単層膜垂直記録媒体における
MRヘッド再生波形のベースラインシフト

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記録ヘッドとして100μm幅のMIGヘッド，再生ヘッドとして2.7μm幅のMRヘッドを用いて，再生波形のベースラインシフトを測定した。ベースラインシフトはトラック端で極大になり，極端部では負の値を取った。トラック端での漏磁磁界とMRヘッドの再生出力のオフトラック特性を元に漏磁磁界がベースラインシフトに与える影響を検討した。漏磁磁界から生じる再生出力と観測されたベースラインシフトのオフトラック特性とは定性的に一致した。また長手軸方向におけるMRヘッドの垂直感度関数を求めた。この感度関数は単峰型ピークを含み，このピークがトラック端での漏磁磁界を拾うことによってベースラインシフトが生じると考えられる。

キーワード 垂直磁気記録，MRヘッド，ベースラインシフト，感度関数，オフトラック特性

Baseline shift in readback waves of MR head for single layer perpendicular recording media

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Abstract
Origins of baseline shift was discussed by the measured off-track properties using a wide write head and a narrow read head with track widths of 100μm and 2.7μm, respectively. The baseline shift became increased when the read head was moved close to the track edge. Beyond the track edge, baseline shift dropped to negative values. Simulating the stray field at the track edge and the sensitivity functions of the MR head along to the track width direction, it was assumed that the output from the stray field showed the same behavior as the baseline shift obtained experimentally. Sensitivity function of the MR head along the longitudinal direction was also determined. The sensitivity function of the MR head could express the sum of a double gap ring head component and a Lorentz peak. This Lorentz peak component gives the in-bit baseline shift originated from the stray field at the track edge.

key words perpendicular magnetic recording，MR head，baseline shift，sensitivity function，off-track dependence
1 Introduction

Readback waves of MR heads on single layer perpendicular recording media exhibit baseline shifts between bits[1],[2]. The magnitude of the in-bit baseline shift depends on write current and off-track position of read heads. In order to avoid the complexity of equalization on read process, it is desirable to reduce the baseline shift.

In this paper, the baseline shift in readback waves from MR heads for single layer perpendicular recording media was studied. Sensitivity functions along to the track width direction and the stray field at the track edge were also discussed. The effect of the sensitivity function of the MR head along to the longitudinal axis were also examined.

2 Measurement of baseline shift

Co/Pd multi-layer medium with 10 nm thickness carbon protection layer was used for the experiments. The multi-layer medium was used to avoid the effect of unsaturated recording. The thickness of the Co/Pd multi-layer was 23 nm. Its magnetic properties were Hc: 2.3 kOe, Ms: 454 emu/cm³ and SQ: 0.96. Table 1 shows specifications of the read/write heads. On baseline shift measurements, H1 head was used for write process. Recording medium was first AC-erased with a 250 kFRP1 signal along the 200μm width. Data was written at the centre of the AC-erased region. Relative velocity between medium and read/write heads was 5.08 m/s. Readback waves on the H3 and H4 heads were digitized on the oscilloscope with single shot mode, then averaged to minimize the jitter. Baseline shift was evaluated by the ratio of the baseline shift to the peak amplitude of the readback wave.

Figure 1(b) and 2(b) show the off-track dependence of the baseline shift at the inner and the outer edges of the recorded track, respectively. In Fig.1 and 2, the amplitude of the readback waves are also shown as (a) in each figure. Filled circles and open circles denote the results of H4 head and H3 head, respectively. The baseline shift exhibited a small value of 5% at the track centre for both heads. The baseline shift became increased when the read head was moved close to the track edge. Beyond the track edge, baseline shift dropped to negative values. Full width half maximum(FWHM) of the increased baseline shift region at the inner track edge were about 2.5μm and 1μm in width for H3 head and H4 head reading, respectively. The FWHM at the outer track edge were about 3 μm and 1.8 μm in width for H3 head and H4 head reading, respectively. The narrow track width reading gave the narrow increased baseline shift region at the track edge.
Since the baseline shift had positive values at the track edge and negative values beyond the track edge, this baseline shift behavior suggested that the stray field at the track edge affected the baseline shift. In this section, the effect from stray field to the baseline shift were examined. Schematic diagram of the head-medium geometry are shown in Fig.3. Since the MR heads have little sensitivity with the \( z \) component of the stray field, only the \( z \) component of the stray field was considered in this section.

