radial position curve, and a profile of the modified track remaining in the media.

C. Data Reduction Procedure

We consider a head positioned partially over a previously written track. Letting the x coordinate represent position across the width of the track, we define a function $W(x)$ as the track-averaged amplitude of the magnetization pattern recorded in the track at position x. Then $W(x)$ is referred to as the written track profile. Let $R(x')\,dx'$ represent the readback response of the head to an increment of track width of unit amplitude and of width dx' centered at position x' relative to the center of the head. $R(x')$ is referred to as the readback response function of the head. Clearly the head will reproduce a signal only if it is positioned such that $R(x')$ overlaps $W(x)$, at least partially. If there is no azimuthal misalignment, so that all the contributions to the net signal are in phase, the observed signal amplitude will be

$$S(x_0) = \int_{-\infty}^{\infty} R(x - x_0)\, W(x)\, dx \qquad (1)$$

where

x_0	position of the center of the head during readback
$R(x - x_0)$	response function of the head about the point x_0
$W(x)$	written profile.

The region of integration, while formally extending from minus infinity to plus infinity, actually extends only over the regions where $R(x - x_0)$ and $W(x)$ are simultaneously nonzero, as shown by the shaded area in Fig. 1. If the position of the center of the readback head x_0 is varied by sweeping the head across the written track, we expect to see a response similar to that shown in Fig. 2.

At the far left of this figure, the head is completely off the written track, and no signal is observed. As the head is swept to the right, the region of overlap becomes first nonzero, increasing to a maximum value when the head is centered over the written track, and then decreasing as the head moves off track to the right, resulting in the response shown.

It is convenient to define the effective widths of the written track profile and the readback functions. We define the width of the written profile w as the width of $W(x)$ near the baseline (say at 1 percent of the maximum amplitude), and the width

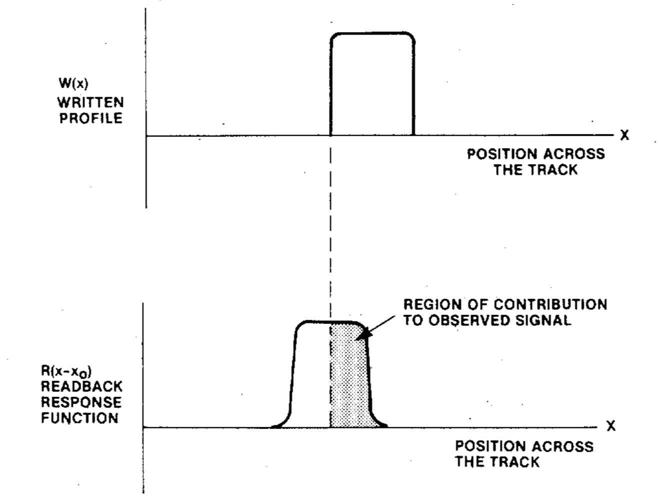


Fig. 1. Written profile and readback response function, showing region of contribution to observed signal amplitude.

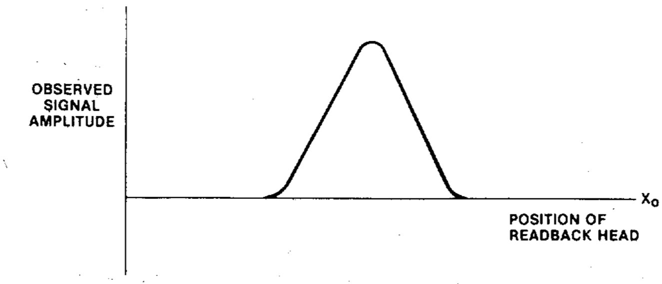


Fig. 2. Observed signal amplitude as readback head is swept across written track.

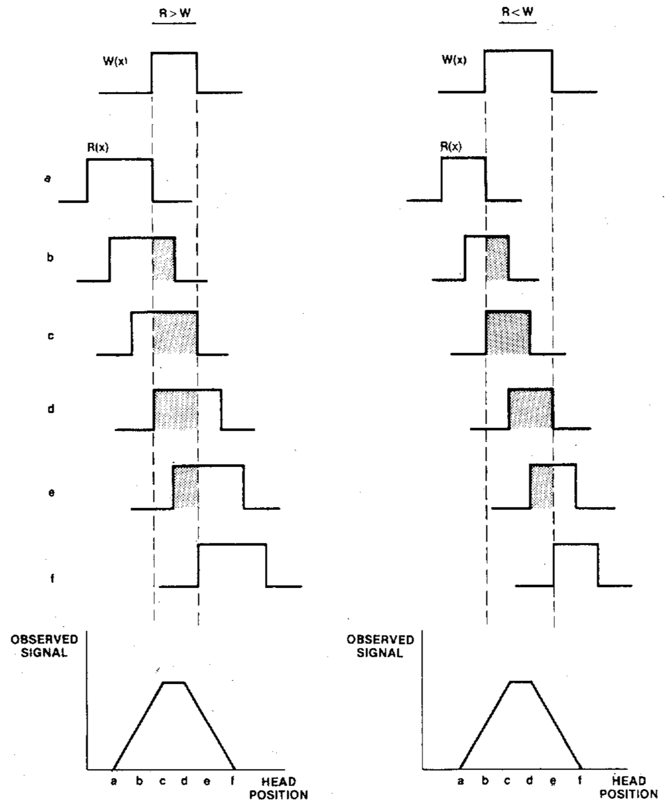


Fig. 3. Details of observed readback amplitude versus head position as readback head is scanned across written track. Left side corresponds to read width greater than written width. Right side corresponds to read width less than written width.

of the readback function r as the width of $R(x)$ at the 50 percent amplitude points. Generally for a given head, r is approximately, but not identically, equal to w. We also expect r to be somewhat wavelength dependent, and w to be somewhat dependent on write current.

It is possible to infer the values of r and w from the observed amplitude versus position curve in Fig. 2. The details leading to the observed amplitude versus head position are shown in Fig. 3 for the case $r > w$ (left side of figure), and $r < w$ (right side of figure). In this illustration both the written profiles and the readback response functions are represented as ideal square-wave functions. There are six positions shown for the readback head as it is scanned across the written track. For each case the shaded area represents the observed signal amplitude. For either case the maximum observed signal amplitude occurs when the narrower of r and w is completely nested in the wider of the two. The difference in the values of r and w results in the flattened central portion of the observed signal response (points c to d). The half amplitude points (points b and e) occur when either of the edges of the wider of $W(x)$ or $R(x)$ is aligned with the center of the narrower of the two, as shown in the corresponding figures. Thus the distance on the observed signal amplitude versus head position between the half-amplitude points $|x_e - x_b|$ is the wider of w or r. Generally this corresponds to r.

The baseline points on the observed curve (points a and f) correspond to where the right side of $R(x)$ first aligns with the left side of $W(x)$, and to where the left side of $R(x)$ first aligns with the right side of $W(x)$, respectively. Clearly the distance between points a and f is $r + w$. By comparing $|x_f - x_a| = r + w$ with $|x_e - x_b| = \max\ [r, w] = r$, one may infer r and w separately. For nonsquare-wave readback functions, the observed signal versus position curve will approach the baseline more gradually. However by redefining the baseline points a and f as the extrapolation points from the steep portion of the curve (we chose the extrapolation at the 20 percent amplitude points), the effective values of r and w may be inferred for this case also.

