Magnetic Recording Head Design

A. S. HOAGLAND
ASSOCIATE MEMBER AIEE

AN analysis of the process of magnetic recording of digital data is presented from which qualitative magnetic head design concepts are developed and their usefulness demonstrated, both in the evaluation of magnetic head structures and in design for high-density storage.

This work was begun in connection with the development of the International Business Machines Corporation (IBM) *305* magnetic disk storage file, where rather stringent requirements necessitated a program for improving the performance of the existing magnetic recording unit. The external constraints imposed on this work essentially limited the design parameters to those concerned with the magnetic head, excluding the gap dimension. The investigation of this subject led to the development of an analytical formulation of the process of magnetic recording which is directly applicable to data recording. The insight derived from the theory and its relative simplicity in application will be demonstrated through its successful employment in guiding head design development in connection with the IBM *305* magnetic disk project.

The paper will first briefly present a general discussion of magnetic data recording, stressing the form of the readback wave form and its relation to bit density. Then the basic theoretical development will be presented and the significance of these expressions to magnetic head design will be stressed. The remainder of the paper will present experimental results and their correlation with the theory, followed by a description of the selected magnetic head for the magnetic disk file and its performance.

Data Recording

Magnetic recording of data involves the storage and processing of binary information, utilizing two states which are capable of being differentiated. For convenience consider NRZ (nonreturn-to-zero) recording in which the storage surface is continuously saturated during writing, in one direction for a "1" and in the opposite sense for a "0." A particular input is then composed of a succession of alternating step changes in writing current. Reading involves a derivative-type action as indicated schematically in the diagram below, illustrating the overall transfer process from input to output. The surface co-ordinate is x, and $\bar{x}$ represents the variable indicating the position of the specified surface magnetization relative to the magnetic head.

$$i(t)\text{---}M(x)\text{---}\phi_h(\bar{x})\text{---}vNd\phi_h/d\bar{x} = e(\bar{x}) = e(vt)$$

where:

$M(x)$ = distribution of magnetization set up in the storage surface
$\phi_h(\bar{x})$ = reading coil flux as a function of surface position
e = open circuit readback voltage
N = number of turns on the reading coil
v = surface velocity; t = time

Hence $e(vt)$ is a pulse-like signal for a step change in $i(t)$[1] and the surface velocity appears as a scaling factor in both time and amplitude for the output signal. An output voltage signal is then associated with each change in the direction of saturation or reversal in writing current.

Consider the output signals for arbitrary input patterns consisting of sequences of alternating step changes in writing current. On readback the magnetic field existing, that due to the magnetization of the surface, is extremely weak and hence the magnetic head will behave very nearly as a linear element. Further, writing definition or the width of a saturation transition region is much less than the corresponding reading resolution, due to the nonlinear surface saturation characteristic. Thus, generally, reading will limit density before the point is reached at which adjacent changes in surface state modify one another. These considerations imply that the principle of superposition may be applied to the overall input-output transfer process, using the characteristic step function output response. The width and wave form of this characteristic response are thus extremely important and such responses will be shown as functions of x, or distance, as only in this manner are they meaningful. As indicated, the velocity enters only as a scaling factor between distance and time and only spatial relations are significant in this recording process. It is evident that bit density considerations will follow directly.

Consider a symmetrical voltage pulse response with the base width of λ. The maximum bit density permissible where no mutual interference is to be allowed, i.e., each saturation change is to be resolved independently, is then equal to $1/\lambda$. On the other hand if the requirement is only that no pattern modulation occurs, implying no signal peak variation, then the bit density has a limit of $2/\lambda$.

Now a typical response signal is shown in Fig. 1. The base-line character (or wave form) is quite important, as well as pulse widths at various levels above the base-line, in density considerations.

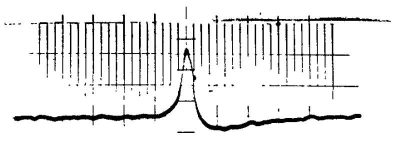


Fig. 1. Typical response signal

Scale: 3.5 mils per division

The "overshoots" may be broader than the main pulse. Thus no single criterion can be used in comparing responses.

