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MODELING OF MIG HEADS USING THE BOUNDARY ELEMENT METHOD

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ABSTRACT – Mini-Composite Metal-In-Gap (MIG) heads for rigid disks are modeled using the boundary element method (BEM) and compared with a standard ferrite ring head. It is shown that the head field gradient at the writing edge of a MIG head can be approximated by a Karlqvist head at high write currents whereas a saturated ferrite head cannot. It is shown that MIG heads with films having saturation magnetizations of 10kG and 15 kG can write media with maximum coercivities of 1240 and 1800 Oe, respectively. An effective write gap is used to account for the saturation of the C0core a MIG head at high write currents, and using the Williams-Comstock model, an equation relating head field gradients to the written transition length parameter shows that MIG heads write sharp transitions at high write currents.

INTRODUCTION

With the advent of high-coercivity media, MIG heads have received interest by both rigid disk and tape industries. Recent work on the modeling of MIG heads has shown conflicting results of the effects of various parameters on the head fields. For instance, Iizuka [1] reports no increase in head field for metal film magnetizations beyond a certain point ($4xM_s = 8$ kG), whereas Kelley [2] reports the opposite.

The purpose of this paper is to report on the use of commercially available BEM software to obtain the head field distributions of mimicomposite ferrite and MIG heads which exhibit saturation effects at high write currents. The BEM software used is MAGNETO, version 2.1 Integrated Engineering Software, Winnipeg, Canada.

LARGE-SCALE RING HEAD

In order to insure the correct operation of the BEM software, the large-scale ring head shown in Fig. 1 was modeled and measured experimentally. The head was constructed with a silicon-steel yoke and MnZn-ferrite pole tips which could be saturated at 25 amp in a 200 turn coil. The longitudinal field H_x was measured with a Hall probe at a distance of 0.07*g above the center of the gap length, g, of the head. A low current of 5 amp was used for the linear range and a high current of 25 amp was used for the saturation range of the permeability of the ferrite pole tips. The origin of the coordinate system is shown in Fig. 1 to be at the center of the surface of the gap.

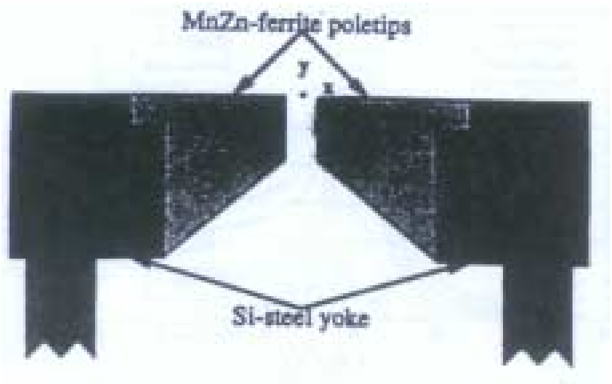

Figure 1: Partial geometry of a large-scale ring head used for BEM. Gap Length = 0.953 cm.
Throat height = 2.337 cm. Turns = 200.

Using the BH tables for silicon steel and MnZn0ferrite, the spatial distribution of the H_x field of the large-scale ring head were calculated and are shown in Fig. 2 with the experimental data. The fit is excellent at low and high currents. Boundary elements as well as subareas in the saturating regions of the head were necessary to obtain accurate solutions at high current. Without subareas, the heads fields were found to be too large and too wide. The experimental data for this saturated large-scale ring head is useful for checking the accuracy of software designed for modeling of nonlinear magnetic circuits.

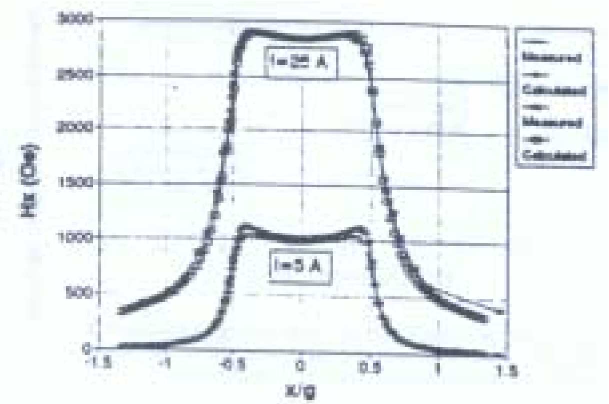

Figure 2: Calculated and measured Hx fields (Oe) vs. x/g for large-scale ring head. Linear region (I=5 A) and heavily-saturated region (I=25 A). Fields were measured at y/g = 0.07 above the head surface.

MINI-COMPOSITE MIG HEAD FOR RIGID DISKS

A minicomposite MIG head with the geometry shown in Fig. 3 was modeled by the BEM software. The MIG heads were modeled with gap films having saturation magnetizations of 10 kG and 15 kG. A standard ferrite ring head with a saturation magnetization of 5 kG was modeled as well. All head fields were evaluated at a distance of 0.25 micrometers from the surface of the head.

