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An Experiment on the Effect of Particle Orientation on Peak Shift in Magnetic Tapes

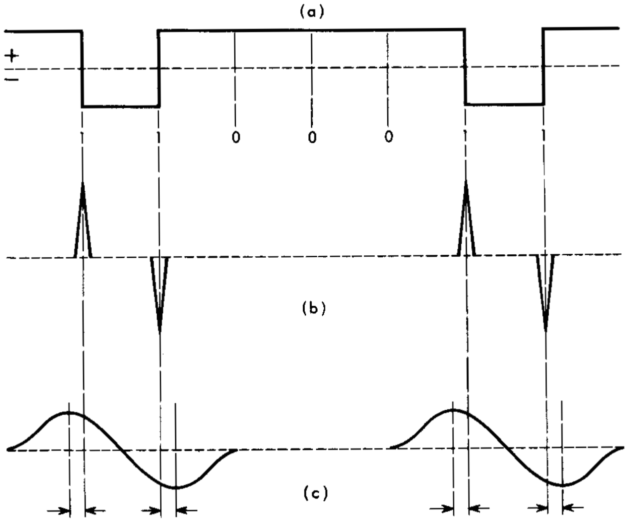
Abstract: One of the limiting factors in high-density recording on magnetic tape is the phenomenon of peak shift. With the NRZI code (flux change on a ONE, no flux change on a ZERO) this means that the reproduced signals from two successive ONES preceded and followed by ZEROS are separated in time by more than the natural bit period. The peaks in the signal output from the two ONES are thus shifted outwards. An experiment is described in which the peak shift is measured in particle-oriented tape as a function of the angle θ between the direction of recording and the direction of orientation. The dc hysteresis properties of the tape were also measured as a function of θ. It was found that the peak shift had a minimum when θ was approximately 65° for the tape and recording head used in this experiment. At this angle the remanence-coercivity was high, while the coercivity and the ratio of remanence to saturation intensity were low. Qualitative explanations of these results are offered and their significance is briefly discussed.

Introduction

In NRZI recording, the direction of magnetization of the recording medium reverses when a ONE is written and remains unchanged for a ZERO. This is shown in idealized form in Fig. 1a. The ideal output from a reproducing head is shown in Fig. 1b; sharp pulses are obtained at the recorded ONES, while the ZEROS give no signal output. In practice an output resembling Fig. 1b is obtained but the resemblance is close only at low bit densities.

A basic problem in high-density magnetic recording is the output peak shift, which appears in a random information pattern when a ONE is followed by several ZEROS. The peak in the signal output of the last ONE moves towards the ZEROS as shown in Fig. 1c. Thus a time error can be introduced into the reproduced pattern, and information would be lost if the shift were ever as great as half the natural bit period.

Figure 1 **a) Direction of magnetization with an NRZI coded pattern.**
b) Ideal signal output from the reproducing head.
c) Actual signal output at high density, showing peak shift.



To study this phenomenon we used a standard recording pattern of two ONES and eight ZEROS repeating and examined the separation between the two ONES in the reproduced pattern. Clearly the medium, the writing process and the reading process all can be expected to play a part in the effect, but in this paper we shall confine our attention to some aspects of the contribution of the medium for the case of very thin coatings. A highly desirable experiment would be one in which one variable, e.g. the coercivity H_c, could be controlled while the others (remanent magnetization intensity I_r, saturation magnetization intensity I_s, thickness, et cetera) were held constant. In practice, however, the uncertainties associated with experiments using samples from different coating runs require that we work with one sample of tape. The magnetic constituent of the tape is γ-Fe_2O_3 in small acicular particles (length ~ 0.5-1.0μ and axial ratio $\sim 7{:}1$) which can be oriented to some extent by passing the tape through a magnetic field while the coating is fluid. With oriented tape, we can make use of the fact that the magnetic properties H_c, H_r, and I_r vary as a function of the angle between the direction of orientation and the direction of measurement (H_r is the *remanence-coercivity*, which is the field required to reduce the remanence to zero). By cutting strips from the tape at various angles to the orientation direction and measuring the peak shift in each strip, we can investigate the dependence of peak shift on the magnetic properties of the tape via its dependence on angle.