A general objective for high-density design is to attempt to obtain a spike-like characteristic output signal, i.e., to eliminate base-line signal and maximize the rate of approach of the signal to the base-line. Considering undesired signal as noise, the overshoots tend to limit the signal-to-noise ratio at lower densities and first cause overlapping of signals as the bit density is increased. However, even with no base-line signal, as the bit density is increased and correspondingly a spacing reduction between adjacent sampling strobes errors will arise with an isolated pulse signal due to the gating of strobes on either side of the strobe which is actually associated with this output indication. This limitation is accentuated by pulse responses with gradual base-line approaches and can severely limit performance.

Theory

In addition to the principle of superposition the principle of reciprocity will be used, these forming the basic tools in this analysis. The applicability of the principle of reciprocity to readback follows as an imediate extension from the

---

A. S. HOAGLAND is with the University of California, Berkeley, Calif.

justification for using the principle of superposition. As employed here the concept of reciprocity states that the magnetic field, H, set up by energizing the reading coil with a small current (assuring low field levels appropriate to readback and likewise the same linear behavior) gives a measure at each space point of the degree of coupling existing between a weak magnetic field source at that point and the reading coil. The space points of concern are those that constitute the magnetic sources of readback, i.e., the storage surface, primarily the track passing under the transducer but also including nearby adjacent tracks.

A reasonable simplification for the objectives desired, and in view of the nature of the problem, is to neglect variations with surface layer depth. This is equivalent to considering the surface as a relatively thin film which is often the case. The depth factor will be treated later. Then functions defined along the surface will depend only on one variable. The centerline of the magnetic head gap (ring structures) will henceforth be chosen as the fixed reference point, *i.e.*, $\bar{x} = 0$.
Then

$$\phi_h(\bar{x}) = \phi_{hx}(\bar{x}) + \phi_{hy}(\bar{x}) \tag{1}$$

where the subscripts denote the reading coil flux contributions arising from each of the two possible components of surface magnetization, M_x and M_y, using a conventional ring-type transducer. The y co-ordinate is normal to the surface, defined positive in the direction of the magnetic head. First only a single track will be considered. The fringing field set up along the storage surface track when the reading coil is energized in the manner described for the reciprocity relation will have the vector components $H_x\bar{x}$ and $H_y\bar{x}$. Then, according to the principle of reciprocity, H_x is a function giving the sensitivity of the reading coil to horizontal surface magnetization and H_y gives the reading coil sensitivity to vertical magnetization.

It can be shown that

$$\phi_h(\bar{x}) = K\int_{-\infty}^{+\infty} M(x-\bar{x})H(x)dx \tag{2}$$

where M and H are vectors combined by a scalar or dot product operation.
Then

$$\phi_{hx}(\bar{x}) = K\int_{-\infty}^{+\infty} M_x(x-\bar{x})H_x(x)dx \tag{3}$$

and

$$\phi_{hy}(\bar{x}) = K\int_{-\infty}^{+\infty} M_y(x-\bar{x})H_y(x)dx \tag{4}$$

where the limits of integration are in practice only for the range over which H_x and H_y are significant. K is a constant proportional to the surface thickness, assuming uniform saturation throughout the surface layer.

Now to clarify the import of these formulas consider an idealized case where $M_y = 0$ and there is a step change in horizontal magnetization M_x from $-M_s$ to $+M_s$. Then

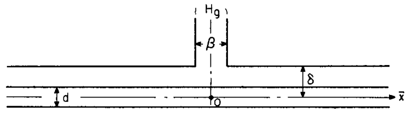


Fig. 2. Idealized magnetic head model

The pole faces extend to infinity.
β = gap size
δ = spacing factor
d = surface thickness
Hg = gap field

$$\phi_{hx} = 2KM_s \int_{\bar{x}}^{\infty} H_x(x)dx \tag{5}$$

and as

$$e(\bar{x}) = vNd\phi_{hx}/d\bar{x} =$$
$$KvN\int_{-\infty}^{+\infty} H_x(x)\ \frac{\partial M_x(x-\bar{x})}{\partial\bar{x}}\ dx \tag{6}$$

