The nature of recorded magnetisation transitions in thin film media

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Abstract

The longitudinal components of the recorded magnetisations in a number of thin film disk media were determined from captured isolated replay pulses using inverse filtering techniques. The computed magnetisations exhibit asymmetry in the tails in the approach to saturation. These recovered magnetisation transitions and their derivatives were linearly superposed to investigate the persistence of recorded magnetisation with recording density. Furthermore, the recovered magnetisation distributions were employed to investigate the effect of transition shape on the noise power spectral densities. The results are compared with experimental observations. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

Most theories of signal-and-noise properties of thin film media involve an assumed shape of the magnetisation transition. In this paper, inverse filtering is used to investigate the shapes of actual recorded transitions for two disk media whose properties are given in Table 1. It is assumed that the magnetisation is uniform throughout the thickness of the media. It is also shown that the recovered magnetisations can be successfully used to characterise the signal-and-noise properties of thin film disk media. In the experiments, recording and replay were conducted using a thin film head with gap length of 0.22 μm, head-to-medium separation of 0.04 μm, symmetrical pole lengths of 3.5 μm each and a track width of 5 μm.

Inverse filtering has previously been used [1] for the recovery of the longitudinal component of the recorded magnetisation distribution from an observed replay pulse. This is achieved using the reciprocity relation:

\[ e_x(\tilde{x}) = \mu_0 w v \delta + \int_{y=-\delta}^{y=\delta} \int_{x'=-\infty}^{x'=\infty} \frac{dM_x(x')}{dx'} H_4(x' + \tilde{x}, y) dx' dy, \]

(1)

where \( e_x(\tilde{x}) \) is the output voltage, \( M_x(x') \) is the longitudinal component of the written magnetisation, \( H_4(x', y) \) is the x-component of the head field per unit current, \( \mu_0 \) is the permeability of free space, \( w \) is the track width, \( v \) is the linear velocity, \( \delta \) is the medium thickness, \( d \) is the flying height and \( \tilde{x} = vt \) where \( t \) is the time. The Fourier transform of Eq. (1) can be found by noting that the integral with respect to \( x' \) is a correlation integral [2], and this produces:

\[ E_x(k) = \mu_0 w v w n \delta \cdot D(k) \cdot H_4(k, 0') \cdot e^{-\delta d} \cdot \left( 1 - e^{-\delta d} \right) \cdot \frac{1}{k}. \]

(2)

where \( E_x(k) \) is the Fourier transform of \( e_x \), \( D(k) \) is the Fourier transform of the magnetisation gradient, \( k = 2\pi/\lambda \) is the wave number where \( \lambda \) is the wavelength, \( H_4(k, 0') \) is the complex conjugate of the head’s surface field transform which for a thin film head is given accurately by Bertero et al. [3]. The last two terms in Eq. (2) are simply the spacing and thickness loss terms, respectively. It can be seen from Eq. (2) that it is possible to evaluate \( D(k) \) by dividing the computed replay spectrum, \( E_x(k) \), by the surface field transform, \( H_4(k, 0') \), and the separation and thickness losses. However, due to the noise present in the captured replay pulse, the division process leads to an enhancement of the noise in the

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Table 1

<table>
<thead>
<tr>
<th></th>
<th>Coercivity, $H_c$(Oe)</th>
<th>Remanence-thickness product, $M_\delta$(memu/cm²)</th>
<th>Magnetic layer thickness, $\delta$(nm)</th>
<th>'a' determined from slope of transition (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disk 1</td>
<td>2000</td>
<td>1.9</td>
<td>30</td>
<td>0.1</td>
</tr>
<tr>
<td>Disk 2</td>
<td>1200</td>
<td>3</td>
<td>40</td>
<td>0.2</td>
</tr>
</tbody>
</table>

evaluated spectrum at high frequencies and at the gap nulls. Filtering of the noise is thus necessary and this was achieved using the Wiener optimal filter. This filter has a response, $\Phi(k)$, of 1 when the replay pulse spectrum is beyond the noise level and 0 at and below the noise level. Thus, the inverse filtering process produces a spectrum for the magnetisation gradient of $\tilde{D}(k)$ described by

$$\tilde{D}(k) = \Phi(k) \frac{E_x(k)}{H_\delta(k,0) \cdot e^{-kd} \cdot \left(\frac{1 - e^{-kd}}{k}\right)} = \Phi(k) \cdot D(k).$$  \hspace{1cm} \text{(3)}

