SESSION 23

AN ANALYTICAL MODEL OF THE WRITE AND READ PROCES IN DIGITAL MAGNETIC RECORDING WITH A LINEAR RECORDING MEDIUM

A. van Herk and P. Wesseling
Twente University of Technology, Enschede, Netherlands

In general it is not possible to derive an analytical expression for the magnetisation distribution, the magnetic field and the readback signal, which are created by writing and reading a magnetisation reversal in digital magnetic recording. However, for the special case that certain conditions are satisfied, explicit analytical expressions for the aforementioned quantities are derived from the basic equations governing the write and read proces.
These relations represent exact solutions in which demagnetising effects are fully taken into account. The conditions which must be satisfied are: 1) The recording material has a linear M-H relation $M=M_r(H/H_c-1)$; 2) The recording medium consists of a film thin enough for neglecting transversal field and magnetisation components; 3) The fields of both the write and read head are described by the Karlqvist expression; 4) The effects of magnetic image charges in the write and read head are neglected; 5) A positive head field is applied to a stationary, negatively premagnetised medium.
If the maximum head field is less than 2 H_c, then the linear M-H relation can be replaced by a special idealised hysteresisloop (fig. 1) for which the exact solution is also valid if the write head field returns to zero.
For a write head with gaplength $g_w \to o$ and medium separation y_w the magnetisation and the demagnetising field are given by the following formulae:

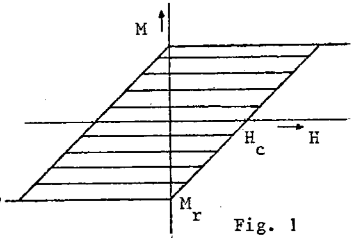


Fig. 1

$$M(x) = \frac{2H_{ow}g_w}{\pi\,\delta} \text{ Re } E_1'\{(1+i\,\frac{x}{y_w})/\alpha\} - M_r,$$

$$H_d(x) = \frac{H_{ow}g_w}{\pi}\left[\frac{2H_c}{\delta M_r}\cdot \text{Re } E_1'\{(1+i\,\frac{x}{y_w})/\alpha\} - \frac{y_w}{y_w^2 + x^2}\right],$$

in which H_{ow} is the write head gapfield, $\alpha = \delta M_r/2H_c y_w$, δ is the medium thickness, $E_1'(z) = e^z \int_z^{\infty} e^{-z}/z\; dz$. All quantities are in mksa units.

If this magnetisation pattern is read with a read head with gaplength $g_r \to o$ and medium separation y_r, the readback signal is given by:

$$u(x) = k\left[\frac{1}{\beta}\text{ Im } E_1'\{(1 + i\,\frac{x}{y_w+y_r})/\beta\} + \frac{x_o/y_w+y_r}{1+(\frac{x_o}{y_w+y_r})^2}\right],$$

in which $k = 2\,\mu_o vb\, h_{ow}g_w H_{or}g_r/\pi(y_w+y_r)$, H_{or} is the read head gapfield for unit head current, $\beta = M_r/2H_c(y_w+y_r)$.

Expressions for $g_w \neq o$ and $g_r \neq o$ are also derived. Only the sum of y_w and y_r occurs, so the effects of write and read head separation simply add together.

Comparison of calculated readback pulse widths with experimental values taken from the literature shows reasonable agreement in the case that the write head field is given by:
$H_w = (H_{ow}/\pi)\{\arctan(x/y_w) + \pi/2\}$, i.e. the field of a "half-Karlqvist-head". This is shown in fig. 2, in which the dots represent experimental values from Curland*).
Figure 3 shows the magnetisation pattern and the demagnetising field for α=o (no demagnetising effects) and α=2.