then,

$$e(\bar{x}) = e(vt)\ \propto\ vH_x \tag{7}$$

This relation states that the output voltage or pulse response wave form will resemble in time the static field distribution function H_x, i.e., the signal amplitude for a given position of the step change in magnetization relative to the magnetic head gap centerline will be proportional to H_x, a weighting function, at that point. Similarly, the output signal arising from a recorded step function change in M_y would be

$$e_y\ \propto\ H_y(\bar{x}) \tag{8}$$

where the subscript on the output voltage indicates that this contribution is due to M_y. Where both components of magnetization exist the two output signal components may be algebraically added to give the output voltage wave form, for $e = e_x + e_y$.

Determination of H

A rapid way to get estimates for the weighting functions H_x and H_y is to make rough field plots for the gap fringing field. Here there is no concern about local saturation effects since these maps are to apply for very weak fields. Qualitative information is generally adequate and, normally, fine detail would not be justified. It will be seen however, that in general a factor such as reading coil location is extremely important. The estimates for these fields from such mapping indicates their important qualitative features and these have been confirmed by a powder pattern technique of field observation.

Figs. 2 and 3 show ring-type structures and qualitative determinations of weighting functions, illustrating the importance of coil location and pole-tip shape. The magnetic potential lines shown in Fig. 2 do not, of course, actually apply within the coil or current source region. The orientation of the fringing field vector along the surface as indicated in Fig. 3, shows the influence of narrowed pole tips in reducing the base-line width (neglecting "overshoots") of H_x.

It is apparent that the information concerning H could be presented in terms of magnitude and angle rather than in the form of the scalar components H_x and H_y. Fig. 3 gives an indication of the angular variation of $H(\bar{x})$ and attention will be given to this aspect of the field H later. It will be noted that with a ring-type structure, giving longitudinal recording, the principal field component will be H_x. The writing process will be considered later but it should be clear that if only horizontal magnetization occurred when writing then the only response function of interest would be H_x and conversely if $M = M_y$ then only H_y is of concern.

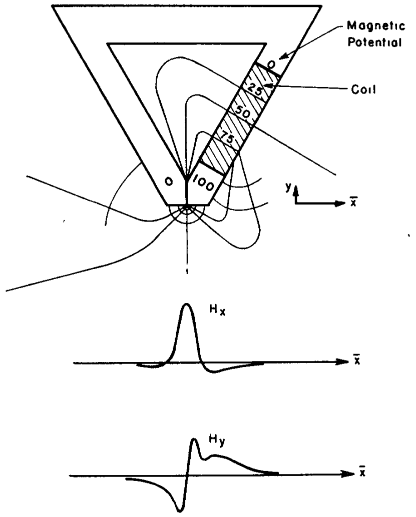


Fig. 3. Field plot showing influence of coil location on H_x and H_y

Voltage and Weighting Function Integrals

Certain statements may be made about the output voltage-time pulse area, other than its independence of

v, in terms of the weighting functions H_x and H_y. Consider a step change in M_x from $-M_s$ to $+M_s$. Then:

$$\phi_h(-\infty) = KM_s \int_{-\infty}^{+\infty} H_x(x)dx \tag{9}$$

and

$$\phi_h(+\infty) = -KM_s \int_{-\infty}^{+\infty} H_x(x)dx \tag{10}$$

Thus if

$$\Delta\phi_h = \phi_h(-\infty) - \phi_h(+\infty) \tag{11}$$

$$\Delta\phi_h = 2KM_s \int_{-\infty}^{+\infty} H_x(x)dx$$

but of course

$$N\Delta\phi_h = \int_{-\infty}^{+\infty} e(t)dt \tag{12}$$

Hence a relation is seen between the output single voltage-time area and the area under the corresponding weighting function. This immediately gives some insight into the possible degree of overshoot area to be expected. Further it reinforces the arguments for the importance of reading coil location since if the coil is so oriented that a uniform horizontal flux field tends to give zero flux linkages then the negative overshoot area must as a consequence be of the same size as the main pulse area; this applies here to both the weighting function and the output signal which would be proportional. These same considerations can be as simply extended to an M_y magnetization component, involving a consideration of the H_y function.