Convoluting (integrating) $\tilde{D}(k)$ with the unit Signum function essentially yields the magnetisation distribution [1].

2. Experimental observations

The isolated replay pulses were captured and averaged using a digital storage scope before downloading to a PC. The replay signal spectra, $E_x(k)$, were determined by computing the numerical FFT for each isolated pulse before filtering. Fig. 1 illustrates a plot of the inverse filtered magnetisation gradient, $dM/dx$, for disk 1 and the magnetisation distributions for disks 1 and 2, respectively. Also shown are the least-squares fitted hyperbolic tangent and arctangent magnetisation distributions for disk 1 with the computed value of the fitted transition width parameter. It can be seen that the recorded magnetisation transition for disk 1 is not symmetrical in the approach to saturation; it resembles the arctangent function on one side and a hyperbolic tangent function on the other [1]. The transition width parameters for the two disks were calculated from the slopes of the magnetisations at the centre of the transitions. The disk with the lower demagnetising ratio $M_\delta/H_\delta$, disk 1, has a smaller transition width than disk 2 as would be expected [4].

3. Linear superposition

High-density recording can be studied by superposing the recovered magnetisation and magnetisation gradients numerically as a function of the reciprocal of bit spacing. Given in Fig. 2(a) and (b) are the results for disks 1 and 2 where the maximum packing density is limited by the bandwidth of the Wiener optimal filter.

4. Transition noise power spectral density

Noise in thin film recording media is mainly concentrated in the transition region [5]. This is characterised as jitter in the transition centre position and variation in the transition width parameter. In this work only transition position jitter will be considered.

Transition centre jitter has been studied by Belk et al. [6], who gave the Fourier transform of the jitter noise voltage as

$$E_d(k) = - (\mu_0 \omega m) \cdot D(k) \cdot H_\delta(k,0) \cdot e^{-kd} \cdot \left[\frac{1 - e^{-kd}}{k}\right] \cdot [1 - e^{j\chi_4}],$$  \hspace{1cm} \text{(4)}

where $\chi_4$ is the square root of the transition jitter variance. The last term in Eq. (4) is the transition shift term. The noise Power Spectral Density (PSD) is calculated using:

$$P_d(k) = \text{Re}[E_d(k)]^2 + \text{Im}[E_d(k)]^2$$  \hspace{1cm} \text{(5)}

The numerical FFTs of the magnetisation gradients, $\tilde{D}(k)$, for the two disks were calculated and used in Eq. (4) in place of $D(k)$ and the noise PSDs were computed using Eq. (5). The resulting spectra shown in Fig. 3a and b are
compared with the measurements where there is a good agreement between the two. However, the value of the head-to-medium separation had to be modified in Eq. (4) to produce the fitting shown in the diagrams. The need for this modification can either be attributed to the imperfect knowledge of the actual value of the flying height or due to the absence of transition width noise term(s) in the noise voltage formulation of Eq. (4).

5. Conclusions

The magnetisation gradients and magnetisation distributions were determined using inverse filtering for 2 disks with different properties. The transitions exhibit asymmetry in the approach to saturation and the measured values of the transition width parameter follow the simplified theories in relation to medium parameters. The computed distributions and gradients were superposed to recreate the roll-off curves and the transition position jitter noise PSD and both were in good agreement with measurements. The need to modify the spacing loss term probably indicates either an imperfect knowledge of the head-to-medium spacing or an incomplete knowledge of noise processes.

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References