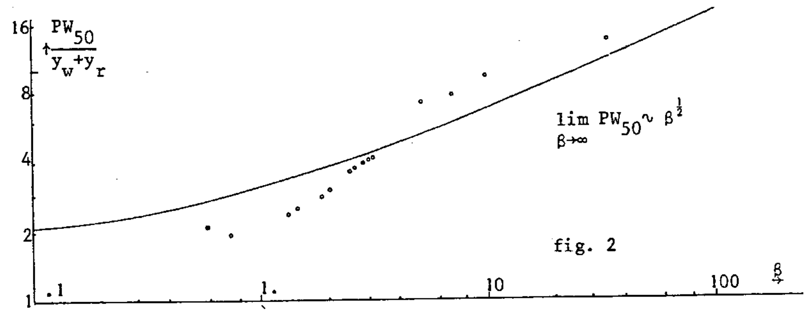


fig. 2

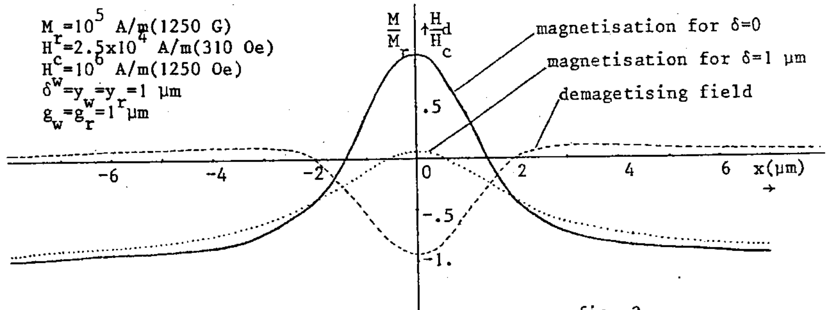


fig. 3

In addition to the use of this exact solution for constructing magnetisation distributions and readback signals, it can also be used for testing the accuracy of numerical methods for the solution of the basic equations of the recording proces in the nonlinear case.

*) N. Curland, Thesis, University of Minnesota (1971)

DYNAMIC SELF-CONSISTENT ITERATIVE SIMULATION OF HIGH BIT DENSITY DIGITAL MAGNETIC RECORDING

Chao S. Chi
Digital Equipment Corp.
Maynard, Mass.

Dennis E. Speliotis
Micro-Bit Corp.
Lexington, Mass.

There is ample evidence that in the present state of development of digital magnetic recording systems, the main limitations on performance are imposed by the writing-demagnetization process -- and in particular by recording demagnetization and asymmetric peak shift -- rather than by the readback process. To adequately handle these problems one must consider the dynamic interaction of the writing-demagnetization process self-consistently and integrally, instead of treating these processes as independent and unrelated. A number of theoretical treatments in the recent literature compute the magnetization distribution for an isolated NRZ transition and for multiple symmetrically spaced NRZ transitions by using a self-consistent iterative approach, which takes into account the interaction of the write-head field, the demagnetizing fields, and the image charge fields. In this work we developed a dynamic iterative model using self-consistent iterations performed at sufficiently small time intervals to essentially simulate a continuous record-free space-readback process, involving the motion of the medium under the write transducer, the gradual separation of the medium from the write transducer region into free space, thus simulating any head contour and flying height arrangement, and the re-introduction of the recorded magnetization pattern under the readback transducer. In addition to the write head fringing field (Karlquist's expression), the demagnetizing fields, and the image charge fields, the model considers a finite flux risetime, the leading edge magnetization distribution,and follows the magnetic history of the medium through the major loop and a continuous family of minor loops. Furthermore, the model incorporates a novel numerical technique utilizing complex Fourier transform pairs thus retaining both amplitude and phase information, and applying it to signal filtering analysis and to the treatment of the head sensitivity functions in the combined time and frequency domains (employing the frequency response of the complex permeability of the transducer material).