Adjacent Track Pickup

The sensitivity of the magnetic head to adjacent track magnetization can be considered by use of the reciprocity principle in the same manner as described, both with and without intertrack shielding. Let z be the transverse co-ordinate and let $z = 0$ at the given track and $z = z_1$ at an adjacent track. Note that since $H_x(z) = H_x(-z)$ the worst case for two adjacent tracks, one on either side of the magnetic head, would arise when both were similarly recorded. Now e.g., $H_x(\bar{x})$ at $z = z_1$ is not only considerably reduced in amplitude over that at $z = 0$ but its relative extent is considerably greater. Since the changes in surface saturation along a track must be alternating, then as the density of these saturation changes increases, there will tend to be a greater and greater effective cancellation of the individual signals. Thus due to the low resolution of a magnetic head with respect to neighboring tracks the lower density patterns are the most troublesome.

Finite Region For Surface Magnetization Change

An approach to an estimate for the significance of neglecting the actual surface magnetization and using an idealized step function change will be indicated by assuming $M = M_x$ and that the change in saturation from $-M_s$ to $+M_s$ occurs over the distance x_1 in a uniform manner. Let ρ equal the effective width of H_x. ρ then gives a measure for reading resolution and is equivalent to the factor λ defined earlier for a characteristic output voltage response. Now

$$M_x = -M_s + 2M_s x/x_1 \qquad 0 \leqslant x \leqslant x_1 \tag{13}$$

$$M_x = -M_s \quad x \leqslant 0; \quad M_x = +M_s \quad x \geqslant x_1$$

then

$$\partial M_x(x-\bar{x})/\partial\bar{x} = -2M_s(x-\bar{x})/x_1 \tag{14}$$

$$\text{for } 0 \leqslant (x-\bar{x}) \leqslant x_1 \text{ or } \bar{x} \leqslant x \leqslant \bar{x}+x_1$$

and

$$= 0 \text{ otherwise}$$

Now substituting these conditions into equation 6 the following expression is obtained for e $(\bar{x})$:

$$e(\bar{x}) \propto \frac{\int_{\bar{x}}^{\bar{x}+x_1} H_x(x)dx}{x_1} \tag{15}$$

which clearly agrees with the earlier expression in the limiting case of a step function magnetization change. The influence of x_1 on the output signal can be quickly estimated. For any value of x_1, e$(\bar{x})$ can be obtained by averaging $H_x(\bar{x})$ over the interval x_1 for a set of values of $\bar{x}$. This procedure is readily done by graphical means.

The principal influence of a finite x_1 is of course to reduce the signal peak and increase the base-line pulse width. It is evident that for an x_1 only several times less than ρ the approximation of the saturation change by a step function is very good. Experimental attempts to determine a magnitude for such a factor on oxide surfaces indicate that the actual situation is even more favorable to the foregoing approximation. This is in accord with earlier statements regarding the importance of reading resolution as compared to writing definition, due to the surface saturation characteristic, since x_1 is a measure of the latter while ρ gives a measure of reading resolution.

Gap Size, Spacing, and Surface Thickness

The inclusion of these parameters in the theory will be outlined by consideration of the simplified head model shown in Fig. 2 and the assumption of a recorded step change in longitudinal magnetization. The extension of this development to other cases is obvious and it particularly lends itself to a ready description of the manner in which gap size, spacing, and surface thickness enter into the determination of the characteristic response. Here, only H_x need be considered.

First neglect the surface layer depth. Then the following expression may be written

$$H_x(0) = g(\delta/\beta)H_g \tag{16}$$

where $g(\delta/\beta)$ is a monotonically decreasing function and $g(0)$ is somewhat less than 1.0. The function g gives the gap fringing field attenuation. The gap size and spacing distance enter in the manner shown for this particular model for here parameter variation actually only involves scaling, a single fringing field plot sufficing. Thus if both β and δ are changed in the same ratio this merely amounts to a magnification or reduction of the entire field plot and the relative field attenuation given by g would remain the same. For an actual head structure the fringing field dependency upon these parameters can again be estimated fairly quickly by mapping. Now almost the entire magnetomotive force will appear across the gap when the reading coil is energized. Thus, $H_g\beta = Ni$. Then

