Peak-Shift Study in High-Density Magnetic Tape Recording

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Summary: This paper examines the influence of magnetic tape, read-write head, and other recording parameters on peak shift encountered in high-density recording. In particular, the effect of prior erase polarity on peak shift is discussed. A technique for examining the remanent moment in a sample of the recorded tape track as a function of write current, density, and angle from the plane of the oxide coating is described.

WITH THE DEVELOPMENT of magnetic tape recording for digital computer input-output devices there came the inevitable demand for higher densities; i.e., more information at a faster rate. Initially, mechanical problems in the tape-handling devices had to be overcome; then attention was focused on the magnetic tape and read-write head. Reliability studies indicated that the magnetic-particle coating had many imperfections which could be handled satisfactorily by using a large writing current in a nonreturn-to-zero (NRZ) saturation writing method. In this manner, saturation could be achieved even when the tape was displaced from the writing head by a defect in oxide coating.

Continued experience with coating improved the surface quality; it became obvious that thinner tape coatings (0.1 mil appears to be a lower practical limit) offered many advantages. The thinner coatings needed less writing current for saturation and, hence, reduced crosstalk problems in the magnetic head. These coatings also allowed a higher density to be written before bit crowding occurred and reduced the signal output. More serious than the reduced signal output at high density was the problem of a time shift in the peaks of the read-back signals when random information was written. Various means of correcting this peak shift, such as refinements in the read and write circuitry and the mechanical construction of the head, the introduction of other frequencies which restrict the density range, and angular orientation[1] have been used. However, since peak shift still remains a problem in high-density magnetic recording, this paper aims at a further understanding of this phenomenon.

Operation and Results

A loop-transport mechanism moving a 1/2-inch by 10-foot loop of tape past a magnetic read-write head at 25 inches per second was used throughout this work. An NRZ writing method, such as the one used in Fig. 1, was employed. Initially, graphs of head output as a function of write current for an all-ones pattern at different densities were obtained. (See Appendix I for specifications on heads and tapes.) These results, as shown in Fig. 2, indicate that both maximum output and the current needed to give this maximum output decrease with increasing density. Peak shift was obtained by writing a 2-ones 8-zeros repetitive pattern at various densities on tape that had been

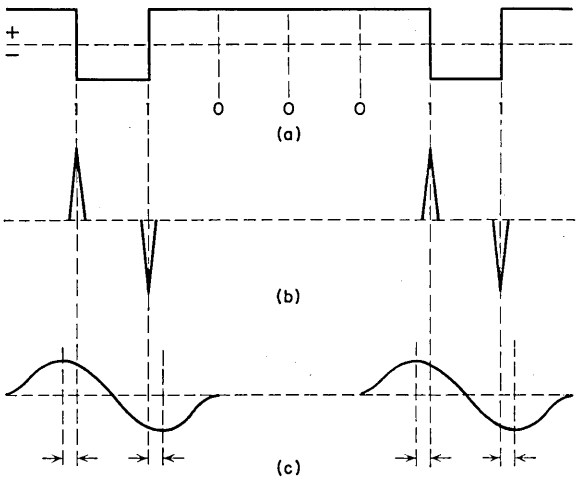

Fig. 1. NRZ writing method

A—Direction of magnetization with NRZ coded pattern
B—Ideal signal output from reproducing head
C—Actual signal output showing peak shift

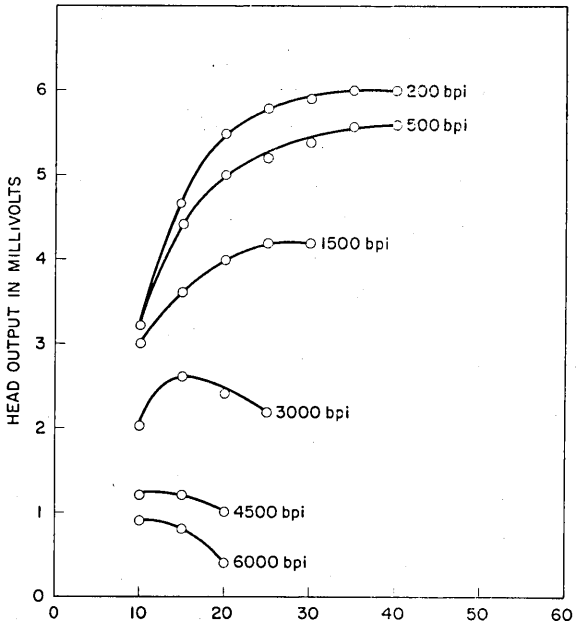

Fig. 2. Signal output as a function of write current (narrow gap head, thick tape) with information density as the parameter