It is also possible to infer the actual shape of $W(x)$ from the observed amplitude versus read head position curve. This is particularly useful for determining the effects of erase elements and adjacent track interference effects, where the actual amplitude versus position information of the track itself is of interest. Consider an arbitrary point on the right half of one of the scans in Fig. 3, where only the leading (right) side of the head is over the written track at a position x; the trailing (left) side is still positioned over unrecorded media. As the head is moved an additional incremental distance dx to the right, the additional observed signal amplitude is simply the additional area covered by the leading edge, or $W(x)\, dx$. This is seen by differentiating (1) with respect to x_0 and noting $d/dx\ R(x)$ is nonzero only near the two edges of the head, and also noting that the head is in a position where $W(x)$ is zero at the trailing edge. That is,

$$\frac{dS(x_0)}{dx_0} = W(x_0 + r/2) - W(x_0 - r/2) \rightarrow W(x_0 + r/2) \qquad (2)$$

where we have assumed the total read width is r. Similarly as the head is scanned further across the written track so that its leading edge is completely off track, the observed slope is described by

$$\frac{dS(x_0)}{dx_0} = -W(x_0 - r/2). \tag{3}$$

Thus the written track profile is simply the slope of the first half of the observed signal amplitude versus head position curve, shifted to the right by half of the effective read width of the head. Likewise it is also the negative of the slope of the second half of this curve, shifted to the left by half the effective read width. Since in the general case, neither of these two curves covers the written track completely, both curves may be derived and plotted. The region of overlap allows a check of the consistency of the procedure, and in cases where the written profile has a recognizable structure, allows the two half-curves to be matched up, to refine the estimate of r.

This approach is expected to work well with heads used in rigid disk applications. However heads used with floppy disks also have separate erase elements positioned on each side of the read/write core. These elements also exhibit a readback response to signals recorded in the media and are magnetically coupled to the main read/write core via air-leakage paths. This crosstalk adds two side lobes to the main readback response function. However for the purpose of analyzing the performance of the disk drive, these side lobes can be included into the written track profile, resulting in an "effective track profile" which contains the main central track, and side "ghost" tracks representing the crosstalk during readback.

This crosstalk has an additional effect on the observed signal versus head position function. Although the crosstalk signal consists of the same frequency as the main signal, in general it will exhibit a different phase, so that it adds vectorially rather than algebraically to the main signal. This effect can modulate the shape of the computed written track profiles, particularly near the two edges of the profile, where the main signal is weakest and the crosstalk contribution is strongest. This effect can often be distinguished from true modulation effects by profiling the track of interest with different signal frequencies, thereby changing the phase relation between the main signal and the crosstalk. This effect can be seen in profiles exhibited in Section III.

In practice noise is present along with the signal. Since differentiating the observed amplitude versus position curve enhances the high spatial frequency noise, selection of an appropriate step size in conjunction with some smoothing was found to be necessary. This allows a trade-off between the "noise" in the derived track profiles and the spatial resolution. We worked with step sizes in the range of 0.01 to 0.04 of the nominal track width of the head. Smoothing consisted of a first nearest neighbor smoothing (1/6, 2/3, 1/6) followed by a second nearest neighbor smoothing (1/10, 0, 8/10, 0, 1/10) where these values were also determined empirically. The net smoothing corresponding to these coefficients can be expressed algebraically as

$$Y_{i'} = a_0 Y_i + a_1(Y_{i-1} + Y_{i+1}) + a_2(Y_{i-2} + Y_{i+2}) + a_3(Y_{i-3} + Y_{i+3}) \tag{4}$$

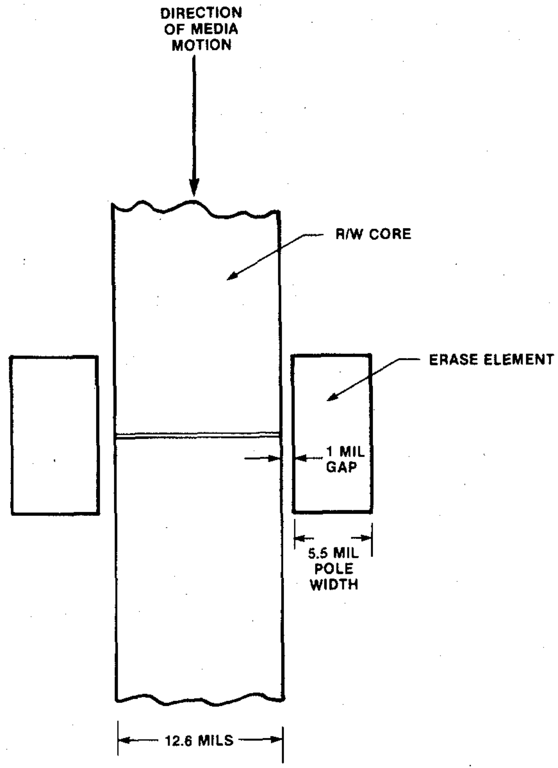


Fig. 4. Shugart 860 head with straddle erase, as viewed from the disk.

where

$a_0 = 32/60$
$a_1 = 9/60$
$a_2 = 4/60$
$a_3 = 1/60$

and where Y_i is the observed value of the amplitude of the ith step as the head is incremented across the written track, and $Y_{i'}$ is the corresponding amplitude of that point after smoothing. Obviously other smoothing coefficients and step sizes can be used to optimize the trade-off between spatial resolution and noise.

It was also found desirable to "subtract" the wide band media and electronic noise from the observed signal, especially near the low amplitude edges of the observed profiles, using $S_i' = (S_1^2 - n^2)^{1/2}$, where S_i is the observed signal amplitude, S_i' is the corrected value of the signal, and n is the value of the wide band noise, as observed when the readback head is completely off the written track.

The procedures described here are highly suitable for computer data reduction and were, in fact, performed by the same computer used as system controller as part of a general track profile program developed for this purpose.

D. Description of Heads Tested

Profile studies were performed on two different types of floppy disk heads. The first head was from a Shugart 860 drive, which is an 8-in disk format 48 TPI drive employing straddle erase for track trimming. The view of the head as

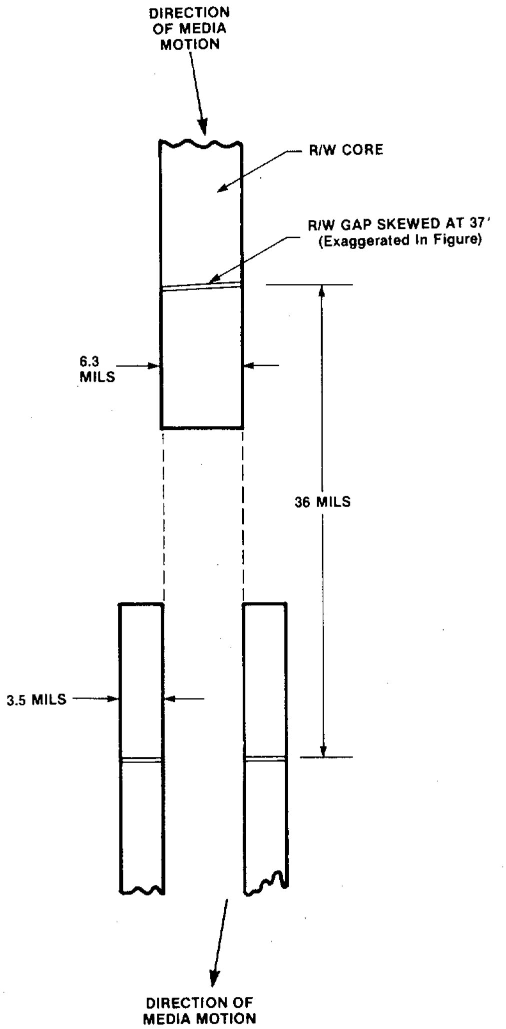


Fig. 5. Shugart 460 head with tunnel erase, as viewed from the disk.

seen from the disk is shown in Fig. 4. The read/write core width is nominally 12.6 mils (315 μm). Straddling the read/write core in the vicinity of the read/write gap are two poles of the horseshoe-shaped dc erase element, which is driven by its own separate coil. When activated, the dc magnetic field flows transverse to the long dimension of the track through the air gaps separating the erase poles from the read/write core, as well as through the read/write core itself. Each of the two air gaps is nominally 1 mil (25 μm) wide. The length and positioning tolerances along the track length dimension are such that at least some portion of the erase structure lies "down stream" of the read/write gap.