$$H_x(0) \propto g(\delta/\beta)/\beta \tag{17}$$

This relation indicates the dependence of the output signal amplitude, for a step function change in M_x, upon the gap size and spacing. If both these factors are halved then g remains the same and the relative magnitude of the peak value of the weighting function, and hence the output signal, is doubled. It is clear that for this idealized head the above reductions are equivalent to scaling the field plot by a factor of 1/2 in each direction and therefore the relative pulse width will be reduced to 1/2 its former value. Thus the weighting function integral value is preserved as would be expected from the previous discussion on this subject.

The surface thickness may be included in the following manner. Let $H_x(\bar{x})$ be replaced by $\overline{H_x}$, the average value of H_x over the surface depth. Now it was pointed out that the constant K in the expressions for flux is proportional to the surface thickness, for uniform magnetization throughout the surface layer, since the total magnetic field source coupling with the reading coil for any value of $\bar{x}$ is proportional to d. Likewise K would be proportional to the head width with the two dimensional type of problem here. Then

$$e(0) \propto d\bar{H}_x(0) \qquad (18)$$

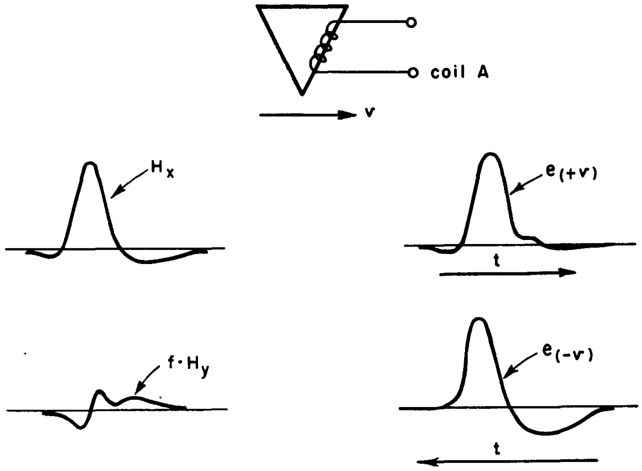
When $H_x(0)$ is a good approximation for the average value of H_x over the surface layer cross section in the plane $\bar{x} = 0$ then the following expression, indicating the signal amplitude dependence upon gap size, spacing, and surface thickness, may be written

$$e(0) \propto g(\delta/\beta)d/\beta \qquad (19)$$

Note that δ is measured to the center of the storage surface layer.

Fig. 5. Effect of oriented surface magnetization

$e_{(+v)} \propto H_x + f\,H_y$
$e_{(-v)} \propto H_x - f\,H_y$
where $f = M_y/M_x$



ORIENTATION OF MAGNETIZATION

Referring to Fig. 3 it is seen that with a ring-type magnetic head structure a qualitative classification of response functions would indicate H_x as an even function and H_y as essentially an odd function, insofar as such a division is concerned. Now consider a step change in saturation magnetization where now the direction of saturation is at some angle with respect to the horizontal, less than 90 degrees. Let M_x be the principal component, assumed a positive step change, and first consider the case where M_y is also a positive step change. Now since the actual change in surface magnetization is composed of these two independent terms the output response is the sum $e_x + e_y$, each term of which is proportional to its corresponding weighting function, adjusted by the actual magnitude of the associated step change in magnetization. As is clear from an inspection of Fig. 5 where this composition of signals is shown, the resultant output signal, $e(+v)$, is unbalanced relative to H_x. Now regard $e(-v)$ in Fig. 5 showing the same composition with only the sign of M_y changed. It is evident that this is a different characteristic output signal possessing another wave form unbalance. The base-line wave form of the output signal is considerably different in these two cases. The effect is easily visualized in terms of the angular variation of $H(\bar{x})$. It follows as a direct extension from the earlier theory that for an oriented step change in magnetization the output signal for each value of $\bar{x}$ is proportional to the scaler product of $H(\bar{x})$ and a unit vector in the direction of M or, in other words, proportional to the magnitude of the component of H in this direction. Now regard in Fig. 4 the region giving rise to the larger H_x "overshoot," this region being located on the coil side of the magnetic head. It is seen that H is oriented along an axis extending into the fourth quadrant, obtained by a clockwise rotation of the horizontal axis. Then for M oriented along an axis traversing the first quadrant, corresponding to the case giving rise to $e(+v)$ in which both M_x and M_y have the same sign, it is evident that the scalar product occurs between two vectors at nearly ninety degrees with respect to one another. The change in sign of M_y, used for obtaining $e(-v)$, rotates M by ninety degrees and therefore orients it along an axis running into the fourth quadrant and much more closely parallel to the axis giving the orientation of H in the region of concern. Thus, it would be expected that the "overshoot" signal response of $e(-v)$ would be considerably more pronounced.