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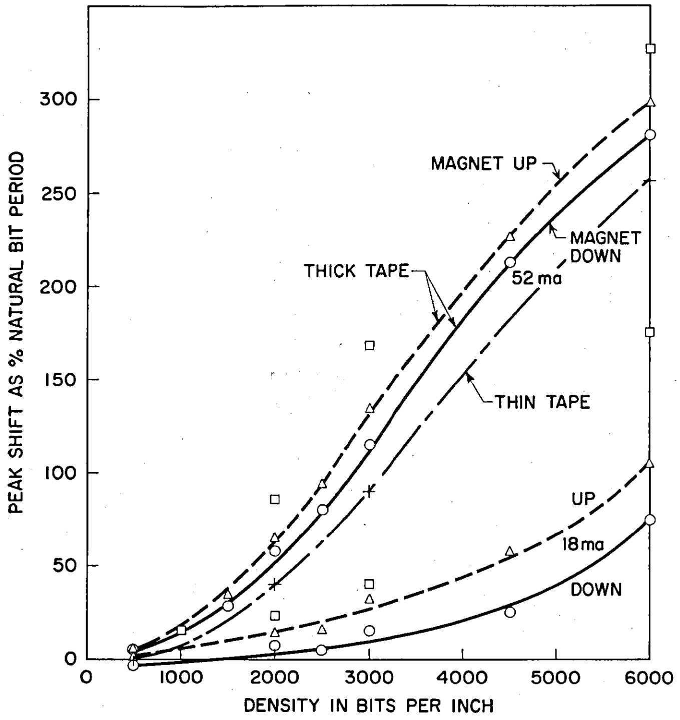


Fig. 3. Peak shift as a function of density

d-c erased by a permanent magnet (H$\sim$320 oersteds and producing no vertical component of magnetization in the tape) and, with the aid of an optical comparator, by noting the shift as a percentage of the writing-bit period from an oscilloscope picture. In Fig. 3, a plot of peak shift (per cent peak shift = 100×actual peak spacing − written bit period/written bit period) versus information density is shown for one head (90-microinch read and write gap) using both a thick tape (0.5 mil) and a thin tape (0.28 mil), two writing currents [18 and 52 ma (milliamperes)], and two polarities of d-c erasure prior to recording. The erase magnet polarity and the write current for the narrow gap head are parameters for the thin tape; the peak shift predicted by superposition of low density pulses is shown by the squares.

It can be seen from Fig. 3 that the higher current (52 ma) which saturates the tape (maximum signal output) has much more peak shift than the 18-ma case, which is a partial saturate condition. The peak shift, of course, increases as the spacing between the two ones is decreased (density increased). Moreover, the direction of erasure prior to recording is seen to affect the amount of peak shift; with one polarity, arbitrarily called down, giving the best results.

At high current, lower peak shift is shown on thin tape than on thick tape. Only the high-current case is plotted, since the low-current results are identical for the thick and thin tapes.

Another read-write head having a 0.5-mil write gap and 0.25-mil read gap was then mounted on the loop tester, and peak shift data were again obtained.

The peak shift results from both heads can be summarized:

1. Peak shift increases steeply with write current or density.
2. Peak shift is influenced by the prior erase field polarity seen by the tape. This effect is more pronounced at low (nonsaturating) write current.
3. An a-c erase condition (not shown) was found to result in peak shifts which lie between the values of the two polarities of d-c erasure.
4. At high currents with both heads, the thin tape gives lower peak shift.
5. At low currents, the narrow gap head produces lower peak shift, with very little difference between thick and thin tapes on either head.
6. The tape direction past the head, in the case of the two tapes used in this experiment, is not a factor.