The second head studied was from a Shugart 460 drive, which is a $5\frac{1}{4}$ in format 96 TPI drive employing tunnel erase for track trimming. The view of this head as seen from the disk is shown in Fig. 5, the erase function is performed by two conventional gapped-ring erase elements, whose gaps lie parallel to, and approximately 36 mils (1440 μm) downstream of the read/write gap. They employ a common erase current coil which generates a longitudinally oriented dc field in each of the erase gaps. The read/write core width is nominally 6.3 mils (252 μm). The spacing between the inner edges of the erase elements is accurately held to the same dimension by means of a nonmagnetic spacer. The nominal width of each of the erase elements is 3.5 mils (140 μm).

The read/write gap is canted at a small angle (37 min), which is exaggerated in the figure. When the head is placed in the drive, it is oriented so that the read/write gap is aligned transverse to the length of the track. This causes the region between the two erase elements to be better aligned to the written track by compensating for the track curvature and the 36 mil offset between the erase gap and the read/write gap centerlines. Even with this compensation, the alignment is not perfect, due not only to the differences in radius of curvature between the innermost track and the outermost track, but also due to tolerances in the alignment procedure itself. The result is that one side of the written track is "clipped" by the erase element which overlaps the track, while the other side of the track is left with a small untrimmed region between the edge of the written track and the beginning of the dc erased region.

III. Results and Discussion

Fig. 6 shows a typical plot of the observed output versus head position for the 8 in drive head with straddle erase. This plot was obtained as follows. First the disk was bulk erased, and a track was written with a $1F$ single frequency pattern with the erase element disabled. Next the head was offset 20 mils (500 μm) and stepped in 500 μin (12.5 μm) increments across the written track for 40 mils (1000 μm), then stepped back across the track using the same step size, but in the opposite direction. The amplitude versus position data were smoothed as described in Section II and is plotted in the figure. These results demonstrate the excellent repeatability and backlash control during the scan. The computed written track width was 12.11 mils, while the effective read width was computed to be 12.37 mils.

Fig. 7 shows a complete profile taken with the same head, consisting of the spatially smoothed amplitude versus position data (large triangular shaped function with peak amplitude of 100 units), and also the computed written track profile (smaller rectangular shaped function with average central amplitude of about 25 units). This profile was generated for a $1F$ signal written at track 5 without using the trim erase. The head was again scanned across a 40 mil region centered at the written track, but in one direction only, and using 250 μin (6.25 μm) steps. With this finer step size, the written and effective read widths were determined to be 12.03 mils and 12.37 mils, respectively. The computed profiles show good self-consistency where the two half-profiles (as determined from the positive slope region and the negative slope region) overlap. This figure also shows several additional features of interest. The written amplitude exhibits a modulation across the width of the track, with a period of about 4 mils, and an amplitude of about 10 percent of the average signal level. Crosstalk effects from the erase elements are seen at the two edges of the computed profile, which cause an apparent "undershoot" in the write profile, followed by a relatively flat region about 5 mils wide at an amplitude of about 6 percent of the on-track signal.

Fig. 8 shows a profile at the same track position written with a $2F$ signal. Since the notch filter cannot be used at this fre-

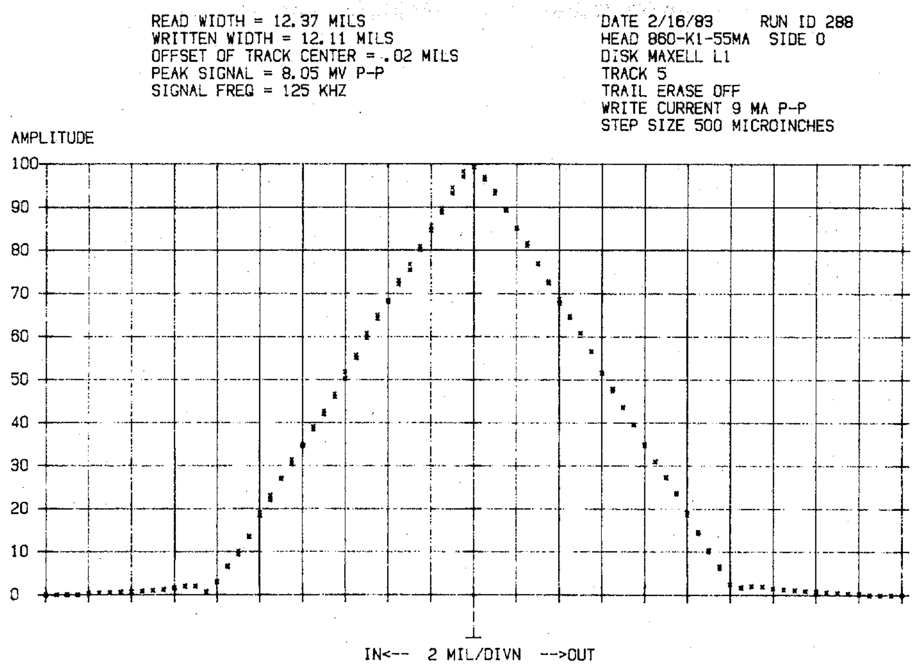


Fig. 6. Typical plot of observed signal amplitude versus head position using Shugart 860 head (8 in format). Center of plot corresponds to the position of the head when the track was written. Each division in the x-direction corresponds to 2 mils of head movement, with increasing x corresponding to movement radially outward. Track was written with erase element disabled.

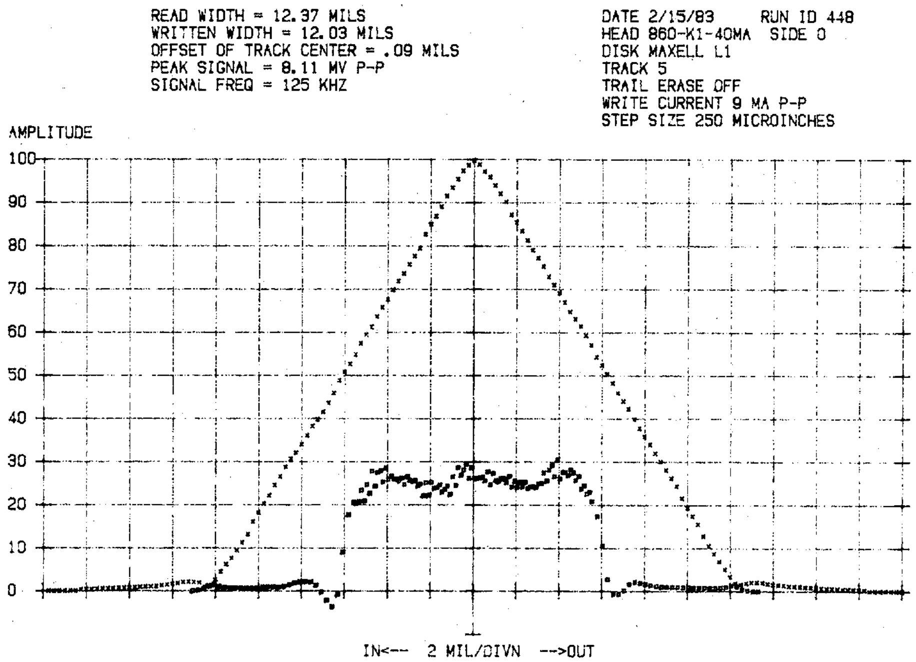


Fig. 7. Typical complete track profile using Shugart 860 head. Large tent-shaped function is smoothed observed signal amplitude versus head position. Smaller rectangular-shaped function with ripples is computed track profile.

quency, the signal is somewhat noisier. However the computed profile still exhibits the same amplitude modulation across the written track, but the crosstalk effects in the vicinity of the track edges are greatly attenuated. Thus we concluded that the amplitude modulation across the written track is real (possibly due to a wear pattern caused by the read head, or by the burnishing head during manufacturing) and is not an artifact caused by crosstalk interference. However not all track locations exhibited this degree of modulation.

Fig. 9 shows a profile of a $1F$ signal at a different radius (track 23) on the same disk, which exhibits a much smaller degree of modulation across the track, but still exhibits crosstalk interference effect near the track edges.