The significance of these two characteristic wave forms will become apparent if the writing process is briefly considered. The storage surface passes through a 2-dimensional recording field when writing. The important portion of this field as far as writing is concerned is the field that the surface passes through on leaving the gap region of the magnetic head. Here a surface cross section horizontally saturated in the gap itself is subject to a not inappreciable vertical magnetizing component as it passes out of the vicinity of the head. Then there will be a tendency for an orientation of the saturated surface magnetization away from the horizontal. Further this orientation will depend on the direction of motion of the surface during writing. The two possibilities are indicated in Fig. 6. It can be seen that the two characteristic output voltage wave forms might be expected, the particular one depending upon the direction of surface motion during writing, except for an entirely symmetrical recording structure. A reversal of the direction of relative motion on reading adds no additional wave forms but merely produces a mirror image of the wave form previously obtained. Fig. 7 shows actual characteristic readback voltage wave forms showing the influence of the direction of surface motion. A delta-type head structure was used with a coil on one leg as indicated in Fig. 5. The leading and trailing leg designations indicate that the coil leg is the one first passed by a surface point and vice versa respectively. Note that the type of oriented

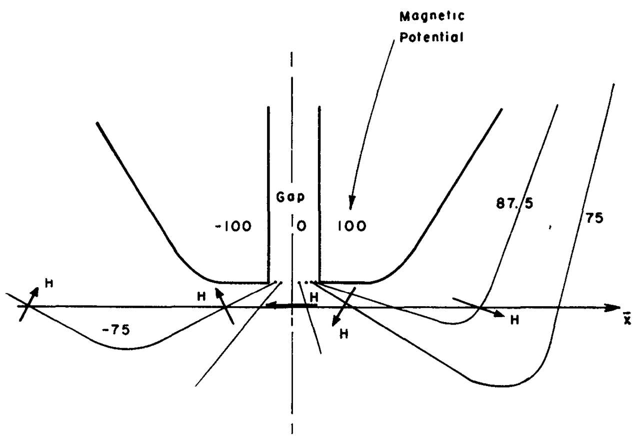


Fig. 4. Influence of narrow pole tips on senstivity function H

magnetization expected is in agreement with that necessary to account for these wave forms in this theory.

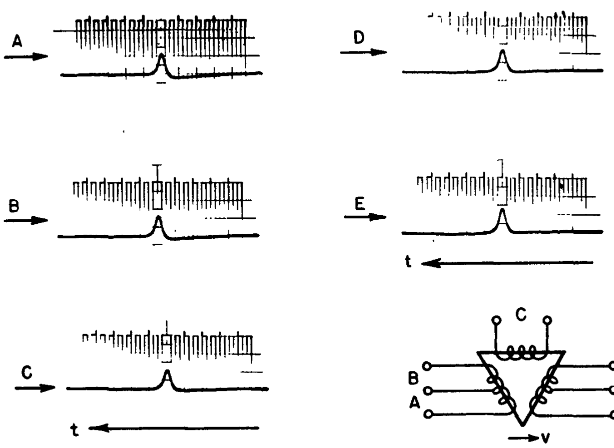


Fig. 8. Delta-type head

Scale: 3.5 mils per division

Theory as Applied in Design

A close interaction existed between experimental work and the refinement and application of the theory. The concepts and relations described readily lend themselves to the interpretation of existing experimental results and further, from them performance predictions can be made for contemplated structures. The concept of an oriented saturation magnetization was essentially developed as outlined to explain early experimental results for which an assumption of a longitudinal step change in magnetization was inadequate. While this orientation factor could not be experimentally determined, this hypothesis of an oriented saturation magnetization led to a definite pattern of behavior which could be examined. All the tests indicated consistent agreement with this picture. The procedure for head design was to use only the step function response for evaluation. Final tests were carried out with several structures using a recording unit and the magnetic head performance under operational conditions correlated excellently with the step function response results.