To test the accuracy and the validity of the model as a tool for optimal design of high bit density systems, we performed a theoretical simulation and comparison with several experimental disk systems,using plated disks with different magnetic parameters and thickness, different transducers, and a range of write current rise times. The comparison was made using the NRZI pattern 101111110001 (preceeded and succeeded by the same saturated remanence state of the medium), at a density of 8000 bits per inch and a velocity of 2252.52 in/sec. The agreement between theory and experiment was excellent. An example is shown in Fig. 1, where the predictions of superposition are also included based on the experimental single pulse (the parameters for this example were: for the disk, Coercivity=325Oe; Remanence=11700Gauss; Squareness=0.7, Thickness=8.8μin; and for the single write/read head, Gap=152μin;Track width=13.5mils;Flying height=52μin;Current=97.5mA; Current rise time=35ns).The superposition predictions are too optimistic, while the dynamic iterative model provides excellent agreement with experiment in absolute timing and signal amplitude.

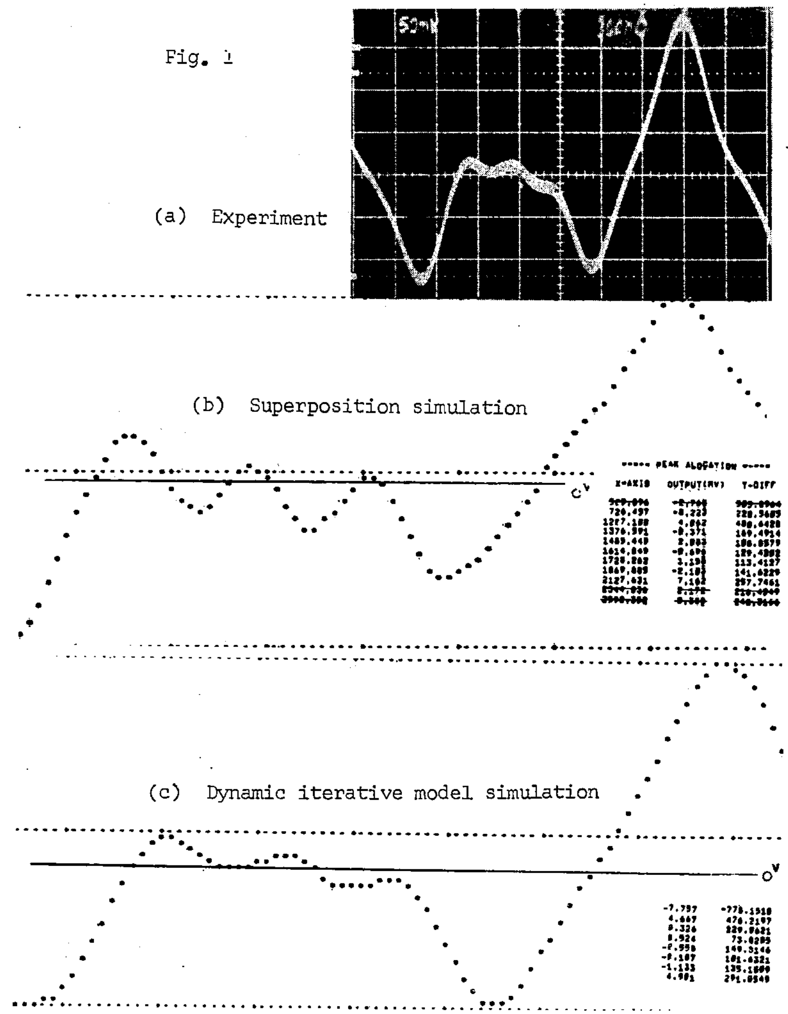


Fig. 1

(a) Experiment

(b) Superposition simulation

(c) Dynamic iterative model simulation

COMPUTER SIMULATION OF HIGH-DENSITY MULTIPLE TRANSITIONS IN MAGNETIC DISC RECORDING

Kozo Nishinoto, Morimasa Nagao, Yoji Suganuma and Hideo Tanaka
Central Research Laboratories, Nippon Electric Co. Ltd.,
Kawasaki, Japan