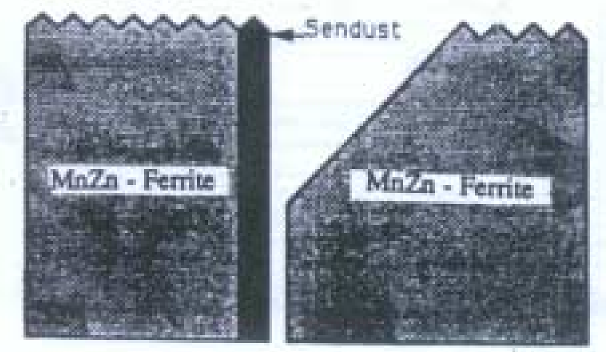

Figure 3: Partial geometry of a MIG head for BEM. Gap length =0.5 mm, throat height = 12.5 mm, metal film thickness = 2 mm. All fields were measured at
y = 0.25 mm from the head surface.

A ring head should write the center of the transition at the media coercivity (H_c) to generate the sharpest written transition. Kelley has reported on the variation of the maximum head field gradient in ferrite and MIG heads with the maximum field amplitude H_x, max which occurs on the center plane of the head gap. Figure 4 shows that the maximum gradient should not be used to represent a ferrite head during writing because the writing gradient, i.e. the gradient at $H=H_c$, drops sharply as the head saturates. However, the writing gradient is shown to remain high for the MIG head. This result suggests that the head field gradient at the trailing or writing I-bar edge of the MIG head to be equivalent to that of a Karlqvist head.

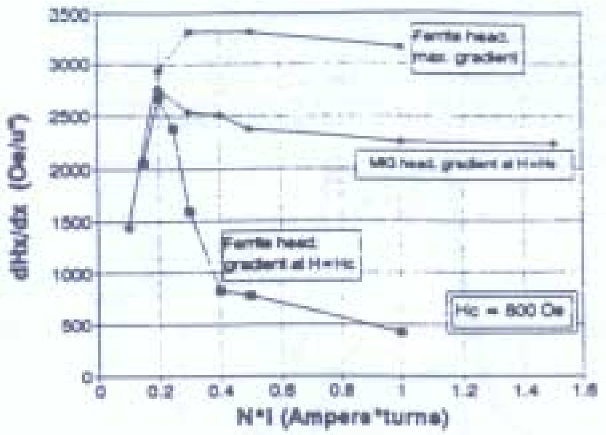

Figure 4: Maximum head field gradients and writing gradients of a standard ferrite head and writing gradient of MIG heads (Oe/microinches) vs. magnetomotive force N*I (amp-turns).

Figure 5 shows the calculated dependence of Karlqvist head field writing gradients on the maximum head field Hx, max. For a given geometry, the Karlqvist head serves as an upper bound of the head field gradient since it has infinite permeability and perfect linearity (i.e. no saturation). The writing gradient is presented as a function of the maximum writing field instead of the writing current in order to avoid having to account for the degradation of the writing efficiency of the head which is quite low when the head saturates.

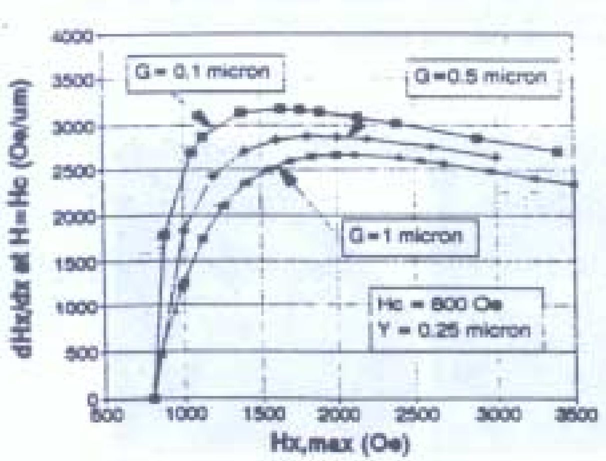

Figure 5: Writing gradients (Oe/μm) of a Karlqvist head vs. maximum H_x field (Oe) for a media coercivity of 800 Oe at a head media separation of 0.25 μm

Note in Fig. 5 that larger gap lengths result in smaller head field gradients. This result will be important later when we explain why MIG heads deviate somewhat from the ideal Karlqvist behavior. Also note that for all three values of gap length of 0.1, 0.5, and 1 µm, the writing gradient goes through a maximum. In other words, even for an ideal head there will be an optimum writing current. We also see that the g= 0.5 µm curve peaks at approximately 2.5*H_c. This explains the origin of the empirical result that $H_{x,\ max}$ should equal 2.5*H_c for minicomposite rigid disk heads to have good overwrite.