Fig. 6

On the basis of the proportionality between the output signal and the weighting functions H_x and H_y the importance of reading coil location and pole-tip shape is readily apparent. Further, with oriented magnetization, even with a symmetrical core structure, the leg upon which a reading coil may be wound is of paramount importance. The prior discussion and the sketches of Fig. 5 indicate that a favorable location for a leg-mounted reading coil would be the "trailing" leg with respect to the surface motion, since an overshoot compensation is possible.

This design theory indicates quite obviously the desirability of reducing gap size, spacing between head and surface, and surface thickness from the point of view of resolution. In the experimental results presented these parameters were fixed and hence these results show an optimization within this framework.

Experimental Results

The following wave forms were obtained in the course of the head design program for the IBM *305*. Some results are from structures constructed primarily to test the usefulness of the conceptual approach described here. Some results then merely illustrate certain points. Following discussions of these results the selected head design and its performance will be indicated.

Fig. 8 shows a delta-type head and the signals obtained on readback from coils located at various positions around the delta, for the same step function change in saturation. The relative influence of coil position on overshoot can be noted. An indication of the compensation effect for the trailing leg coil position on overshoot can be seen. The leading and trailing leg identifications apply to the head orientation with respect to surface motion during writing. The signals obtained when a completely different ring-type head structure was used for writing with, however, the same gap size, indicated that the recorded magnetization is primarily dependent on the gap field and not greatly influenced by pole piece shape.

Fig. 9 shows the characteristic output signal for two delta structures, both with the favorable trailing-leg coil location but one (*S-25*) possessing a pointed-type pole piece design compared to the other (*S-29*) whose pole tip edges, adjacent to the surface, are withdrawn much more gradually. The compensation of overshoot is such that insofar as overshoot is concerned the responses are nearly equivalent. However, the greatly increased pulse steepness in base-line approach and consequent reduction in the base line pulse width is noticeable. This result agrees with that expected from the estimated form of H_x. In one sense this pointed-type head is a tailored design for the problem at hand. As would be expected, if these magnetic heads were deliberately spaced much closer the compensation action may not be nearly as satisfactory. This was the case, the relative magnitude of the overshoot increasing. This effect was more pronounced the narrower the tips.

DESIGN RESULTS

The final selected design was a head with a 2-mil radius tip and the coil assembly located on the trailing leg, as indicated in Fig. 10. The operational tests at increasing bit densities clearly established the importance of the sharp base-line approaches for the characteristic pulse response, for other structures while lacking this feature did eliminate the overshoot as well. The performance of this head under the nominal operational conditions of a 1-mil spacing, 2-mil gap, and a 1-mil surface layer resulted in a conservative estimate of about a 13-mil base line pulse width for the characteristic response and a peak signal to peak overshoot ratio of greater than 20. Nominally, no pattern modulation, or readback amplitude attenuation, would be expected below 150 bits per inch (bpi) storage density. Fig. 10 shows a pattern readback at 115 bpi, a figure which represented an equipment limita-

