**In Situ Measurement of the Remanence Curve of Magnetic Recording Media**

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**Abstract**

The remanence curve of a recording medium represents the remanent magnetization of a written bit cell as a function of the applied field in the medium during the write process. At small transition densities in a longitudinal medium the demagnetizing field in the bit cell is negligible, and the longitudinal field can be identified with the longitudinal head field component. We describe a measurement technique which yields a normalized remanence curve of the recording medium under the actual conditions of the write process directly as a function of the write head current. This may be a more useful result than the standard representation as a function of the applied field. The result, however, could be represented in the standard form if the head field function and the flying height are known.

The measurement consists of writing a low frequency, saturated all-ones pattern, and subsequently overwriting a new all-ones pattern at the same frequency, but displaced in phase, using the head current value for which the remanence is to be measured. The new head field has the same direction as the original field for part of the cycle, leaving the magnetization of this part of the bit cell unaffected. It has the opposite direction for the remaining part, reducing or partially reversing the magnetization of this part of the bit cell to the corresponding remanence value. On reading this record with an inductive read head, the area under each voltage pulse yields the remanent magnetization for the overwrite current used.

In our measurement the area under the pulses is determined by digital sampling and integration. Several transitions on a track can be sampled and averaged, providing a measure of the precision of the technique.

**Introduction**

The remanence curve of a recording medium represents the remanent magnetization of a written bit cell as a function of the field in the medium during the write process. The standard technique for measuring a remanence curve[1] uses the same equipment as a hysteresis loop measurement and may require destructive methods of preparing the specimen to be measured. We describe a measurement technique which yields a normalized remanence curve of the recording medium under the actual conditions of the write process directly as a function of the write head current.

The *in situ* remanence curve measurement technique relies on the fact that at small transition densities in a longitudinal medium the demagnetizing field in the bit cell is negligible, and the longitudinal field can be identified with the longitudinal head field component. The procedure is schematically illustrated in Figure 1. A track on a disk, or on a loop of tape, is first written with a series of widely spaced transitions, using a write current $I_0$ sufficient to saturate the medium (Figure 1a,1b). Next, the track is overwritten at the same spacing, but with the new transitions offset from the original writing by $\Delta t$, and with write current $I_1 < I_0$ (Figure 1c). During the part of the write cycle when the head field is in the direction of the already written magnetization, the track is unaffected. During the part of the cycle when the head field is opposite to that of

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**Figure 1.** A schematic description of the *in situ* remanence curve measurement technique (separation of transitions in experiment is larger than implied by this illustration).
the previously written record, it reduces or partially reverses the magnetization. The resulting medium magnetization is illustrated in Figure 1d for the case where $I_1$ is large enough to reverse the magnetization but not large enough to saturate the medium. The subsequent magnetic pattern is read with an inductive head, resulting in the sequence of pulses illustrated in figure 1e. According to the reciprocity theorem[2] the output voltage, $v(t)$, of a disc moving with a velocity, $v$, relative to the head is given by

$$v(t) = \kappa' \int_{d}^t dy dy \left[ \frac{\partial}{\partial x} M(x - x', y) \right] dx$$  \hspace{1cm} (1)

where $\kappa$ is a constant and $x'=at$. The area under a pulse or of a group of pulses can be obtained by integrating $v(t)$ over an interval that begins and ends in the region between pulses. The integral of $v(t)$ from some arbitrary $t_1$ to $t_2$ in Figure 1d, corresponding to $x_1$ and $x_2$ in Figure 1e, is

$$\int_{t_1}^{t_2} v(t) dt = \kappa' \int_{d}^{d} dy \left[ \frac{\partial}{\partial x} M(x - x', y) - M(x - x_1, y) \right] dx$$  \hspace{1cm} (2)

If the width in $x$ of the head sensitivity function is narrow compared with the bit cell, then Eqn. (2) becomes, with bars indicating $y$-averages,

$$\int_{t_1}^{t_2} v(t) dt = \kappa' \left[ \bar{M}(x_2) - \bar{M}(x_1) \right]$$  \hspace{1cm} (3)

Inspection of Figure 1, in conjunction with Eqn. (3), shows that the area under the pair of pulses between $t_1$ and $t_2$ is proportional to twice the remanent magnetization corresponding to a particular overwrite current, $I_1$, while integration over two positive or two negative pulses is proportional to twice the remanence magnetization of the medium, $M_r$.

**EXPERIMENTAL PROCEDURE**

The experimental apparatus used is typical of most disc test stations and is similar to the apparatus described by Belk et al. [3]. The recording channel of the tester is characterized by a flat, wide bandwidth response and the read/write process is controlled by custom in-house electronics. The magnetic parameters of the tested discs are shown in Table 1.