Fig. 10 shows a typical profile for the case where the written track is significantly narrower than the readback function of the head. The track was prepared by first writing a normal track; the head was then positioned 1 mil radially inward and the trim erase element was activated. The trim erasure was re-

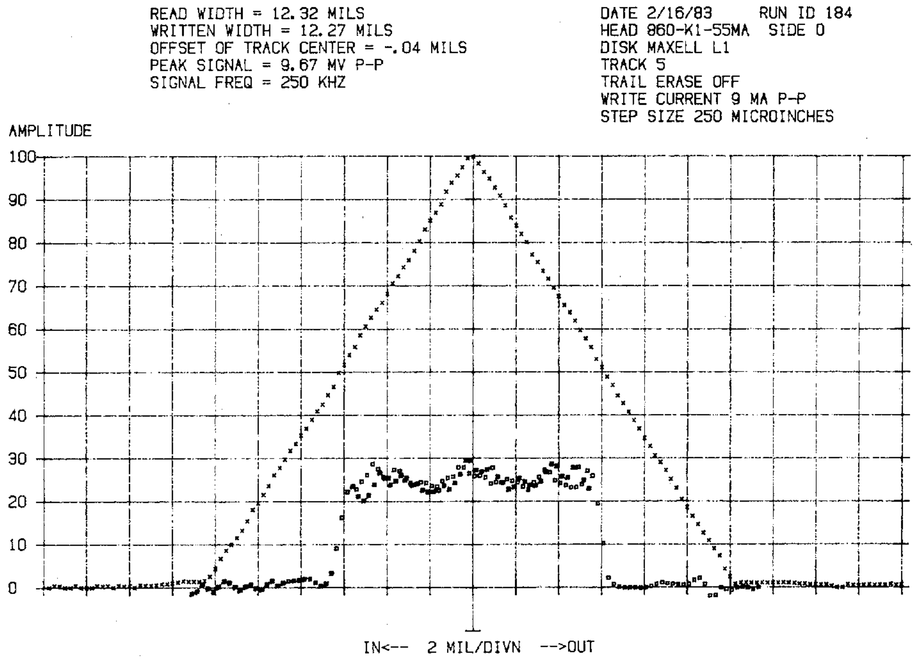


Fig. 8. Same as Fig. 7, except written frequency is $2F$ (250 kHz) rather than $1F$ (125 kHz).

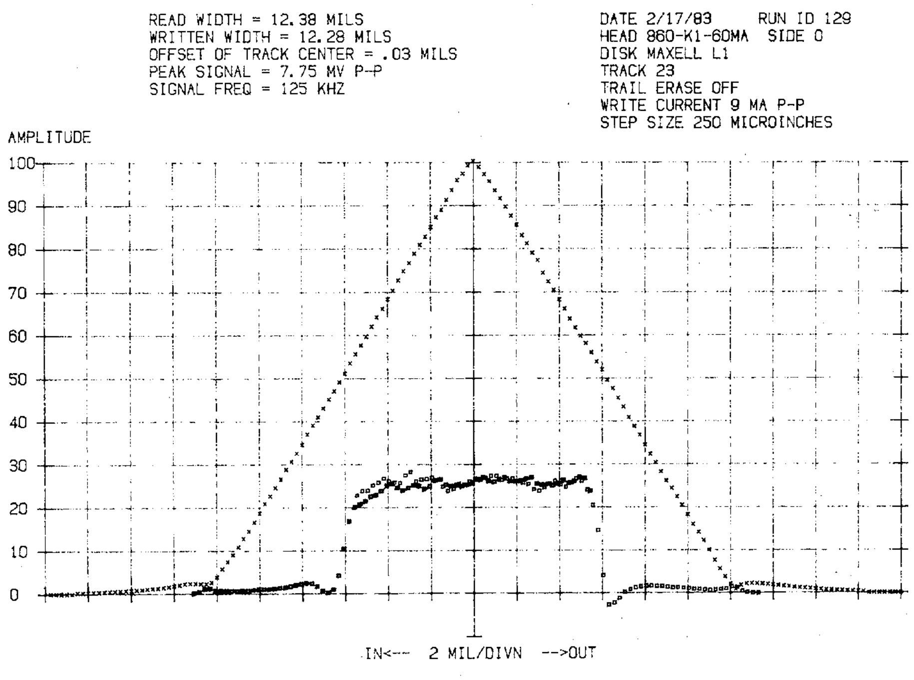


Fig. 9. Track profile performed at track location exhibiting only a small degree of amplitude versus position modulation.

peated with the head positioned 1 mil radially outward. The resulting track was then scanned in 250 μin steps over a 40 mil band, in the usual manner. The observed amplitude versus position data exhibit the characteristic flattened peak typifying significant differences between r and w. The computed profile still exhibits the radial amplitude modulation. The computed width of the remaining track is 9.95 mils, while the effective read width of the head was computed as 12.29 mils.

The results of a slightly different procedure are shown in Fig. 11. A track was written at a frequency of $1F$; the head was then offset by 1 mil and the write circuit was activated for 1 revolution using a dc current to remove all but the innermost 1 mil of the track. The resulting "filament" was then scanned in 250 μin steps as shown. The observed amplitude versus position data represent the readback function $R(x)$ of the head itself, but averaged over the approximate 1 mil width band of the written track.

The next series of figures demonstrates straddle erase element profiles as a function of the dc erase current used. In each experiment a track was first written at a frequency of $1F$. Next one of the two erase elements (either the radially inner or outer element) was positioned so that it was entirely con-

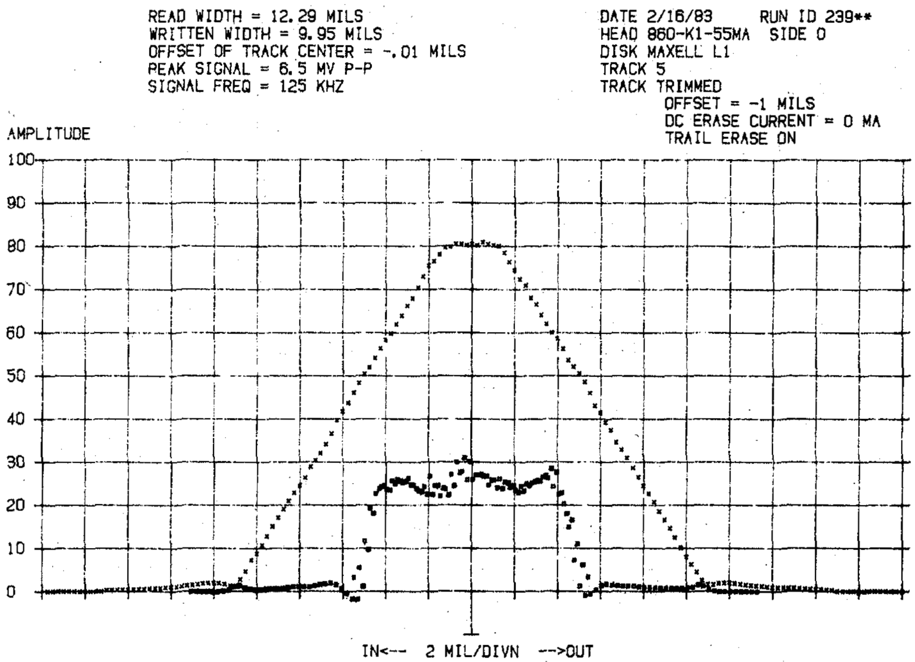


Fig. 10. Track profile for case when the written track is narrower than readback head. Taken with an 860 head.