coil A leading

coil A trailing

Fig. 7. Actual wave forms showing effect of direction of surface motion

Scale: 3.5 mils per division

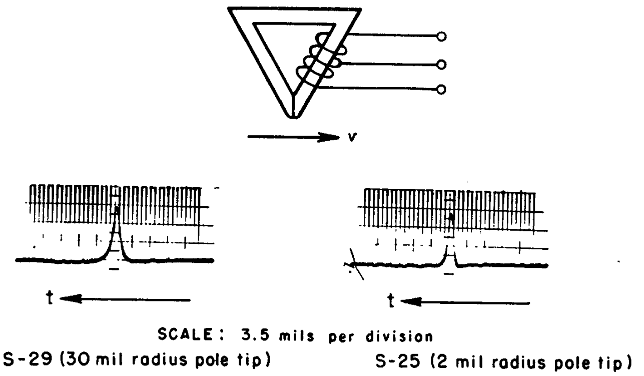


Fig. 9

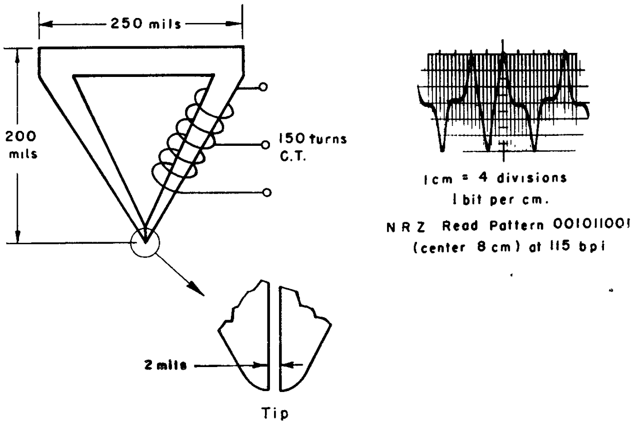


Fig. 10

tion at the time. The specified maximum operating density was 100 bpi.

Summary

A method for magnetic head design has been presented which stresses a conceptual point of view regarding the recording process which gives considerable insight into the problem. Qualitative principles are made available as guides in design and allow a ready approach to evaluation and interpretation. Further, these methods can be usefully applied from crude estimates to any desired degree of refinement, and they lend themselves directly to a study of recording structures of a more radical nature.

References

1. MAGNETIC DRUM RECORDING OF DIGITAL DATA, **A. S. Hoagland.** *AIEE Transactions,* vol. 73, Sept. 1954, pp. 381–85.

2. FIELD MEASUREMENTS ON MAGNETIC RECORDING HEADS, **D. L. Clark, L. L. Merrill.** *Proceedings, Institute of Radio Engineers,* New York, N. Y., vol. 35, Dec. 1947, pp. 1575–79.

3. STUDIES ON MAGNETIC RECORDING (Part II), **W. K. Westmijze.** *Philips Research Reports,* Eindhoven, Netherlands, vol. 8, June 1953, pp. 161–83.

A Terminal for Data Transmission Over Telephone Circuits

ENOCH B. FERRELL

THE Bell Telephone Laboratories has for some time been interested in digital transmission as a means of communication between automatic switching systems.

In a recent experiment, a simple terminal for data transmission has been demonstrated. Between two such terminals it would be possible to send data back and forth over ordinary telephone channels at the rate of 750 bits per second, or 1,000 words per minute.

The demonstration equipment involves magnetic tape to magnetic tape transmission using amplitude modulation of a 1,200-cycle carrier. It employs a 7-bit self-checking code.

For a long time the Bell System has been interested in sending numbers from one place to another over ordinary telephone lines. When you place a call to someone on the other side of town, your central office must pass that party's number to his central office as part of the instructions for completing the call. This has been done over the same trunk that is used a few seconds later for the actual conversation. It has been done at speeds of less than ten bits per second—speeds comparable to that of the telephone dial. This has been extended to cover calls between cities, over a large part of our long-distance network. The speed has been doubled by the use of multifrequency signaling, which sends two out of five frequencies in the voice band.

Some time ago a study was made of various methods of transmitting digital data at considerably higher speeds. Part of this study is reported in a paper "Transmission of Digital Information over Telephone Circuits"[1] by Horton and Vaughan. With the coming of age of electronic digital computers and data processing techniques, it is apparent that this high-speed transmission may serve needs other than those of the control of telephone switching.

Bell research people have been considering what sorts of data transmission could occur over the great variety of transmission facilities that exist in the telephone system. Teletypewriter which is already in considerable use might be mentioned. For the most part a teletypewriter channel uses a narrow frequency band of something like 150 cycles and transmits digital information at the

---

ENOCH B. FERRELL is with the Bell Telephone Laboratories, Inc., Murray Hill, N. J.