\[
H_z = 2M_s \left\{ \left( \tan^{-1} \frac{z - Tw/2}{z} - \tan^{-1} \frac{z + Tw/2}{z} \right) - \left( \tan^{-1} \frac{z - Tw/2}{z + \delta} - \tan^{-1} \frac{z + Tw/2}{z + \delta} \right) \right\}
\]

where \( M_s \) is magnetization of the medium, \( Tw \) is track width, and \( \delta \) is the thickness of the medium.

Table 1: specifications of the heads

<table>
<thead>
<tr>
<th>No. structure</th>
<th>H1</th>
<th>H2</th>
<th>H3</th>
<th>H4</th>
</tr>
</thead>
<tbody>
<tr>
<td>flying height [nm]</td>
<td>MIG</td>
<td>MIG</td>
<td>merged MR</td>
<td>merged GMR</td>
</tr>
<tr>
<td>( gl ) [( \mu \text{m} )]</td>
<td>0.25</td>
<td>0.26</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>inductive ( T_w ) [( \mu \text{m} )]</td>
<td>97</td>
<td>6.5</td>
<td>3.3</td>
<td>1.1</td>
</tr>
<tr>
<td>turns</td>
<td>15</td>
<td>30</td>
<td>14</td>
<td>unknown</td>
</tr>
<tr>
<td>MR ( sgl ) [( \mu \text{m} )]</td>
<td>-</td>
<td>-</td>
<td>0.25</td>
<td>0.17</td>
</tr>
<tr>
<td>( T_w ) [( \mu \text{m} )]</td>
<td>-</td>
<td>-</td>
<td>2.7</td>
<td>0.8</td>
</tr>
</tbody>
</table>

3 Stray field analysis

In order to analyze the sensitivity of the MR head along the track width direction, off-track profile of the read heads were observed with a micro-track method[3]. After the 40 kFRPI signal recording with H3 or H4 head, both sides of the written track were DC-erased to make a 0.3 \( \mu \text{m} \) width track, as shown in Fig.4. Then the off-track profile of the amplitude of the 40 kFRPI signal was measured with each MR head. Figure 5 shows the sensitivity of the MR heads along the track width direction. Filled circles and opened circles denote the result of the H4 head and H3 head, respectively. Off-track profile of each head were of a triangular shape. The profile of the H4 head had a narrow width and a steep shape. For H3 head, the off-track profile showed asymmetry against the track width direction.

Figure 3: Schematic diagram of the head-medium geometry.

Figure 4: Making micro track by DC-erasing both sides of the recorded track.
by convolving the perpendicular component of the stray field and the sensitivity of the MR head along the track width direction. The off-track profile used for calculation is shown in Fig. 6. Where triangle (dashed line) is a modeled sensitivity of the real MR head. The rectangle (solid line) is an ideal model for the off-track profile of the read head. On each model, the read heads have 2.7\( \mu \)m in width. Figure 7(a) shows the calculated \( H_z \) at \( z = 60 \) nm, \( \delta = 23 \) nm and \( Tw = 97 \mu \)m. Figure 7(b) shows the calculated output from the stray field.

The stray field has a value only near the track edge. Its width was of the order of 100 nm. The output made from the stray field had positive values at the track edge and dropped to negative values beyond the track edge. This behavior is consistent with the experimental results of the baseline shift, qualitatively. The FWHM of the output was 910 nm and 1650 nm for the rectangular shape and triangular shape, respectively. Therefore, it is indicated that the broadness of the baseline shift at the edge comes from that of the sensitivity profile of the MR head in track width direction.