<table>
<thead>
<tr>
<th>Disc ID</th>
<th>Disc 1</th>
<th>Disc 2</th>
<th>Disc 3</th>
<th>Disc 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition</td>
<td>CoPt</td>
<td>CoPt</td>
<td>CoNiPt</td>
<td>CoPt</td>
</tr>
<tr>
<td>$H_c$ (Oe)</td>
<td>650</td>
<td>870</td>
<td>866</td>
<td>1650</td>
</tr>
<tr>
<td>$M_0$ (emu/μm²/cc)</td>
<td>44</td>
<td>39</td>
<td>54</td>
<td>20</td>
</tr>
<tr>
<td>$\delta$ (Å)</td>
<td>400</td>
<td>400</td>
<td>1000</td>
<td>130</td>
</tr>
<tr>
<td>$S^*$, $S$ [S=S]</td>
<td>0.90</td>
<td>0.89</td>
<td>0.90</td>
<td>0.85</td>
</tr>
<tr>
<td>$P_{50}$ (ns)</td>
<td>101.5</td>
<td>80.2</td>
<td>83.4</td>
<td>54.0</td>
</tr>
<tr>
<td>$D_{50}$ (kdfpi)</td>
<td>24.0</td>
<td>30.0</td>
<td>30.0</td>
<td>45.0</td>
</tr>
</tbody>
</table>

Disc 1 and Disc 2 were manufactured by the Disc Memory Division of Hewlett-Packard in Boise, Idaho. Disc 3 is an example of a commercially available disc manufactured by Komag. Disc 4 is a high coercivity disc fabricated at Hewlett-Packard Laboratories in Palo Alto, California. During writing all of the discs were spun at a velocity of 12.7 m/s which corresponds to a flying height of 0.1 μm.

The thin film head used had the following parameters: gap length 0.25 μm, pole tip lengths 3 μm, and track width 14.5 μm.

The readback waveform was recorded on a Hewlett-Packard 8000 oscilloscope. In order to reduce noise, the signal from a particular set of transitions was averaged 64 times and the digitized records were averaged.

**RESULTS AND DISCUSSION**

The write frequency used in the experiments was 0.25 Mbps which yielded a bit density of 0.5 kibits. After writing a saturating first signal, the second phase shifted signal is written at the write current for which the remanent magnetization is to be measured. The design of the write electronics causes the second signal to be written with a random phase shift relative to the first. The phase shift results from a random response of the write electronics to the triggering pulse. As in the schematic sketch of Figure 1, a series of pairs of positive and negative pulses is created. A typical readback waveform is illustrated in Figure 2.

The normalized remanence curve is computed by integrating the output voltage. The integration of one pulse of a normal signal (not overwritten) or, on an overwritten disc, the integration of two successive positive or negative pulses is proportional to twice the remanent magnetization of the medium, $2M_r$. The integration of any successive oppositely directed pulses is proportional to twice the magnetization for which the remanence value is being measured, $2M_{r+}$. An integrated waveform is illustrated in Figure 3. A normalized remanence value is computed by dividing $M_{r+}$ by $M_r$ as determined by the integrations. A remanence curve is constructed by computing the remanence values for the proper range of write currents. A typical remanence curve is shown in Figure 4. The standard remanence curve could be computed if $M_r$ is measured or by integrating the head sensitivity function, for example as measured with a microloop[4][5].

To test the accuracy of the technique we integrated over two consecutive positive pulses, contained in a half period (4000 nanoseconds), obtaining a value which is proportional to twice the remanent magnetization of the medium after saturation. We calculated a value for each digitized signal corresponding to each write current tested. The mean calculated value for all write currents for disc 3 was 1675 μV ns with a standard deviation of 84 μV ns. This deviation is a measure of the accuracy of this technique. To test the effects of noise on the calculated value from one digitized signal, we integrated over the same interval, but starting from different points within the saturated region, resulting in a value of 1656 μV ns with a standard deviation of 53 μV ns. We used the same averaging procedure on an integration over one positive pulse and one negative pulse. The mean value for a single value of write current was 1209 μV ns with a standard deviation of 134 μV ns. From write current to write current the range of the standard deviation was 76 to 225 μV ns. These large deviations are attributed to the large, irregular magnetic domains created when a medium...
2 one can readily see that the saturated region is not as noisy as the unsaturated regions.

Note that an integration of one full cycle of overwritten magnetization should be zero. An integration which yields a nonzero value over one cycle indicates the presence of a D.C. offset in the recorded data which must be compensated. The offset is divided by the number of data points in a full cycle is subtracted from each data point. This correction improves the accuracy of the technique.

The technique can also be used to measure head current which generates the remanence, $H_{r}$, for specific write conditions. When the overwrite signal is written with a field equal to $H_{r}$, the magnetization is reduced to zero. Table II compares the write currents which correspond to $H_{r}$ and which were obtained from two different techniques. The first column lists the results from the in situ remanence curve measurement technique. The second column lists the maxima of the Reverse D.C. Erase Noise which, according to Aoi et al., coincides roughly with $H_{r}$. In each case $I_{w1} > I_{w2}$ and the difference is comparable. This trend may be significant. One may speculate that the greatest randomness is reached in a field $H_{r}$ and that the subsequent relaxation does not affect the noiseless; in a field below the point of maximum randomization may have passed.

Table II. Write current values corresponding to $H_{r}$ measured by the in situ remanence curve measurement technique, $I_{w1}$, and by the Reverse D.C. Erase Noise Measurement method, $I_{w2}$.

<table>
<thead>
<tr>
<th>DISC</th>
<th>$I_{w1}$ (mA)</th>
<th>$I_{w2}$ (mA)</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>9.17</td>
<td>8.60</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>7.77</td>
<td>7.26</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>12.10</td>
<td>10.89</td>
<td>10</td>
</tr>
</tbody>
</table>

CONCLUSION

We have demonstrated a nondestructive technique for measuring a normalized remanence of a magnetic recording medium under the operating conditions for a disk or tape drive. The accuracy of the technique appears adequate for application.

REFERENCES