Track edge fluctuations

M. W. Muller and R. S. Indeck
Electrical Engineering Department, Washington University, St. Louis, Missouri 63130

E. S. Murdock and R. Ornes
Hewlett-Packard Labs, Palo Alto, California 94304

Track edge fluctuations on recording media affect signal-to-noise ratio and servo control, and can provide clues to the medium's magnetic microstructure. We write track edges on longitudinal thin-film magnetic recording media by dc erasing the medium and writing a saturated dc track of opposite magnetization direction on the erased band. We then "read" the position fluctuations of the x-component reversal of one edge of the written track by centering a head on that edge, and by stepping the head across the edge. Since a straight track edge would not produce any flux change in the read head coil, the voltage output of the head arises from flux changes due to track edge fluctuations. The spectrum of the fluctuations can be deduced by decorrelating the read head sensitivity function from the voltage spectrum. We have used this procedure with several low- and high-noise thin-film media and we find in each case a $k^{-b}$ spectrum ($k = $ wave number) with $b$ near 1. We propose a model which interprets the fluctuations as a superposition of uncorrelated protuberances from a nominal straight edge, and we deduce the size distribution of the protuberances which will generate the observed fluctuation spectrum. Simulated reconstruction of the track edge resulting from a weighted superposition of the protuberances permits semiquantitative inferences to be drawn from the model about the medium microstructure.

I. INTRODUCTION

As tracks are narrowed and track densities are raised in the drive for higher information storage density in magnetic recording, the track edge regions do not scale and occupy an increasing fraction of the medium surface. Consequently, irregularities of the track edge generate an increasing fraction of the total medium noise. Moreover, ease and accuracy of locating track edges are an essential requirement for embedded servo systems.

The structure of both track edges and transitions is determined by the geometry and dynamics of the write head field, and by the magnetic microstructure and magnetostatics of the recording medium. They differ because of the different write field and demagnetizing field geometry near track center and track edge. This study focuses on the longitudinal film media which currently dominate high density disk recording. In these media, the demagnetizing geometry difference is especially pronounced: A transition may be thought of as analogous to a charged domain wall, a track edge as analogous to a Néel wall.

Because of the differences, the strategies for minimizing transition and track edge fluctuations may differ. A large body of experimental observation and measurement and of theoretical interpretation and prediction has helped to formulate strategies for the suppression of transition noise.\textsuperscript{1-3} The literature on track edge fluctuations is much sparser.\textsuperscript{4,5} We report here on some results obtained with a new technique for measuring track edge fluctuations, and we propose a plausible model to interpret the results.

II. EXPERIMENTAL PROCEDURE

We write track edges on a longitudinal thin film medium by dc band erasing the medium and writing a saturated track of opposite magnetization direction on the erased band (Fig. 1, write). This results in the writing of two dc track edges as shown in the figure. We then "read" the track edges using two procedures, as follows: (1) We fly the read head (approximately) centered over one of the track edges and record the spectrum and/or the integrated power of the signal induced in the head (Fig. 1, read 1). (2) We "walk" the read head in 0.5 μm steps across the reversed track, beginning in the dc erased region on one side and ending in the dc erased region on the other side, and record the spectrum and/or the integrated power at each step (Fig. 1, read 2). The same or different heads and flying heights may be used for the write and read operations. In the measurements reported here we used the same inductive write and read heads: AMC single-

![FIG. 1. Scheme of the experiment: writing a dc reversed track and reading with a displaced head.](image-url)
crystal ferrite heads with track width \( w = 10.6 \mu m \) and gap width \( g = 0.52 \mu m \), head efficiency \( \epsilon = 90\% \); the head coil winding has 48 turns. Measurements were carried out on several media; because of space restrictions, we confine this report to results on two media: disk 1, with \( M_s = 397 \) emu/cm\(^2\), thickness \( \delta = 0.07 \mu m \); and disk 2 with \( M_s = 887 \) emu/cm\(^2\), \( \delta = 0.03 \mu m \), coercivity \( H_c = 1260 \) Oe, squareness \( S^* = 0.90 \); written and read at \( h = 0.1 \mu m \).

### III. INTERPRETATION OF THE EXPERIMENTS

We interpret the measurements in terms of inductive heads; the discussion would apply to magnetoresistive heads but with some modifications. Since a straight dc track edge would not produce any flux change in the read head coil, the voltage output of the head arises solely from flux changes due to track edge fluctuations. The concept track edge is intuitively clear; but since the actual edge is not a sharply defined line with the magnetization \( m \) pointing in the forward (+x) direction on one side and in the reverse (−x) direction on the other, rather a region where \( m \) turns more or less gradually, we need an unambiguous definition. We formally define the track edge \( e(x) \) as the locus of zero net longitudinal flux component through the condition

\[
\int_{z_e - w/2}^{z_e + w/2} m_s(x,z)dz = 0,
\]

where \( w \) is the width of the read head, and where we assume that the film is thin enough so \( m \) is in-plane and constant through the film thickness. In the experiment the read head travels along a straight line, say \( z = 0 \), and hence the net flux under the head (the above integral with limits \(+w/2\)) fluctuates (in the limit \( \delta \rightarrow 0 \)) as \( 2M_s\delta e(x) \). The output voltage, from reciprocity, is the correlation integral

\[
v(x) = \text{const} \int_{-w/2}^{w/2} dz \int_{-\infty}^{\infty} dy \int_{-\infty}^{\infty} dx' \frac{\partial}{\partial x'} m_s(x-x',z)h_s(x',y,z),
\]

where \( h(x,y,z) \) is the head sensitivity function (field per unit current). This expression can be seen to be proportional to \( d\xi/dx \). It interprets the measurement denoted “read 1” in Fig. 1. It can also be seen that the output is unaffected by a small constant displacement of the head center from the track edge, as long as the track edge remains under the head center region where \( h \) is independent of \( z \) (with a magnetoresistive head such a displacement would add a constant term to the voltage).