Evaluation of multiple transitions in magnetic recording has so far been carried out only by means of the superposition method in spite of the existence of the effect of demagnetizing fields at high recording densities.[1,2] The reason is considered to be that an appropriate magnetization curve model has not been available. Recently, Potter and Schmulian[3] established an excellent model, but application of the model to multiple transitions recording is doubtful. In the present work, computer simulation of multiple transitions are carried out on the basis of an improved Potter and Schmulians' model, in which magnetizations change reversibly even on minor loops. Results are discussed in comparison with those obtained by the superposition method.

In computations, Karlquist's head fringe field is applied, magnetization patterns are computed self-consistently and, finally, readback voltages are obtained using the reciprocity theorem. One dimensional grid of the medium is 10 to 15 micron long, in which three to nine transitions are written. Table 1 shows values of parameters used in the computations. The medium corresponds to a plated metallic thin film appropriate for high-density recording.

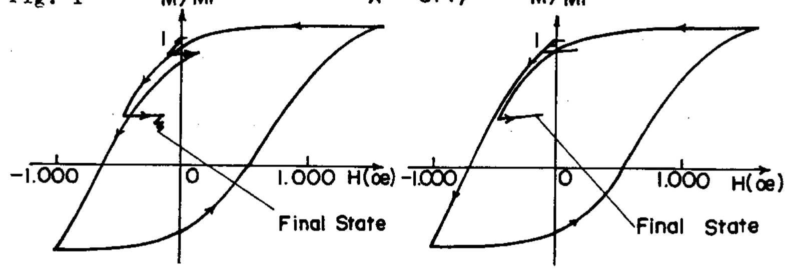
Figure 1 shows magnetization changes during multiple transitions writing in the present improved model, as compared with Potter and Schmulians'. Irreversible changes of magnetization in the latter are not seen in the former. Figure 2 shows magnetization and readback voltage patterns written at 25,400 flux reversals per inch. The fact that the period observed in them is the same as that of the writing head field indicates the validity of the computations. Ratios of readback voltages obtained by computer simulation to those by superposition of isolated readback pulse by simulation are shown as a function of transition density in Fig.3. The ratios decrease with increasing transition density. This can explain semi-quantitatively the fact that measured readback voltages were always smaller than those calculated by superposition (Fig.9 in ref.2). Phase differences between readback voltages obtained by the two methods also become larger with increasing transition density. However, there is a small difference in peak-shift values in a double frequency encoded pattern. These results agree qualitatively with Tercic's result[2] on two transitions recording.

The considerable difference in readback voltages of multiple transitions obtained by the two methods suggests that evaluation of high-density recording performance should be done by self-consistent computation.

References

1. J.C.Mallinson and C.W.Steele, IEEE Trans.Magn, Mag-5, 886(1969)
2. E.J.Tercic, IEEE Trans.Magn, Mag-9, 335(1973)
3. R.I.Potter and R.J.Schmulian, IEEE Trans.Magn, Mag-7, 873(1971)

Fig. 1



Potter and Schmulians' Model　　Improved Model

Fig. 2

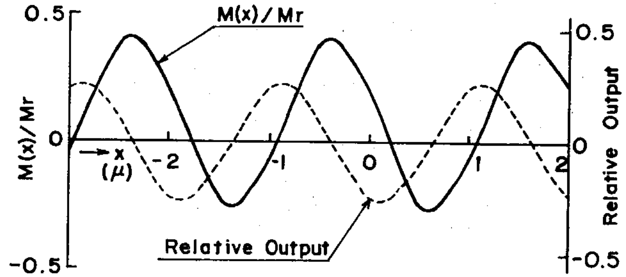
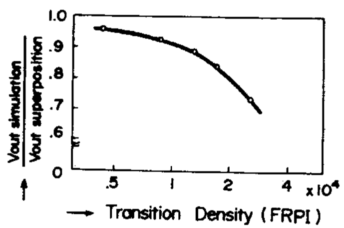