We shall show that the angular dependence of peak shift is quite pronounced and that low peak shift in a given sample is favored by high H_r, low H_c and low I_r/I_s.

Experimental procedure

Tape samples were prepared in a conventional way by mixing γ-Fe_2O_3 powder with suitable solvents and plastic binder materials in a high-speed ball mill for several days and then coating the mixture on Mylar sheet 12″ wide and 0.001″ thick. While the coating was still fluid, a magnetic field of about 800 oe was applied to the tape in a longitudinal direction in an attempt to align the oxide particles.

The finished coating had a thickness of 0.00016″ (measured on a Leitz Ultra-projectometer) and thus was much thinner than that of conventional oxide tapes (0.0005″). A thin coating was chosen to enable measurements to be made at recording densities of 3000 bits per inch. The packing density of the oxide in the tape was about 38% by volume.

The nature of the alignment produced by the applied field can be seen from Figs. 2 and 3. Figure 2 was taken by transmitted light with an optical microscope on a very thin sample loaded to 20% by volume, the purpose of the low loading being to enhance the light transmission of the coating. The electron micrograph (Fig. 3) was obtained by the following procedure. The Mylar was precoated with an aqueous solution of polyvinyl alcohol, which was allowed to dry before the oxide mixture was applied. In this case the loading was 1% by volume and the coating was made extremely thin, again to increase transmission. By immersing the tape in water, the polyvinyl alcohol could then be dissolved and the oxide film floated to the surface; the film was next prepared for transmission electron microscopy. From these Figures it will be seen that although gross chaining and streaming of the oxide particles occurred in the magnetic field, the alignment on a particle scale is very imperfect. Since electron microscopic examination of the powdered oxide invariably shows clumps of particles, no matter how thoroughly one tries to disperse the particles it seems likely that much of the oxide is coated onto tape in this form. Within the clumps many of the particles lie parallel and side by side, but a considerable randomness in orientation is also found.

Figure 2 **Transmission micrograph of thin oriented tape with oxide loading 20% by volume.**
Magnetic field of about 800 oe applied.

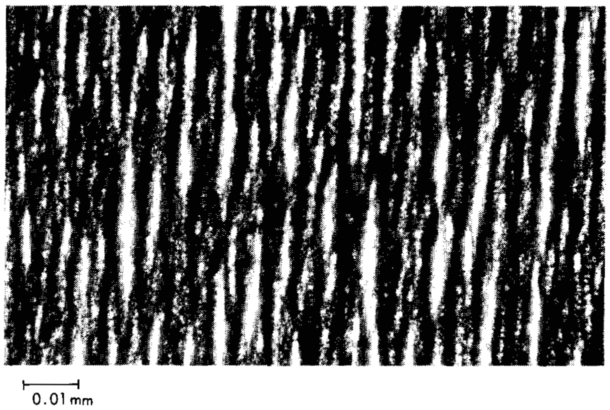
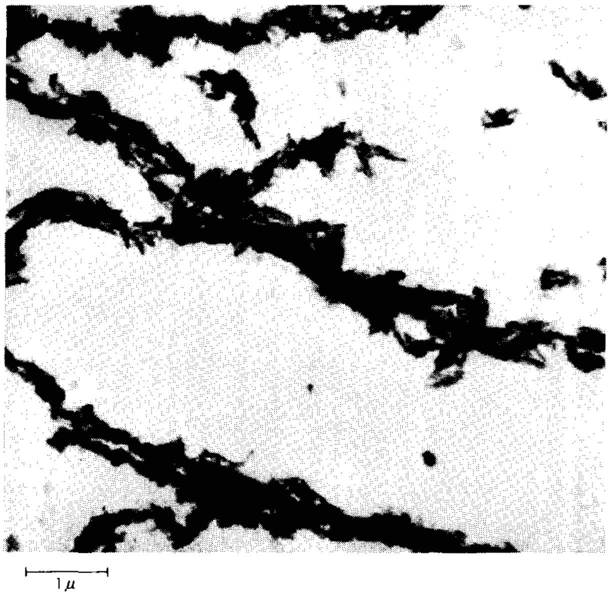


Figure 3 **Transmission electron micrograph of thin oriented tape with oxide loading 1% by volume.**
Magnetic field of about 800 oe applied.