In conjunction with the loop-tester work previously described, samples of both thin and thick tape were written with both heads on an a-c erased tape using an all-zeros pattern. These samples were then developed with bitter pattern suspension to find the track location, and a 0.5- by 0.045-inch piece was cut from the recorded track with a scalpel. The remanent moment was then measured, using a sensitive torsion-balance magnetometer, as a function of write current.[2] Slight differences between the sample sizes were corrected by applying a 5,000-oersted d-c field and measuring the total moment.

In Fig. 4, the results for both thin and thick tapes are shown for the narrow gap head, along with the conventional satura-

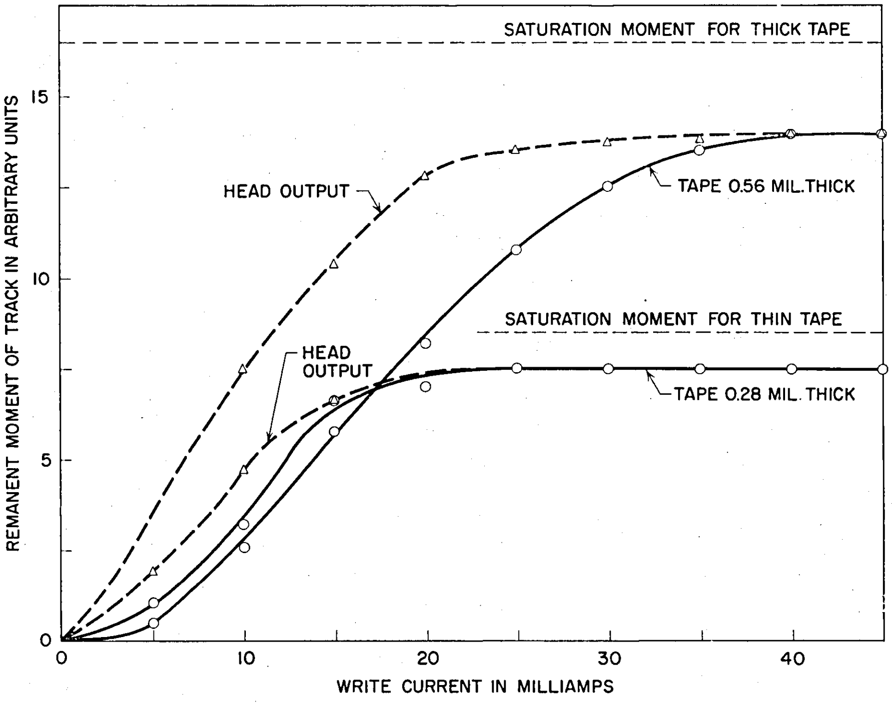


Fig. 4. Remanent moment of recorded track and normalized signal output from the narrow gap head as a function of write current for both tape thicknesses

tion curve (signal output versus write current) normalized to the remanent-moment maximum value. The saturation remanent moment after the application of 5,000 oersteds is shown for each tape by the horizontal dotted lines. It can be seen that the saturation (peak) values of both remanent moment and head output are obtained at the same value of write current and that 10–15% of the particles in the tape are not switched by the write field. Bate's recent determination of the Preisach diagram[3] for γFe_2O_3 particles showed that approximately 10% of the particles are not switched by a field of 500 oersteds. Therefore, it may be concluded that, in the present case, the effective field seen by the tape at maximum write current is less than 500 oersteds.