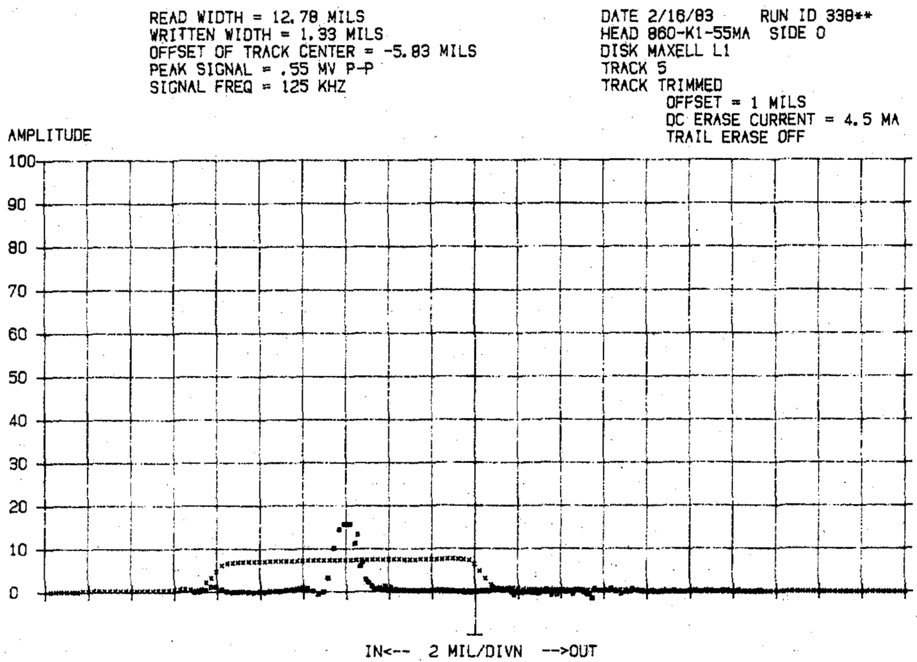


Fig. 11. Track profile of a very narrow written track. Taken with an 860 head.

tained within the region defined by the written track. The erase element was than activated for 1 disk revolution, and the resulting pattern was scanned in 250 μin steps over the 40 mil region centered on the original track position. The results for 60 mA dc erase current are shown in Figs. 12 and 13 for the outer and inner elements, respectively. This value of erase current is the one used during normal operation of the head in the drive. For each case the resultant profile consists of the original approximately rectangular function of amplitude 25 units and width 12.3 mils, but with a rectangular shaped region erased to very low amplitude and of width of about 7 mils running through the interior. This width is approximately the sum of the erase air gap (~1 mil) and the erase pole thickness (~5.5 mils). The track profile before erasure is as shown in Fig. 8.

At this point it is worthwhile to observe that the shape of the observed amplitude versus head position curve is quite complex; however the computed effective track profiles, determined as described in Section II, are quite straightforward in their interpretation.

Figs. 14 and 15 show the results of a similar set of experiments, but using a reduced value of erase current of 30 mA.

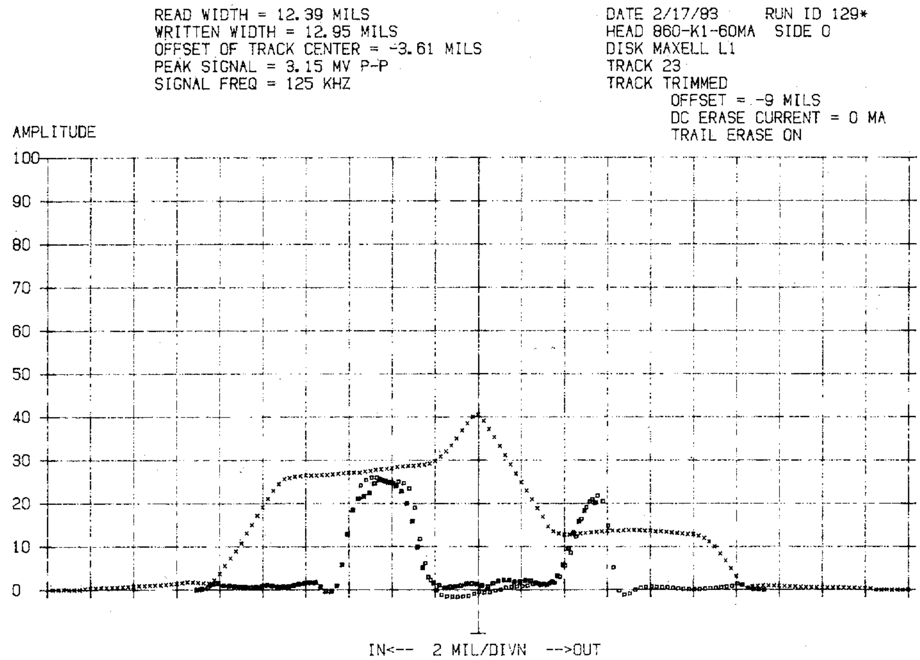


Fig. 12. Track profile for outer straddle erase element for 860 head, using erase current of 60 mA.

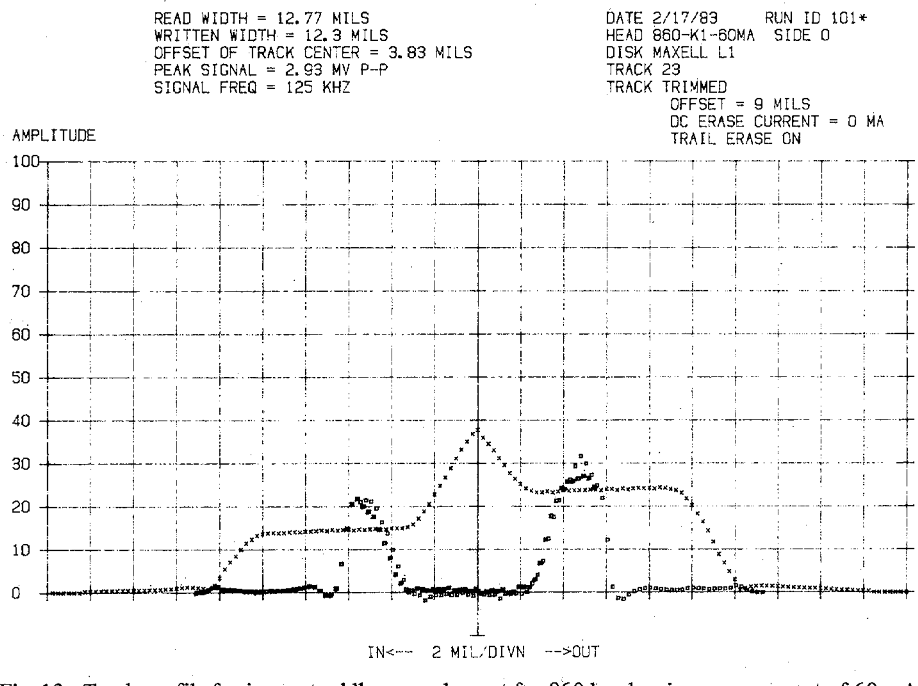


Fig. 13. Track profile for inner straddle erase element for 860 head, using erase current of 60 mA.

In this case the dependence of the erase efficiency across the erase structure is apparent. The erase efficiency is largest directly under, and in the immediate vicinity of the air gap. It is close to 100 percent in this region. Under the erase poles, some erasure still occurs, but at reduced levels. For the outer element (Fig. 15) the signal amplitude under the portion of the erase pole farthest from the read/write core decreased from 25 amplitude units to about 10 units, corresponding to an erase efficiency of 60 percent. For the inner element, the signal decreased from 25 units to about 6 units, corresponding to an efficiency of about 76 percent.