Figure 6 shows to what extent the writing gradients of ferrite and MIG heads with 0.5 µm gaps deviate from the Karlqvist head at high write currents. Note that for low $H_{x,\ max}$, the ferrite and MIG heads follow the Karlqvist approximation. For larger $H_{x,\ max}$, the writing gradient of the ferrite head decreases abruptly whereas the writing gradient of the MIG head decreases only slightly.

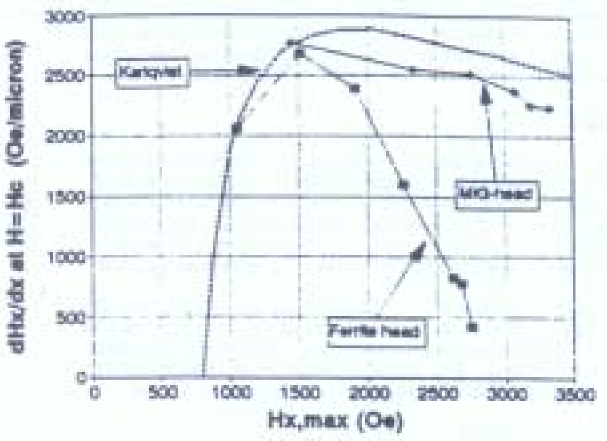

Figure 6: Writing gradients (Oe/micrometer) of a ferrite and a MIG head vs. maximum H_x field (Oe) for a media coercivity of 800 Oe at a head-media separation of 0.25 µm. Dashed line is a Karlqvist head for g=0.5µm.

Next, an attempt will be made to account for the deviation of the writing gradient of the MIG head from the Karlqvist head shown in Fig. 6. We know that the C-side saturates at high write currents and generates large values of H_x field 0.25 mm from the surface of the head as shown in Fig. 7.

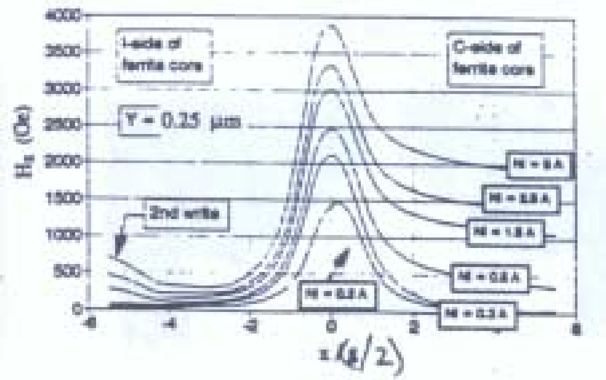

Figure 7: H_x Fields vs. x/g of a MIG head for various magnetomotive forces N*I (amp-turn) at a separation of 0.25 µm showing saturation (presence of H_x field) on C-side of the ferrite core.

By plotting a family of curves of the writing gradients for various values of gap length and determining where they intersect the data derived from the BEM model, the dependence of an effective gap length on $H_{x,\ max}$ was obtained as shown in Fig. 8. This result suggest that saturation of the C-side of the MIG head can be represented by an increase in its gap length which improves overwrite with only a small loss of writing gradient on the I-side of the core.

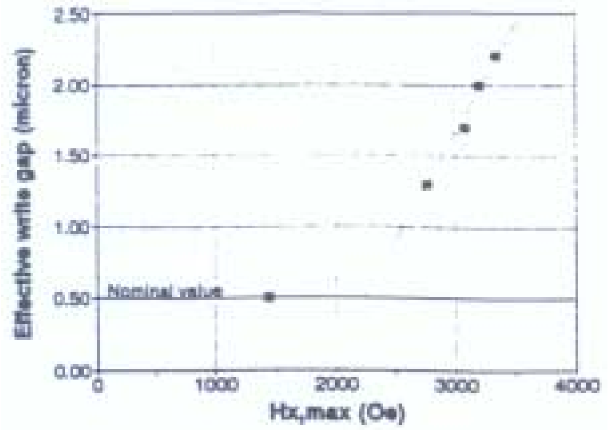

Figure 8: Effective write gap length (µm) vs. maximum H_x field (Oe) for a MIG head at high write currents

The effect of the magnetization of the film in the gap of the MIG head on the maximum longitudinal field was also investigated. Kelley [2] found a linear dependence of the maximum coercivity media a MIG head can write, $H_{c,\ max}$, as a function of the magnetization of the gap film. Kelly used a 5% degradation in the normalized maximum trailing edge gradient as a criteria for determining $H_{c,\ max}$. Using the results shown in Fig. 9 and $H_{x,max}$=2.5*$H_{c,max}$, the maximum recordable media coercivities become