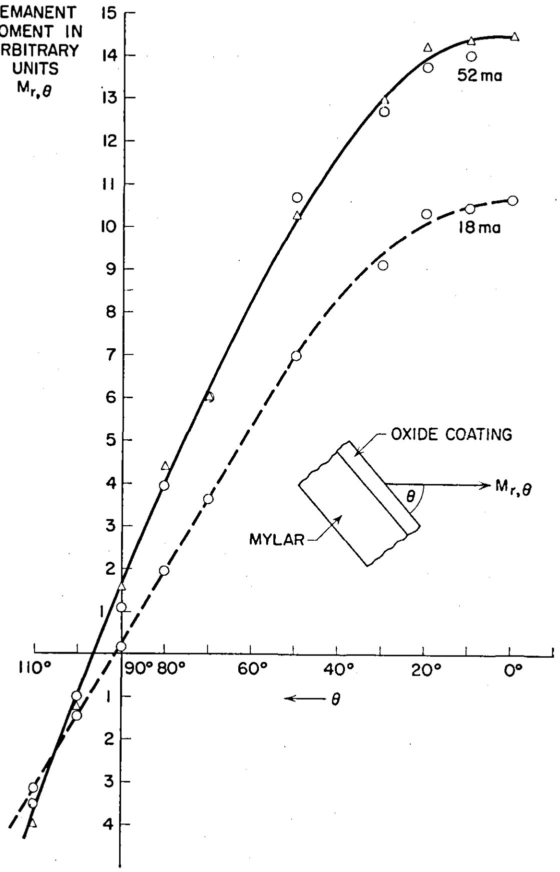


Fig. 5. Remanent moment of a track of all zeros as a function of the angle between measurement direction and tape plane

Similar results were obtained for the wide gap head; however, at 18-ma write current, an approximately 30% higher remanent moment was found on the thick tape than on the thin tape. This may be explained by the assumption that, for the narrow gap head, the effective field penetrates less than the thickness of the thin oxide coating, while for the wide gap head, the field penetrates beyond the thickness on the thin coating and results in more moment in the thick sample.

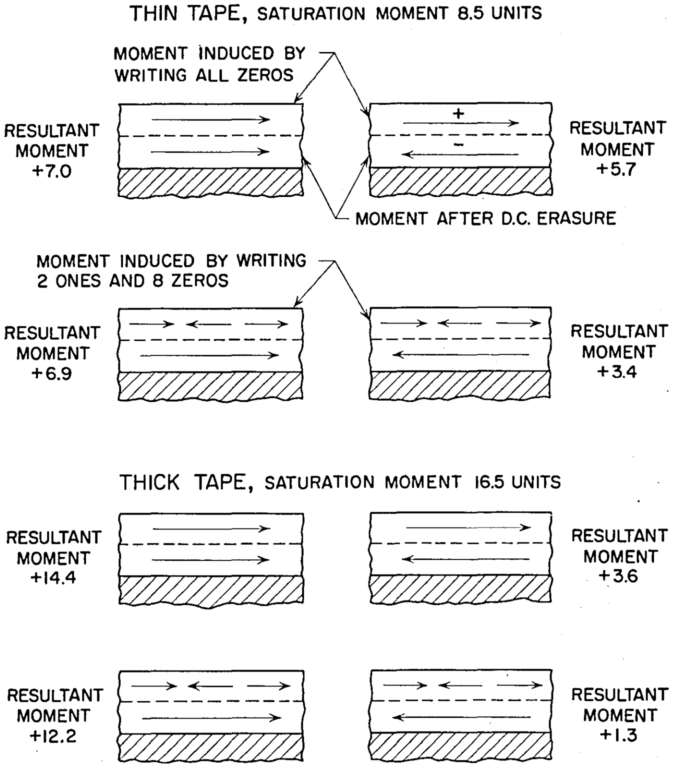
As the tape moves beyond the write-head trailing edge and out of the region where it can be affected by the head field, a substantial component of the field is perpendicular to the plane of the tape. In addition, the process of aligning the γFe_2O_3 particles in the tape is an imperfect one, leaving many particles with their easy directions of magnetization perpendicular to the plane of the tape. Thus, in consequence of the perpendicular component of the head field and the incomplete alignment of particles, a perpendicular component of the remanent magnetization could be predicted. This was investigated by writing an all-zeros pattern on a previously a-c demagnetized thick tape and rotating the sample in the torsion-balance magnetometer so that the remanent moment at an angle θ to the plane of the tape could be measured for $0^\circ \leq \theta \leq 110^\circ$. These results are plotted in Fig. 5, which clearly shows that $M_r \neq 0$ when $\theta = 90^\circ$. The same curve was obtained by reversing the direction of tape with respect to the head. This shows that the distribution of particles was symmetrical about a normal to the tape. In Fig. 5, results for two values of write current are given and points for both tape directions of the higher current are plotted; the ratio of the perpendicular component of magnetization to the longitudinal component in the tape is shown to be larger for higher write currents.