Although significant erasure takes place under the entire erase pole, the region of erasure extends only for a very short region under the read/write core. This "undercutting" was determined by writing a track with the dc erase element turned on, and profiling the resulting tracks to determine the resultant written track widths. This was performed using various values of erase current, and comparing to the case with no erase current. For these measurements the signal frequency used was $2F$ (250 kHz), to reduce crosstalk effects near the track edges. A typical profile is shown in Fig. 16, for an erase current of 60 mA. The computed track widths are summa-

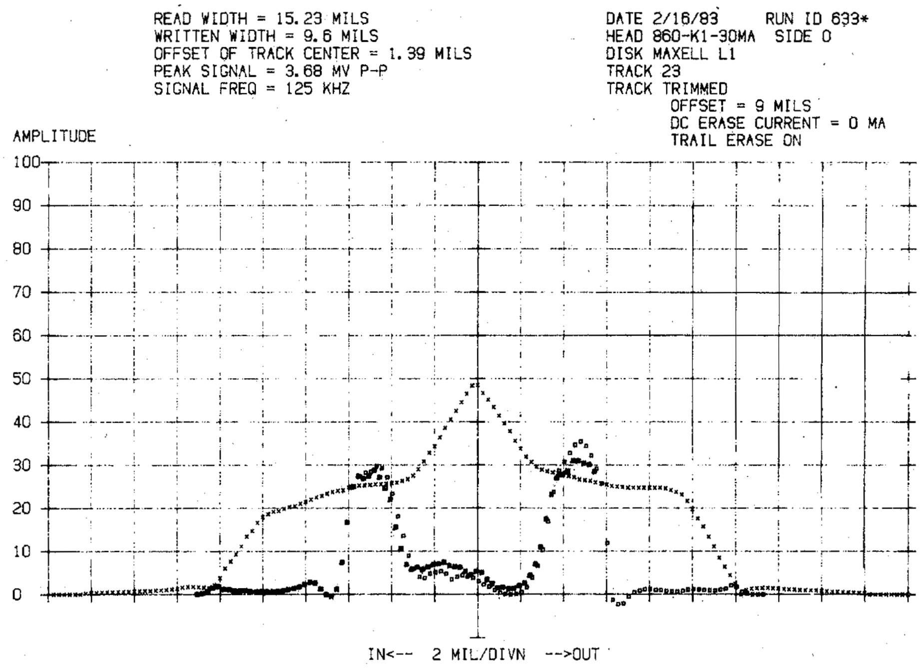


Fig. 14. Track profile for outer straddle erase element for 860 head, using erase current of 30 mA.

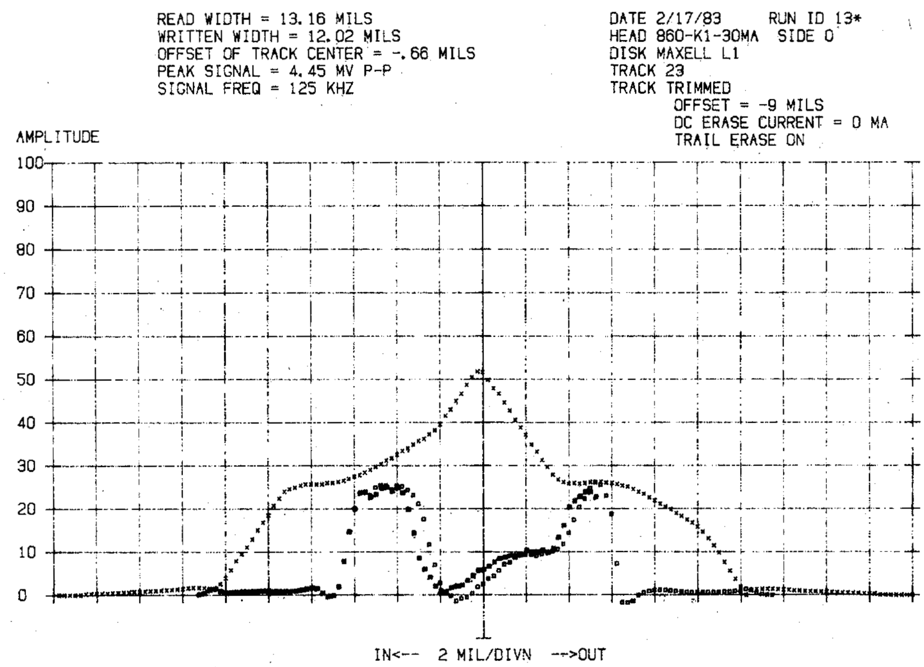


Fig. 15. Track profile for inner straddle erase element for 860 head, using erase current of 30 mA.

rized in Table I. As the erase current is increased, the erase element trims further into the written track under the read/write core, thereby reducing the written track width. However, even at the maximum value of erase current used, the track width decreased only 650 μin (16.25 μm), or 325 μin (8.13 μm) on each side of the track.

Another series of experiments was performed to determine to what degree the read/write core exhibits an intrinsic trim erase capability during normal writing, distinct from the erase elements. Such a phenomenon results from fields in the side-fringing region of the head which, although not strong enough to record into the media, are strong enough to erase previously recorded signals. The experiment was performed as follows: a track was written at $1F$ and profiled. The observed written track width was 12.36 mils. The head was then moved radially outward 12.00 mils and was used to write a track at frequency $2F$ for 1 disk revolution. Thus a small band of about 0.36 mils width along the outer edge of the track originally written

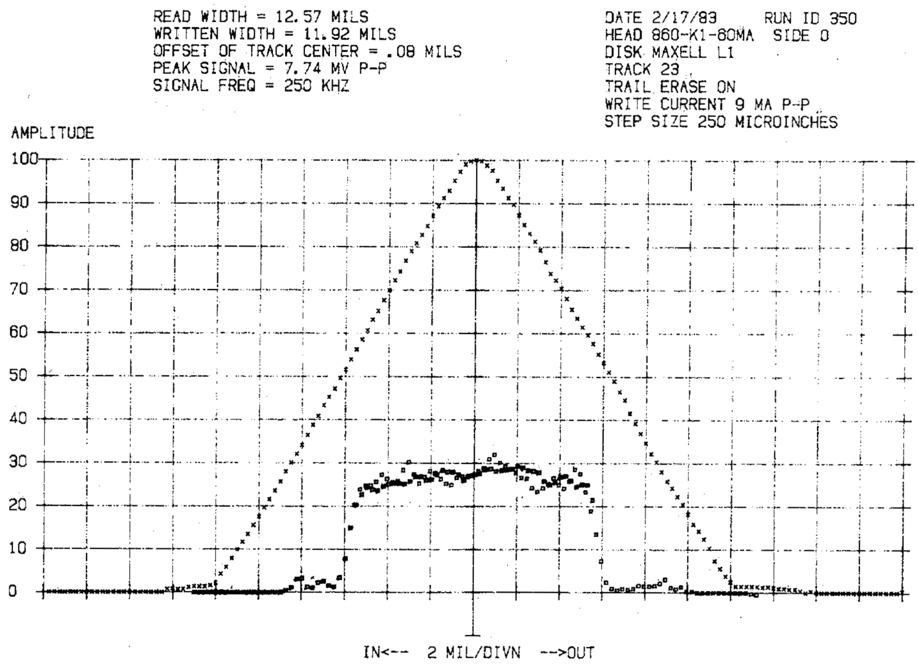


Fig. 16. Track profile for 860 head after track was written with straddle erase enabled, using erase current of 60 mA.

TABLE I
EFFECTIVE WRITTEN AND READBACK TRACK WIDTHS VERSUS STRADDLE ERASE CURRENT

Erase Current	Computed Written Track Width	Computed Readback Track Width
60 mA	11.92 mils	12.57 mils
40 mA	12.01 mils	12.58 mils
20 mA	12.32 mils	12.81 mils
0 (erase off)	12.57 mils	12.64 mils

with $1F$ was updated with the inner edge of the new track written at $2F$, using the value of write current normal for this head. The resultant pattern was profiled using the notch filter tuned to the $1F$ frequency of the original track. In the absence of any intrinsic side trimming occurring during the writing of the second track, the observed width remaining on the original track would be 12.00 mils. A track width less than this would result from side trimming occurring at the inner edge of the head during the writing of the new track. Indeed, the observed width determined by profiling the original track was 11.59 mils, indicating a trim erasure distance of 0.41 mils at the value of write current used. By repeating this experiment, but shifting the head radially inward before writing the $2F$ pattern, the trim erase distance for the outer edge of the read/write element was found to be 0.31 mils. The average of these two, 360 μin (9 μm) represents the implicit side-trimming distance of this head. While this effect is not currently utilized in floppy disk heads, its presence in rigid disk heads may be very important in the performance of these drives at high track densities.