Table 1

Gap field	H_g	4,000 Oe
Gap length	g	1.0 μ
Spacing	D	0.3 μ
Saturation magnetization	M_s	800 G
Squareness	S	0.85
Coercive force	H_c	700 Oe
Medium thickness	δ	0.05 μ

Fig. 3



ON RECORDING HEAD FIELD THEORY

J. C. Mallinson
Ampex Corporation, Redwood City, California

In well known studies, both Booth[1] and Westmijze[2] used the Schwartz-Christoffel method of conformal transformation to deduce exactly the fringing field adjacent to the gap of an infinitely permeable head of semi-infinite dimensions. Later, Fan[3] solved the same problem by harmonic analysis of Laplace's equations in the regions above and in the gap. His results, which are completely equivalent, are cast in the form of a series of integrals. The first integral of the series is precisely the Karlquist[4] expression and it dominates everywhere except close to the gap edges. The Karlquist formula has been shown to result from uniform magnetic pole sheets on the gap faces. Thus we may conclude that, to a good approximation for regions outside the head, the magnetization within the head may be considered uniform and orthogonal to the gap.

Although the Karlquist model is widely used because of its simplicity, it unfortunately contains a basic flaw. Consider the Fourier transformation $\longleftrightarrow$ of the Karlquist formula for the longitudinal field component, H_x,

$$\frac{H_0}{\pi} \tan^{-1} \frac{2gy}{x^2+y^2-g^2} \longleftrightarrow 2g H_0 \frac{\sin kg}{kg} e^{-|k|y},$$

where k is the wavenumber $(2\pi/\lambda)$, $2g$ is the gaplength, x and y are the usual longitudinal and normal coordinates, and H_0 is the deep gap field.

This transform is just the reproduce head flux transfer function or spectrum for a thin lamina of tape at distance y. At short wavelength, $\lambda = 2g$, the spectrum vanishes giving the "first gap null". At $\lambda = \infty$ however, the spectrum is equal to $2gH_0$. The Karlquist model predicts that the head has a nonzero dc response! It is easy to prove that this prediction violates physical reality. For example, the line integral of H_x must be zero for any path above the head since no current loop is threaded.

We demonstrate that this failing is not due to the Karlquist approximation; none of the models discussed above yield a line integral value of zero. The dc response is rather a consequence of assuming the head dimensions to be semi-infinite.

In order to obtain physically reasonable spectra, the computation must include the whole head. This has been done by Westmijze[2], Elabd[5], Potter et al[6] and Mallinson and Steele[7] whose results yield zero dc response. Unfortunately these calculations are of such complexity as to be almost beyond practical utility. Simpler theories are needed.

We conclude by suggesting two elaborations of the Karlquist model which yield zero dc responses. In the first, applicable to shallow gaps, the spectrum still shows the "first gap null" at $\lambda = 2g$. The second case applies to heads with narrow pole tips. Here a constructive interference phenomenon takes place which can significantly improve the short wavelength resolution of the head; the "first gap null" wavelength now falls in the range $2g > \lambda > 1.4g$.

References:
1. A. D. Booth, Brit. J. Applied Physics, 3, 307 (1952)
2. W. K. Westmijze, Philips Res. Reports, 8, 161 (1953)
3. G. Fan, IBM J. Res. Develop. 5, 321 (1961)
4. O. Karlquist, Trans. Royal Inst. Tech. Stockholm, 86, 1 (1954)
5. I. Elabd, IEEE Trans. Audio, 11, 21 (1963)
6. Robert Potter et al, IEEE Trans. Mag. 7, 689 (1971)
7. J. C. Mallinson and Charles W. Steele, IEEE Trans Mag. 8, 503 (1972)

NARROW RECORDING HEADS

Gordon F. Hughes
Xerox, Palo Alto Research Center, CA

Summary

As track widths, intertrack guardbands, and head-to-track positioning tolerances decrease in magnetic recording systems, read/write fringing off the sides, or gap corners, of the head can become significant. Conventional two-dimensional design equations ignore this effect.