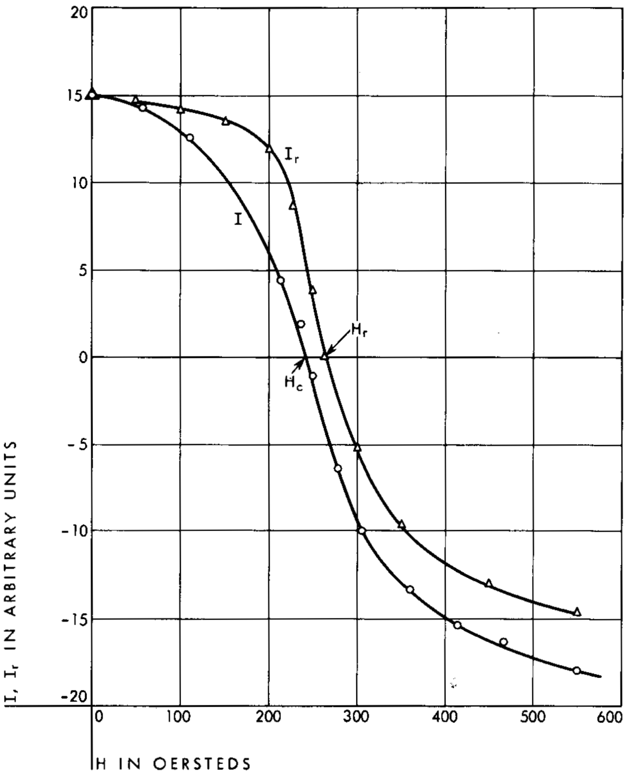


Figure 4 **Intensity of magnetization *I* and remanent-intensity I_r as a function of magnetic field, measured at 0° to the direction of orientation.**

In order to measure the angular dependence of peak shift it was necessary to cut strips (8″ × ½″) from the 12″ wide tape at several angles to the orientation direction and then to splice the strips into a 10-ft loop of tape so that it could be run on a loop tester. The peak shift was measured by recording on the loop the pattern described above, reading the pattern back and photographing the oscilloscope trace of the pulses. The time between the peaks could then be found by measuring the photographs on an optical comparator. The pattern was recorded at a basic bit period of 3000 bits per inch on the tape, which had previously been erased by means of a permanent magnet. A single-gap head was used having a gap of 90 microinches and a shape which ensured that, at a tape speed of 25″/sec, the tape was in contact with the head at all times. The WRITE-current which gave maximum output at 3000 bits per inch was chosen. Comparator measurements of the photographs gave peak-to-peak time values which were reproducible to within ±2%. By changing the oscilloscope time-base frequency, the output pulses from all the flux-changes occurring in the strip could be displayed at the same time on the oscilloscope. From the photographs of the signal envelope the output voltage as a function of the angular orientation of the strip could be measured.

For dc magnetic measurements a disk-shaped sample 1 cm in diameter was punched from each strip after the longitudinal direction had been marked. The hysteresis characteristics were measured on a torsion-balance magnetometer of the type described by Bate,

Figure 5 **Intensity of magnetization *I* and remanent intensity I_r as a function of magnetic field, measured at 90° to the direction of orientation.**