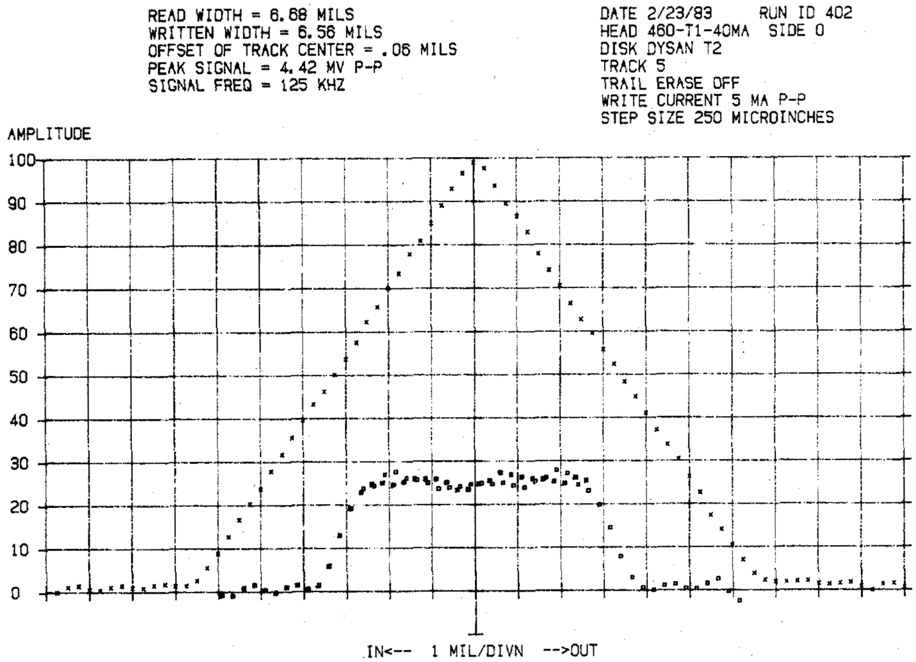
Track profile measurements were also performed using a 5-in drive head with tunnel erase. Again to minimize interference effects from crosstalk between the erase elements and the main read/write core, most of the studies were performed at $2F$ (125 kHz), but at the expense of degraded signal-to-noise ratio. Fig. 17 shows a typical profile for a track written without using the erase elements. Since the track width of this head is narrower than for the 8-in head, the head was scanned over a 20 mil band (rather than a 40 mil band), again in steps of 250 μin. Again the track chosen (track 5) exhibited a small degree of amplitude modulation across its width. The effective written and readback widths were 6.56 mils and 6.68 mils, respectively.

Fig. 18 shows an erase efficiency scan of the outer erase element at an erase current of 40 mA (value of current normally used with this head). Erase efficiency is close to 100 percent and is quite flat across the entire erase structure width of 3.5 mils.

Fig. 19 shows the erase efficiency for the same erase element at an erase current of 25 mA. In this case the erase efficiency has fallen to about 85 percent across the central portion of the erase element. (Recall that the digital smoothing spreads out the high spatial frequency variations over a distance corresponding to about two steps, which in this case is 500 μin).

The effects of a transverse offset of the position of the erase elements relative to the position of the written track due to azimuth misalignment and track curvature effects are shown in Figs. 20 and 21. For each of these measurements, a track was written with the erase element turned off. In one case the head was moved radially outward 2 mils (Fig. 20) and the erase element was activated for 1 disk revolution; for the other figure (Fig. 21) the head was moved inward 2 mils before the erase element was activated.

Each of the resulting tracks was profiled, and the profiles were compared to the unerased case typified by Fig. 16. In



ig. 17. Typical track profile for 460 head ($5\frac{1}{4}$ in format). Track written with erase element disabled.

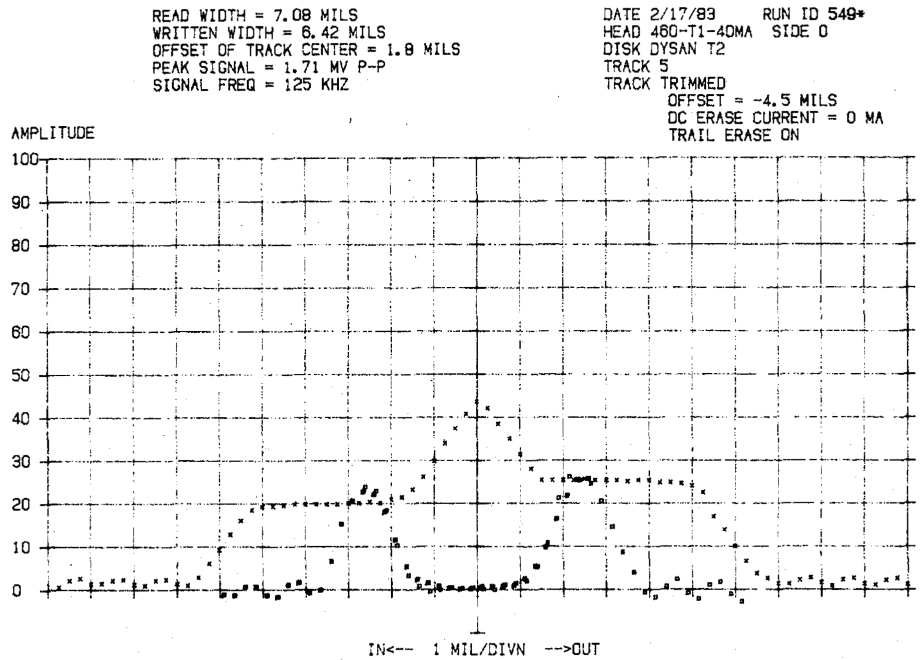


Fig. 18. Track profile of outer tunnel erase element for 460 head. Erase current was 40 mA.

the case where the head was moved radially inward by 2 mils prior to trim erasure, the written track width decreased by 2.58 mils. For the case where the head was moved outward by 2 mils, the written trackwidth was decreased by 1.31 mils. These results imply that the aximuthal misalignment of the erase elements is about 0.64 mils radially inward. Thus this particular head, during normal operation with trim erase, leaves a band of unerased media on the inner side of a freshly written track which is about 0.64 mils wide, and trims off an approximately equal amount of the freshly written track from the outer edge.

IV. Summary

We have refined a method for measuring track profiles applicable to both rigid and floppy disk formats. This method may be used not only to determine the effective read, write, and erase widths of these heads, but also can be used to determine the actual structure of the written track across its width.

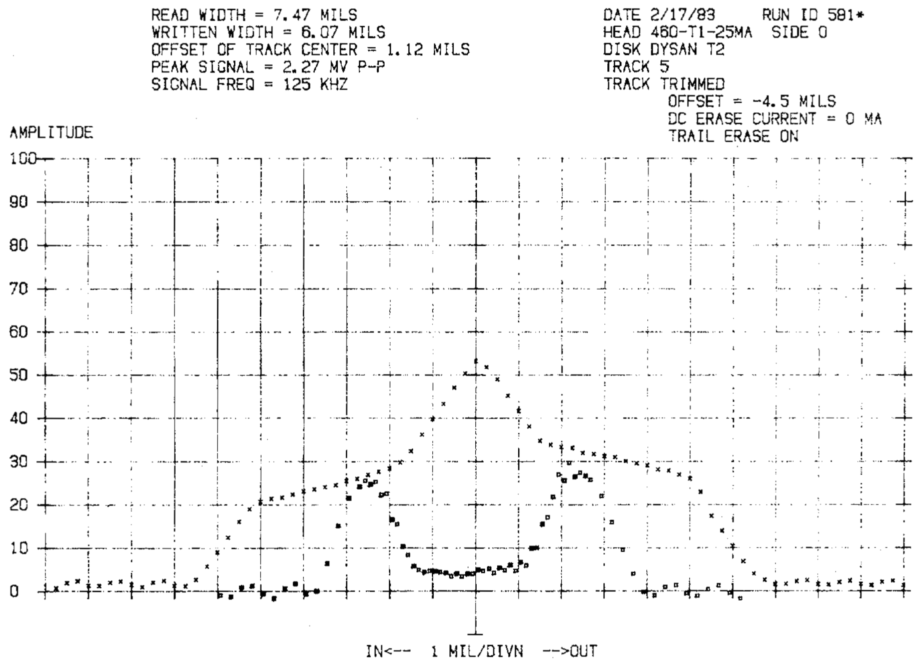


Fig. 19. Track profile of outer tunnel erase element for 460 head, using erase current of 25 mA.