1240 Oe for a 10 kG film MIG head and 1800 Oe for a 15 kG film MIG head.

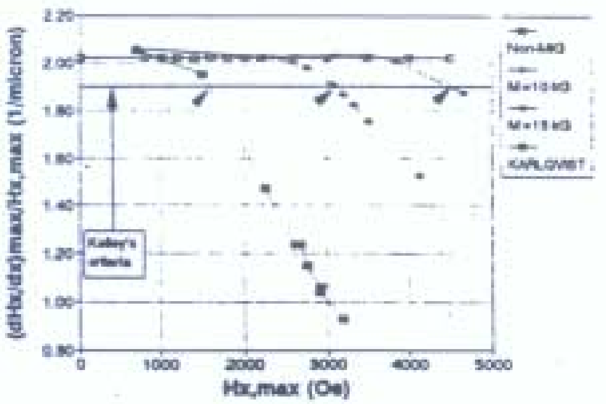

Figure 9: Maximum trailing edge gradients/H_x, max (1/µm) vs H_x, max for a standard ferrite head and MIG heads with gap film saturation magnetizations of 10 kG and 15 kG. The dotted line is the 5% degradation of the head field gradients used by Kelley [2] to find the maximum recordable media coercivity.

On the other hand, Iizuka et al [1] found no increase in the writing field of MIG heads with gap films having higher saturation magnetizations. The reason for this is that they held the magnetomotive force N*I fixed. However, because of C-side saturation, higher saturation magnetization MIG films require larger writing currents. In fact, for a 15 kG film MIG head it is advisable to deposit a film on the C-side as well as the I-side. If this is not done, the excessive currents required to write will limit its performance.

Williams and Comstock [3] derived an expression for the written transition length parameter, a, using the Karlqvist head assumption and arrived at the result that at H=Hc, the head field gradient is given by dH/dx=Q Hc/y. This approximation of the writing field gradient is fairly accurate. However the Karlqvist approximation in the case of a MIG head is unnecessary since the BEM analysis can be used to obtain the writing gradients. Furthermore, in the case of a standard ferrite head, the Williams-Comstock model would fail to predict the sharp decrease in the head field gradient at high write currents. Using the procedure of Williams and Comstock, the following relation was derived between the written transition length parameter, a, and the writing gradient of any head:

$$\mathbf{a = K + (K^2 + (4M_2d / [dH/dx]))^{1/2}}$$

Where $K=Hc(1-S^*)/(\pi\,[dH/dx])$. Since K^2 is small it can be ignored.

The calculations of the transition length parameter, a, for a standard ferrite head writing on 800 Oe media and a 10 kG film MIG head writing on 1200 Oe media as a function of the writing magnetomotive force are shown in Fig. 10. A commensurately smaller transition length was obtained for a 15 kG film MIG head. The minimum in the transition length parameter written by a ferrite head corresponds to the usual maximum observed in the readback voltage vs. write current.

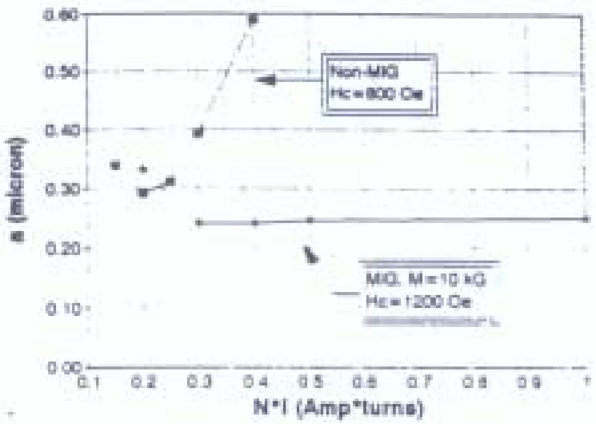

Figure 10: Transition lengths parameters, a (µm) vs. magnetomotive force N*I (amp-turn) for a standard ferrite head writing on media with 800 Oe coercivity and a 10 kG film MIG head writing on a media with 1200 Oe coercivity.

CONCLUSIONS

Both standard ferrite and MIG ring heads behave as Karlqvist heads prior to saturation. The head field gradient of a standard ferrite head drops sharply when the head is overdriven. However, the head field gradient of a MIG head C-core driven well into saturation is still approximated fairly well by the Karlqvist head. A small increase of an effective gap length can be used to account for the saturation of the C-side of the core. Following the Williams-Comstock approach, it is possible to use BEM calculations of head field distribution to obtain written transition length parameters. The transition length parameter of a ferrite head goes through a sharp minimum vs. magnetomotive force, whereas the transition length parameter written by a MIG remains essentially constant. This insensitivity of MIG heads to overwriting is well-known experimentally [4].

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