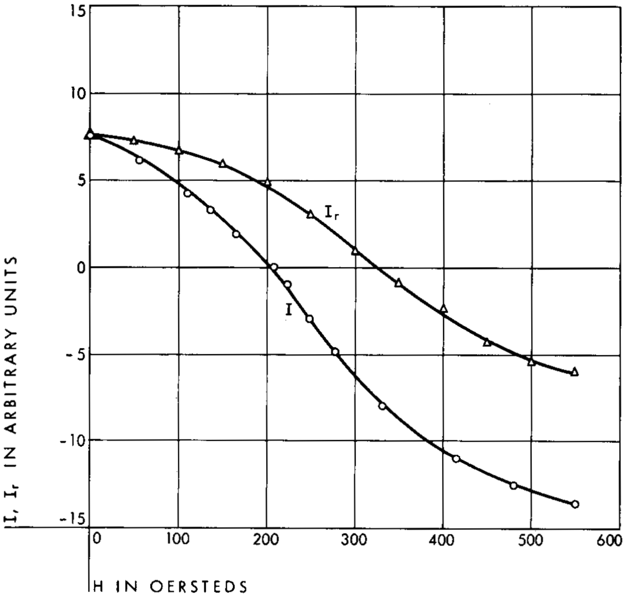
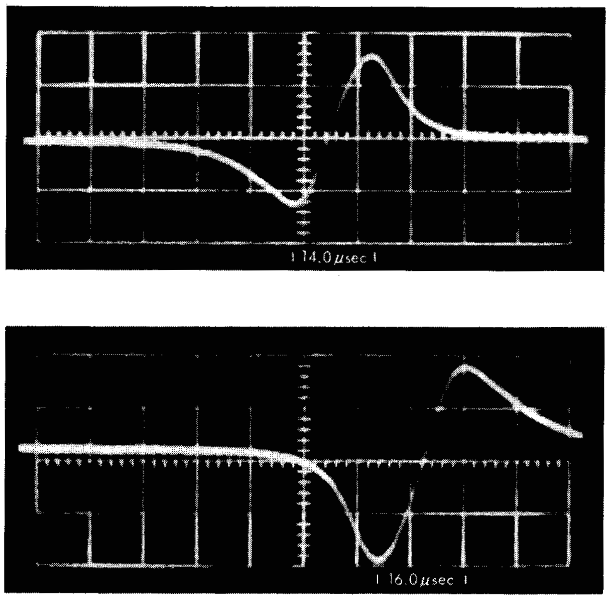


Figure 6 **Output signal from the two ONES pattern upper at 65°, lower at 0°, to the direction of orientation.**
The basic bit period is 13.3 μsec.



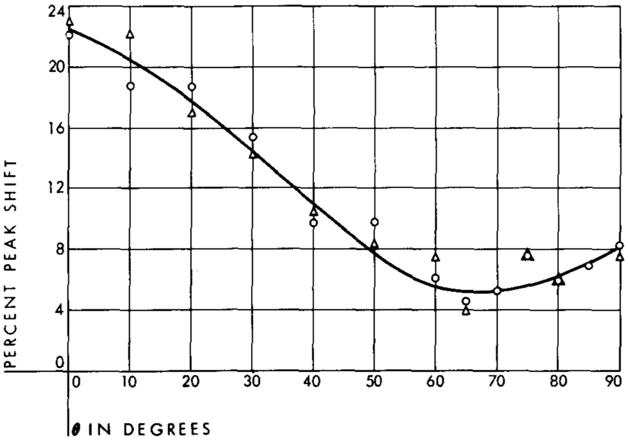


Figure 7 **Peak shift (expressed as a percentage of the fundamental bit period) as a function of angle between direction of measurement and direction of orientation.**
Results of two experiments shown.