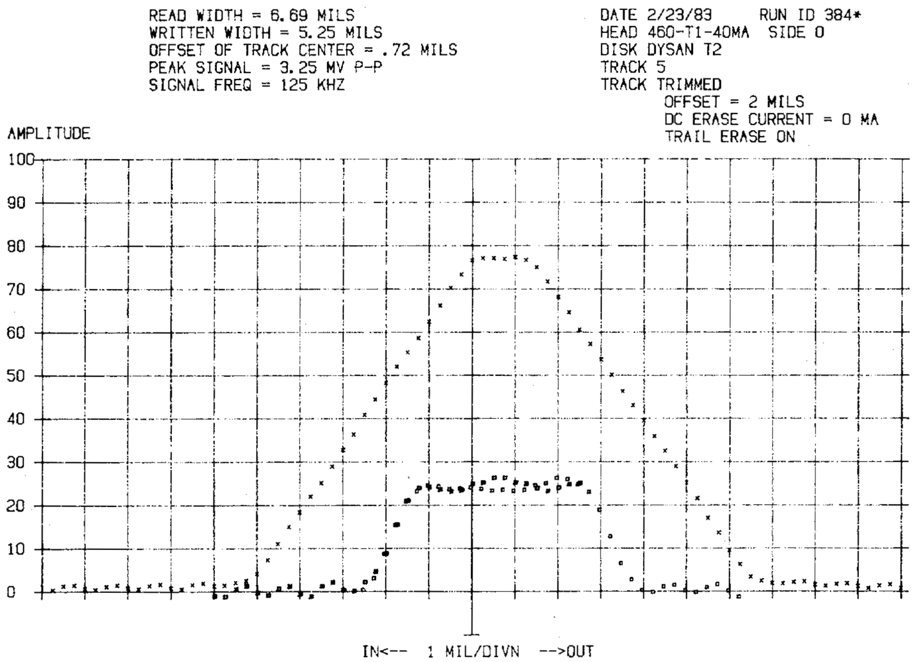


Fig. 20. Track profile after trimming with head moved radially outward 2 mils, using 460 head.

This structure can be determined in the as-written condition, or after the track has been modified by partial erasure or rewriting.

We applied this method to a floppy head/disk format to evaluate straddle erase, tunnel erase, and intrinsic read/write core side erase characteristics. We found that the straddle erase elements erase most strongly under the air gaps, and also under the straddle erase poles, but with a reduced efficiency. By applying sufficient magnetomotive force with the erase coil, and ensuring that the erase structure does not saturate, the region of trim erase can be made to extend under the erase poles, as well as under the air gap, and to a small extent under the read/write core during readback.

We found that the tunnel erase elements erased reasonably uniformly across their entire widths but, due to the relatively large offset between the centerlines of the read/write gap and

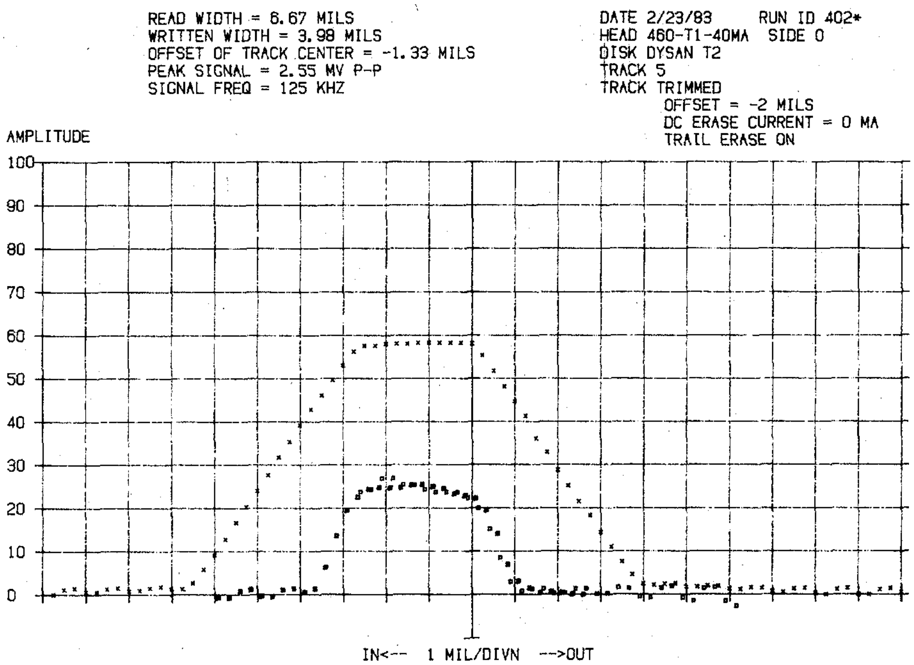


Fig. 21. Track profile after trimming with the head moved radially inward 2 mils, using 460 head.

the erase gaps, were subject to azimuthal misalignment between the edges of the written track and the regions of erasure.

We also found that the read/write core exhibits an implicit trim erase characteristic occurring during normal writing. The effective trim erase distance extends about 360 μin to each side of a freshly written track.

This method has a number of additional applications. It can be used for determining written track width versus write current, and readback width versus wavelength. For rigid disk heads the effective track width can be related to side bevel angle of the head, as well as the physical width of the head. The effective trim erase distance implicit to various geometrics without explicit erase elements may be measured. Such measurements could, for example, be used to evaluate thin film heads with misaligned poles, unequal pole widths, or with one pole which "wraps around" the other pole. The effective trim erase distance can then be used to determine the track-following requirements of the servo system, and the ultimate track densities which can be attained.

References

[1] E. R. Katz and T. G. Campbell, "Effect of bitshift distribution on error rate in magnetic recording," *IEEE Trans. Magn.*, vol. MAG-15, no. 3, p. 1050, May 1979.

[2] G. F. Hughes and D. S. Bloomberg, "Recording head side read/write effects," *IEEE Trans. Magn.*, vol. MAG-13, no. 5, p. 1457, Sep. 1977.

[3] A. Van Herk, "Side fringing fields and write and read crosstalk of narrow magnetic recording heads," *IEEE Trans. Magn.*, vol. MAG-13, no. 4, p. 1021, July 1977.

[4] D. Lindholm, "Magnetic fields of finite track width heads," *IEEE Trans. Magn.*, vol. MAG-13, no. 5, p. 1460, Sep. 1977.

[5] A. Van Herk, "Analytical expressions for side fringing response and crosstalk with finite head and track widths," *IEEE Trans. Magn.*, vol. MAG-13, no. 6, p. 1764, Nov. 1977.

[6] D. A. Lindholm, "Spacing losses in finite track width reproducing systems," *IEEE Trans. Magn.*, vol. MAG-14, no. 2, p. 55, Mar. 1978.

[7] R. E. Fayling, "Variations in recorded flux transitions with distance from track center," *IEEE Trans. Magn.*, vol. MAG-17, no. 5, p. 2460, Sep. 1981.

[8] A. Van Herk and H. Bijl, "Measurement of side -write, -erase, and -read behaviour of conventional narrow track disk heads," *IEEE Trans. Magn.*, vol. MAG-13, p. 1641, Nov. 1979 (abstract only, presented at INTERMAG 1979, New York).