Magnetic field calculations are presented for a three-dimensional head where the track width is not infinite compared to the head gap length, guardband, or positioning tolerance.

Analysis

A potential theory analysis of the three-dimensional narrow head in the figure is made. Karlqvist's[1] assumption of a linear potential variation across the gap is used, and his 2D analysis is compared to the present 3D method. *

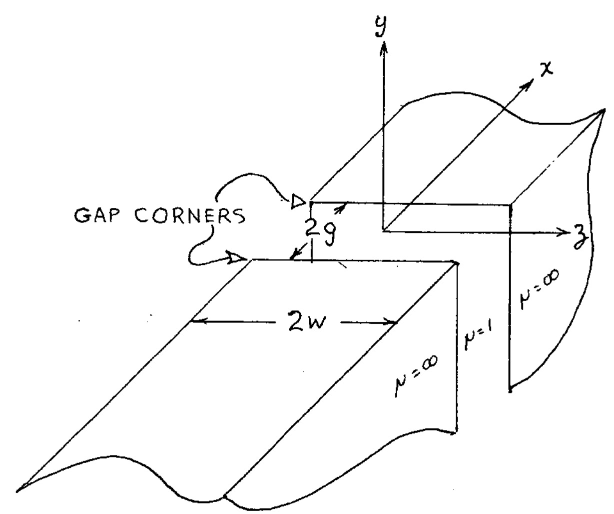
The resultant field formulas are used to evaluate: (a) head effective writing track width; (b) effective reading track width, via head sensitivity function; (c) off-gap-corner contribution to overall field gradient; (d) off track read or crosstalk response; and (e) discussion of relevant realities such as broken gap corners, finite head permeability, finite gap height, and 3D calculations of head inductance.

Performance of a dual-gap pre-erase head is discussed, having a uniform erase and read/write width 2w = 97 um, and a long erase gap 2g = 51 um in order to pre-erase an effective guardband 30 um each side of the head.

* This 3D Dirichlet Problem is explicitly solved for the scalar magnetic potential $V(x, y, z) = \sum_i \int V(S_i)(\partial G/\partial n_i)dS_i$ by means of a Greens Function[2] ($G(x, y, z, x_1, y_1, z_1)$ constructed from an infinite series of image point charges, whose normal derivative is integrated over the head boundary surfaces S_i at known potential $V(S_i)$.

1. O. Karlqvist, Trans. Royal Inst. of Tech., Sweden, No. 86, 1954.

2. W. Smythe, Static and Dynamic Electricity, McGraw Hill, N.Y., 1950, Sect. 3.08.



RECORDING HEAD GEOMETRY

THEORITICAL STUDY OF INTEGRATED MAGNETIC HEAD IN HIGH RECORDING DENSITIES

J.P. Dejouhanet - J.P. Lazzari
Compagnie Internationale pour l'Informatique
rue Jean Jaurès - 78340 Les Clayes-sous-Bois
FRANCE

The structure of integrated heads offer better possibilities of optimization than conventionnal heads. The length of the gap and the thickness of the pole tips can be optimized in order to obtain the best efficiency of the head during the write process.[1]

This optimization rely on the magnetization distribution of a single transition. We will here study three transitions the distance of which beeing adjustable. The purpose of this paper is to show, that the optimization of the write process is not always really convenient for high density recording.

We use an iterative method the principle of which is identical to the one used for the calculation of a single transition. This method extended to three transitions gives the magnetical story of the magnetization as faithfully as possible. During the computations the magnetization varies on the major B-H loop or on the minor cycles taking into account the transition interactions and the demagnetizing fields. After the third position the head is translated faraway. In order to better understand the method a full detailed diagram will be given.