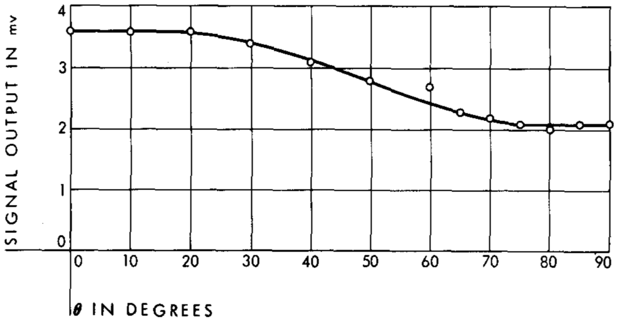


Figure 8 **Output voltage as a function of θ.**

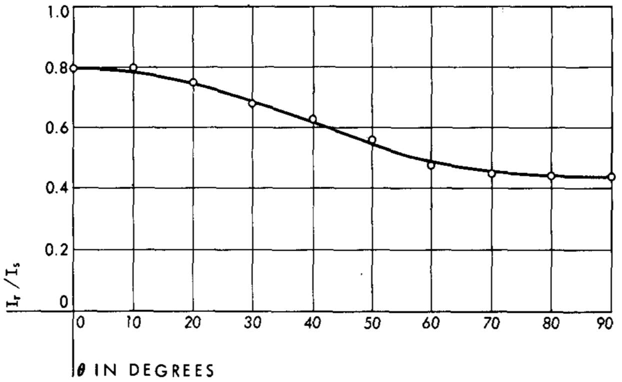


Figure 9 **I_r/I_s as a function of θ.**
(This shows dependence of remanent intensity I_r on θ since I_s is the same for all samples.)

Schofield and Sucksmith.[1] In this apparatus a field of 5000 oe could be applied to saturate the specimen and the intensity of magnetization measured in fields ~1000 oe. Figures 4 and 5 show the dependence of I and I_r on field at 0° and 90°, respectively. The ratio of thickness to diameter of the samples was so small that external demagnetization effects could be neglected.

Results

Figure 6 shows photographs of the pulses obtained from strips oriented at 0° and 65°; the decreased peak separation at 65° can be seen. The peak shift is calculated by subtracting the natural bit period from the observed peak separation and expressing the difference as a percentage of the natural bit period. The angular dependence of peak shift is shown in Fig. 7. Data from two separate experiments have been plotted in this Figure and show good agreement. The experiment was repeated many times at different positions along the tape, always with the same result for a given batch of tape coating and for the single-gap head used.

The variation in output voltage of the two ONES pattern with orientation is shown in Fig. 8; little change was found between 0° and 30°. Between 30° and 75° a drop of about 40% was observed, with no further drop from 75° to 90°. The angular dependence of output voltage follows closely the variation of I_r/I_s with angle shown in Fig. 9. This type of behavior is to be expected if we are dealing with single-domain particles, whatever their mode of magnetization reversal may be. The relatively low value of I_r/I_s at 0° is a reflection of the imperfect alignment in the samples. However, any multidomain particles would also reduce this value. The graph of H_c against θ (Fig. 10) shows a peak at about 30° from the direction of orientation. This result agrees with previous work[2] on samples of 5%, 20% and 60% loading, which showed peaks at 50°, 50° and 10°, respectively. The remanence-coercivity H_r, however, increases monotonically (Fig. 10) from 0° to 90°; this result is also expected in view of measurements of H_r reported previously on the 5%, 20% and 60% samples. The difference between the angular variation of H_c and H_r has been explained[2] in terms of incoherent rotation of the magnetization vector in the oxide particles for small values of θ.

Discussion

For this sample of oriented tape of fixed thickness and for this recording head, it appears that the most favorable (i.e., lowest) peak shift is obtained when the pattern is written along a track which lies at about 65° to the direction of orientation. At this angle the remanence-coercivity H_r is very near its largest value, while the coercivity and I_r/I_s have small values. The latter result is particularly surprising since high "squareness" (I_r/I_s) has previously been considered essential for high-density recording on both theoretical[3,4] and intuitive grounds. It has been shown theoretically by Kostyshyn[4] and experimentally by Roark[5] that the peak shift described above is a result of the overlapping of the positive and negative pulses which occurs when the pulses are recorded at high densities. Thus, the prime factor in determining peak shift is the pulse width which depends on the reproducing-head characteristics, the head-to-tape spacing and the length of the transition region between two oppositely magnetized areas on the tape. This region is, of course, partially demagnetized and its effective length will depend on H_r, H_c, I_r, thickness, and the field from the head. If then the tape is oriented so that the direction of travel corresponds to high values of H_r, higher magnetic fields from the head will be needed to write permanently on the tape. That is, for a given WRITE current the transition region will lie closer to the gap in a region of higher field and higher field gradient, and hence the transition region should be shorter. It appears from Figs. 7 and 10 that the angular variation of peak shift is much more closely related to the variation of H_r than of H_c. This is understandable since, in the writing process, we are concerned mainly with the irreversible magnetization changes rather than the combination of reversible and irreversible ones characterized by the coercivity.