The magnetization in the tape was also measured at a high and low density to determine if the head field was penetrating the tape equally well at all frequencies. This was accomplished by using several samples of the thick tape and writing an all-ones pattern on a d-c erased tape at 200 and 6,000 bpi (bits per inch) at write currents of 18 and 52 ma. In this manner, the d-c erase field moment was reduced by the written pattern, and the influence of the write-head field penetration was determined by the amount of remanent moment left on the sample. At low current, it was found that the 200-bpi density penetrated the tape to a 30% greater depth than the 6,000-bpi density; for high current the penetration depth was identical for both high and low density. From these results, it was concluded that the density does not affect the field put out by the head and that the low current difference can be attributed to imperfect head-to-tape contact.

In Fig. 6, a table of typical values obtained from track samples measured in the magnetometer is shown; results of two recorded patterns are given for both tape thicknesses. The track samples were measured in the same manner as those in Fig. 4 with one additional piece of information, the resultant magnetization of the 2-ones 8-zeros pattern, which theoretically should be 80% of the all-zeros case. Thick and thin samples at 18 and 52 ma on the narrow gap head are shown for both erase polarities. By simple calculation, it was found that the ratio of the 2-ones 8-zeros remanent moment to the all-zeros moment was 0.81 for thin tape and 0.75 for thick tape; this is in good agreement with the theoretical figure of 0.80.

Another fact established by this figure is that the erase polarity giving the greatest peak shift (up) is opposite to the polarity of the zeros region on either side of the two ones and in the same direction as the polarity of the region between the ones. The explanation is that at low current, where there are still some particles with the prior erase polarity, the zeros regions to the outside are reduced in intensity by particles having the opposite erase polarity, thus producing greater peak shift. These regions are believed to have a greater influence on peak shift than the region between bits. The converse is also true, but to a lesser extent; i.e., the region between bits is reduced by demagnetization when the erase polarity is in the opposite direction, but the peak shift is not affected to the same extent.

Fig. 6. Remanent-moment measurements made on tracks written with the narrow gap head at 18 ma



At high current (52 ma) the major portion of the tape coating is saturated by the writing head, and the prior erase polarity is removed. Consequently, it is reasonable to expect that the erase-magnet polarity should have less effect at higher write currents; Fig. 3 verifies this.

Up to this point, emphasis has been on the contribution of prior erase field polarity, which is really a small portion of the total peak shift encountered in this work (Fig. 3). To determine the major cause of peak shift, low-density (2-000-bpi) noninterfered single pulses were photographed for all the head, tape, and write-current conditions described previously. These were enlarged on an optical comparator and superimposed positive-to-negative at a distance corresponding to the density required.[4] In Fig. 3, typical values of the peak shift predicted by superposition are shown beside the actual measurements. It is believed that the inability of the reading head to distinguish between the wide magnetic transition regions induced in the tape at saturation currents is the main cause of peak shift. Therefore, two approaches can be taken to reduce peak shift: the resolution of the reading head can be increased, or the width of the transition regions can be reduced, for example, by reducing the coating thickness, the writing current, or the range of switching fields in the magnetic material.

Conclusions

Peak shift in high-density magnetic tape recording has been studied as a function of read-write head gap, write current, information density, oxide-coating thickness, tape, and erase field direction. It was found that the erase field polarity to which the tape is subjected prior to recording does influence the peak shift. It is believed that the major cause of peak shift is the cancellation of flux in the reading head from adjacent bits resulting from wide transition regions between bits at saturation write current. A new technique of measuring the remanent moment of a small section of a recorded track as a function of write current, density, and angle from the plane of the oxide coating was used in this work. Variations of the technique are currently being used in a new series of experiments in this area.

Appendix. Head Specifications

1. Narrow gap read-write head: a single-gap head with a 90-microinch gap, 100 turns center-tapped, and a 47-mil track width.
2. Wide gap read-write head: a 2-gap *729 IV* head with a 0.005-inch write gap, a 0.0025-inch read gap, 100 turns center-tapped, and a 47-mil track width.
3. Thick tape: 0.56-mil gamma-iron-oxide coating, 40% volume loading, oriented in the direction of tape motion on a 1.5-mil base material.
4. Thin tape: same as thick tape but with 0.28-mil oxide coating.

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