Results enable us to know the density limitation of an integrated head with a given medium Fig. 1.

Fig. 2 shows transitions recorded with the same gap length, but with various pole tip thickness (3,3 µm, 5,1 µm, 6,9 µm). On these threes recording we see various pick shifts.

In conclusion this study shows that the pole tip thickness of integrated heads is an important parameter for the magnetic pick-shift.

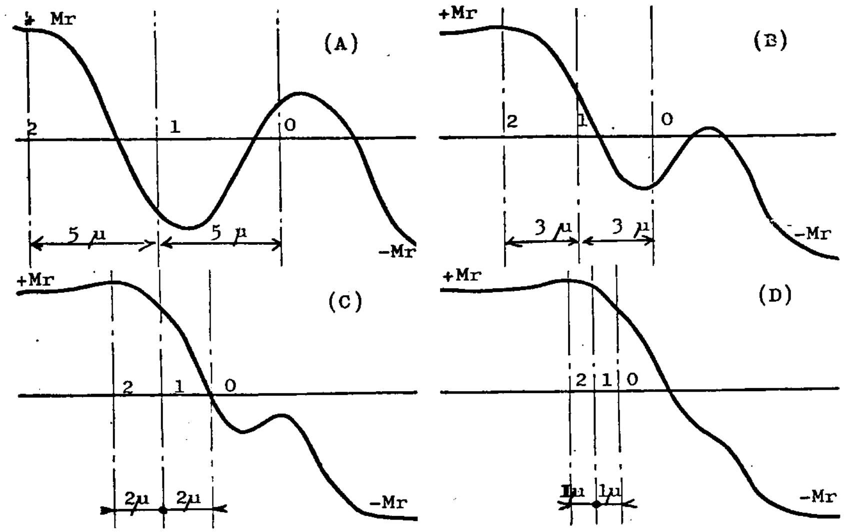


Fig 1 - Gap length 1 um, pole tip thickness 6 µm, magnetomotive force ; 4 AT head to medium spacing 1 µ medium characteristics, Hc = 300 œ, γFe_2O_3 layer thickness 2 µ, the density limitation would be 5000 bit/cm (12500 bpi)

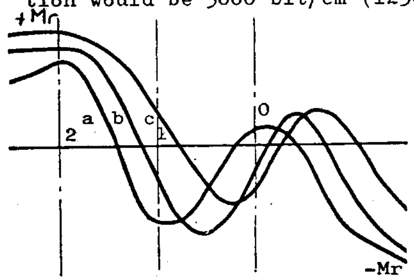


Fig 2

pole tip thickness : a= 3,3 µ
b= 5,1 µ
c= 5,9 µ

REFERENCE

1. J.P. Lazzari "Integrated Magnetic Recording Heads Applications" IEEE Transactions on Magnetics, VOL. Mag-9, N° 3, Sept 1973, pp 322-326

MAGNETIZATION REVERSAL BEHAVIOR IN HIGH DENSITY RECORDING

K. Ramachandran and R.F. Soohoo
University of California, Davis, California 95616

Introduction

In this paper, the magnetization reversal behavior for spots in high density digital recording is studied. Two specific cases are examined: (1) narrow track width or large number of tracks per unit width and (2) narrow bit width or large number bits per unit length. Referring to Figure 1, the maximum storage capacity of a recording medium can be reached either by narrowing the track width w or by increasing the bit density (which is equivalent to reducing δ). In our model, ellipsoidal ferromagnetic particles are replaced by anisotropic point dipoles arranged in a regular spatial array, as reported by us earlier.[1] A number of new results will be given here.