Since the Fourier transform of the correlation integral of two quantities is the product of their spectra, we can obtain a track edge noise flux power spectrum \( S_e(k) \) by correlating the measured voltage spectrum with the transform of the sensitivity function

\[
S_e(k) = \text{const} V(k)/KH(k))^2
\]

where \( k \) is the wave number. Apart from the use of a Karlqvist head sensitivity function in the decorrelation, \( S_e(k) \) is fully experimental.

In the next section we shall propose a model of the track edge which yields the measured noise flux, and which provides an instructive picture of its microstructure. The parameters of the model can be made more definite by an independent measurement of the mean excursion of the track edge from its average position. The measurement denoted “read 2” in Fig. 1 provides an upper limit on this excursion. As the head is stepped across a track edge, the fluctuation signal drops from its full value, when the head is centered on the edge, to the very small noise signal from the saturated film. The width of the drop depends on the width of the track edge and the range of its fluctuations, and on the width of the lateral drop-off of the head sensitivity function. In principle the head’s side-reading contribution to the measured width could be removed by a second decorrelation, but we have not attempted such a data reduction with the results we are reporting here.

### IV. RESULTS

The track edge noise flux spectra, measurement “read 1,” of disks 1 and 2, with the specifications given above, are shown in Figs. 2(a) and 2(b). Apart from a very wide range of the prefactor (several orders of magnitude between the noisiest and quietest media tested), the \( k^{-b} \) spectrum is typical of longitudinal media, with the exponent in the range \( 0.74 < b < 1.25 \) in the low-wave-number spectral region that contains the bulk of the noise power.

The results of measurement “read 2” for disk 2 are plotted in Fig. 3. The quantity plotted is integrated noise power as a function of head position. Note that in this measurement the same head was used to write the reversed track and to read the track edges. The dip in the center occurs when the read head is centered on the reversed track, so that both

\[
\text{FIG. 2. (a) Track edge noise flux spectrum of disk 1. (b) Track edge noise flux spectrum of disk 2.}
\]
edges are seen by the less sensitive side-reading sensitivity function.

V. MODELING AND SIMULATION

The magnetization structure of a polycrystalline film may include charged and uncharged domain walls, isolated grains with different magnetization directions, low anisotropy, and weakly magnetized regions, all of which may affect the microstructure of transitions and track edges. It has proved useful for studies of transition noise to adopt a simplified approach restricted to the analysis of fluctuations of position (jitter) and of width. At present, our track edge measurements are insensitive to width fluctuations (we plan to augment the technique to add this capability), and therefore we have developed a model that simulates only jitter, i.e., lateral fluctuations of the track edge center as defined above. The measurement denoted "read 2" reflects a combination of track edge width and head side reading.

The model is a superposition of uncorrelated protruberances from a nominal straight edge, with a distribution that gives rise to the measured flux spectrum. To construct the model, we assume a simple shape for all the protruberances, and characterize the distribution by a size parameter \( \lambda \). The spectrum of a single protruberance of size \( \lambda \) is \( f(k; \lambda) \). The normalized size distribution function of the protruberances is \( g(\lambda) \). Then the power spectrum of a weighted superposition with an overall density of \( n \) protruberances per unit length of track edge is

\[
S_n(k) = \text{const} \ n \ \int_{\lambda_{\text{min}}}^{\lambda_{\text{max}}} d\lambda |f(k; \lambda)|^2 g(\lambda),
\]

where all the head and medium parameters are lumped into the constant. The density \( n \) and the form of \( g(\lambda) \) are determined to fit the measured spectrum. The limits of the integral are the smallest and the largest size expected to be represented in the distribution [i.e., \( g(\lambda) \) is assumed to vanish outside the interval \( \lambda_{\text{min}} < \lambda < \lambda_{\text{max}} \). \( \lambda_{\text{min}} \) is obtained from the measurement, and dominates the normalization; because the spectra are decreasing power laws, it turns out that the integral is quite insensitive to \( \lambda_{\text{max}} \).

The observed power-law spectra can be fitted analytically with protruberances of rectangular, Gaussian, and probably several other shapes. Figure 4 shows simulated track edges constructed from rectangular protruberances that would generate the noise spectra of Fig. 2. These simulated track edges are intended to provide a visual impression of the track edge wavering associated with medium inhomogeneities (note the difference between longitudinal and transverse scale). It is apparent from the simulations that the track edge jitter is much smaller than the combination of edge width and sensitivity function fall-off shown in Fig. 3.

VI. CONCLUSION

We have demonstrated an experimental technique for measuring the noise associated with the magnetically recorded track edge. We have analyzed the noise power spectrum measured with this technique and have found that the data could be fitted to a simple power law and be statistically significant. The track edge center could be modeled by a random superposition of protruberances having a distribution function fitted to the experimental power law. We found that this simple model produced track edge jitter of several thousand angstroms for one medium tested, and deviations an order of magnitude smaller for a less noisy disk. To include higher-frequency components the read head gaplength and flying height should be smaller and preliminary results show a dramatic decline (steeper slope) of the higher spectral components.

The technique is useful as a simple qualification test for media intended to be used in high track density applications. The model also suggests an interpretation of the physical origin of the track edge noise.

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