The baseline shift was found to be affected not only by the stray field at the track edge but also the sensitivity profile of the MR head along the track width direction. So there are three possibilities to reduce the baseline shift at the track centre without varying the track width. (1): reduce the flying height of the read head. (2): reduce the medium thickness. In these cases, stray field from the medium is localized at the track edge. Thus the baseline shift at the track center is reduced. (3): use steeper sensitivity profile of the read head along the track width direction become steepest; as shown in Fig. 7(b), rectangular shape is desirable.

4 Sensitivity functions of the MR head along to the longitudinal axis

In previous section, it is probable that the baseline shift arise from the stray field at the track edge. While double gap ring head model is known as sim-
ple model of the MR head[4]. From this model, the output of the MR head should be proportional to the 2nd derivative of the magnetization. Thus there are two possibilities to observe the stray field at the track edge.

1. The magnetization (stray field at the track edge) between transitions varies

2. The sensitivity function of the MR head differ from the double-gap ring head

In order to show which possibilities above are effective, the perpendicular sensitivity function of the MR head along to the longitudinal axis was estimated from read-back waves. In the following procedure, only the perpendicular component of the magnetization was considered.

H2 and H3 heads were used for write/read process. By using the H2 head, 2 kFRPI signal was written on the medium. Then readback waves of the H2 head and H3 head were digitized on a digital oscilloscope. From the readback waves of the H2 head and sensitivity function of the ring head along to the longitudinal axis, recorded magnetization was obtained using the deconvolution on frequency domain. The sensitivity function of the ring head was calculated from the result of Fourier analysis[5]. In this calculation, the sensitivity function was integrated over the medium thickness and differentiated on time.

Readback waves of MR head, $E_{MR}$, is represented as

$$E_{MR}(y) = \sum_{y'=-\infty}^{y=\infty} M_\perp(y-y')S_{MR}^\perp(y')$$  \hspace{1cm} (2)

where $M_\perp$ is the perpendicular magnetization on medium and $S_{MR}^\perp$ is the perpendicular sensitivity function of MR head. From the readback waves of the H3 head and perpendicular magnetization obtained above, $S_{MR}^\perp$ was calculated by solving the linear equation(2). Since $S_{MR}^\perp$ has a value around the $y' = 0$, $y'$ in equation (2) was restricted within $|y'| < 5\mu m$.

For a ring head with gap length:0.25 $\mu m$, magnetic spacing: 40 nm, and medium thickness: 23 nm, Fig.8 shows the perpendicular sensitivity function. Figure 9(a) shows the readback waves of the H2 head with write current $Iw = 60$ mA. Deconvolving the readback waves by the sensitivity function of the ring head, the perpendicular magnetization on the recorded medium was obtained. Result is shown in Fig. 9(b). Combining the obtained magnetization and readback waves of the H3 head, shown in Fig. 9(c), the sensitivity function of the MR head was calculated. Result is shown in Fig.10 with solid lines. When $Iw$ was varied in the range of 5~60 mA, the sensitivity function of the MR head did not changed.
The sensitivity function of the MR head could be represented with the sum of two terms; (1) a magnetic field of a double gap ring head, and (2) a Lorentz peak. The term(1) and the term(2) were also shown in Fig.10 with gray line and dashed line, respectively. The output from the double-gap ring head term gives the dipulse for a perpendicular transition, not causing baseline shift. On the other hand, the output from the Lorentz peak term is proportional to the magnetization, giving the in-bit baseline shift originated from the stray field near the track edge.

5 Conclusion

The origins of the baseline shift was discussed by the measured off-track properties using a wide write head and a narrow read head. Combining the stray field analysis and the sensitivity function of the MR head along to the longitudinal axis, the Lorentz peak component which is contained within the sensitivity function of the MR head gives the in-bit baseline shift originated from the stray field at the track edge.

References