Narrow Track Width

Analysis of an array representing the case of narrow track width using typical γ-Fe_2O_3 parameters yields the following results: the switching initiation field H_{si} is found to be -113.10 oe, and the coercive force H_c and switching completion field H_{sf} are -1501.35 oe. H_{si}, H_c and H_{sf} level off with increase in the number of particles along the z direction. It is interesting to note that reducing the track width results in an assembly coerce force larger than the corresponding single particle value H_{cp} = 800 oe. The effect of reducing the thickness of the coating is the same as that of reducing the track width. If we reduce the thickness of coating and the track width simultaneously, the limiting recorded bit is a linear array of elongated particles oriented along the z direction. It can be shown that an array of infinite number of particles arranged along the z direction has a coercive force H_c, given by:

$$H_c = -(H_{cp}+H_I) \qquad (1)$$

where

$$H_I = \frac{2\mu}{(Sb)^3} \sum_{n=1}^{\infty} \frac{1}{n^3} \qquad (2)$$

The Riemann Zeta function $\sum_{n=1}^{\infty} \frac{1}{n^3}$ is tabulated in standard math tables. Thus H_c for a linear array of infinite number of particles in the z direction is found to be -803.884 oe. Since the hysteresis loop is rectangular in this case, H_{si} and H_{sf} are also equal to -803.884 oe.

Narrow Bit Width

Analysis of an array representing the limiting case of narrow bit width yields the results shown in Figure 2.

1. R.F. Soohoo and K. Ramachandran, "Switching dynamics of an assembly of interacting anisotropic ferromagnetic particles", presented at the 19th Annual Conference on Magnetism and Magnetic Materials in Boston, Mass., November 1973, (to be published).

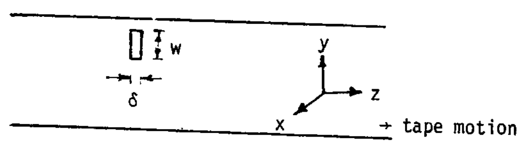


Figure 1. RECORDED BIT ON A DIGITAL TAPE

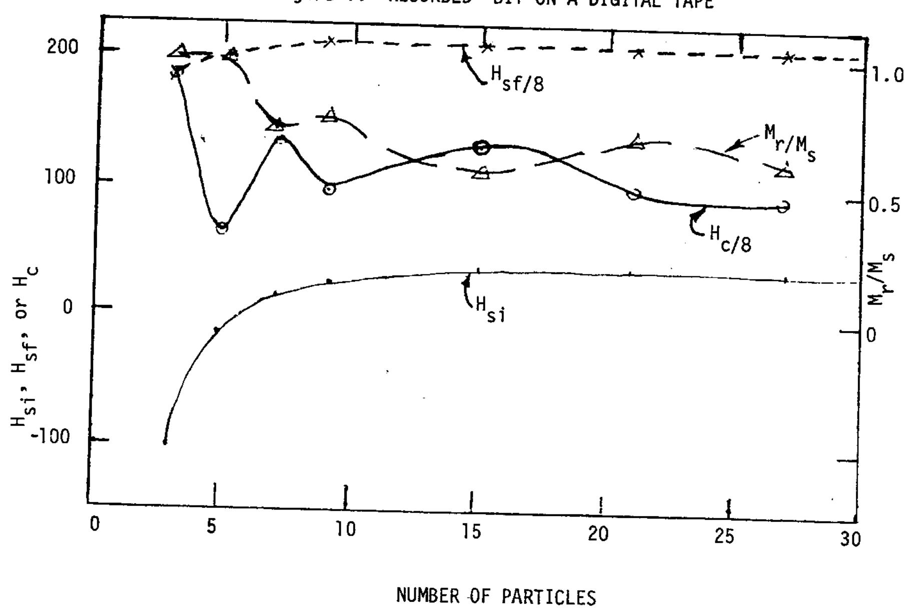


Figure 2. H_{si}, H_c, H_{sf} and M_r/M_s (squareness ratio) vs. no. of particles.