It should be mentioned that "negative peak shift," i.e., the peaks closer together than the natural bit period, has occasionally been observed, though not in the present experiment. The phenomenon can occur if the field from the recording head is not strong enough to erase the previous magnetic history of the tape,[6,7] e.g., in tapes erased with a strong permanent magnet. To discover whether the angular dependence of peak shift was affected by the previous history of the tape, we repeated the measurements on tape which had been ac erased and obtained the same angular dependence as that shown in Fig. 7. We therefore conclude that negative peak shift did not play a significant part in our experiment.

There seems to be a rather close connection between the angular variation of output voltage and the remanent intensity (plotted in Fig. 9 as I_r/I_s). This is to be expected since the time rate of change of flux at the reading head obviously depends on the intensity of magnetization of the recording medium, among other parameters. Also, since both the self-demagnetizing field of a region and the demagnetizing fields due to adjacent regions depend directly on the remanent intensity, we should expect the transition region to be narrower, and therefore the pulse width smaller, when I_r is small. Hence smaller values of I_r should result in low peak shift, as found experimentally (Figs. 7, 9).

Considering now the incremental permeability of the tape, this is greater when measured along the direction of orientation than when measured perpendicular to this direction, as we see from Figs. 4 and 5. Thus we can expect the flux lines from the magnetized regions to leave the medium more readily when the permeability is low than when it is high. Hence the lower permeability implies a narrower transition region and reduced peak shift, as was observed.

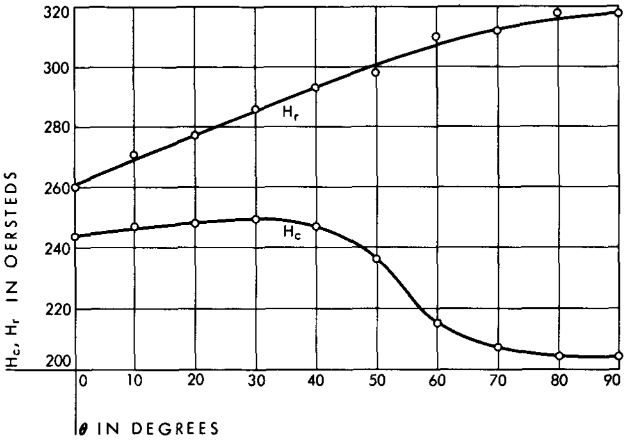


Figure 10 **Coercivity H_c, and remanence-coercivity H_r as a function of θ.**

Conclusions

It is known that peak shift depends on a number of factors, e.g., tape coating thickness, tape-to-head spacing, head configuration, et cetera. We have shown that the peak shift of a two-ONES pattern also depends to a considerable extent on the angle between the direction of orientation of the tape and the direction of the recorded track, the shift being smallest at 65° under the conditions of our experiments. The signal output also decreases with increasing angle, and thus from a practical point of view it seems desirable to choose an angle which is a compromise between low peak shift and high output. For the case discussed here the optimum angle is approximately 45°.

Since the magnetic properties H_c, H_r, and I_r/I_s also depend on θ in a rather complex way, it is not possible at the moment to isolate the dependence of peak shift on any one of these properties. However, it does seem that H_r plays a dominant part here, certainly a more important part than H_c, but further work is needed to clarify this dependence. Finally, it must be remembered that peak shift is a complex phenomenon and that the effect of other contributing factors must be minimized before angular orientation can be of significance.

Acknowledgments

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References

1. G. Bate, D. Schofield, and W. Sucksmith, *Phil. Mag.* **46,** 621 (1955).
2. G. Bate, *J. Applied Phys.* **32,** 239S (1961).
3. R. Schools, *J. Applied Phys.* **32,** 42S (1961).
4. B. Kostyshyn, *IRE Internat. Conv. Rec., Pt. II, Electronic Computers* (1961).
5. C. S. Roark, M.S. Thesis, E.E. Dept., Syracuse Univ., 1962.
6. D. F. Eldridge, *IRE Internat. Conv. Rec., Pt. VII,* 141 (1959).
7. K. Teer, *Philips Res. Rep.* **16,** 469 (1961).

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