dc track edge interactions

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We have developed an experimental method for investigating the interaction between two dc track edges by studying the track edge noise. We conclude that two edges do not interact when they are several micrometers apart, but the noise reduces nearly to zero when their separation is less than about half a micrometer. There is a transition region that exists between these two limits. The net track edge noise power from two dc edges is quantized, implying that in our experiment track edges interact around the complete revolution of the disk or not at all.

BACKGROUND

In the drive to increase areal density in magnetic recording, a design goal of 1 Gb/square inch been reached in an IBM laboratory by an increase in both linear bit density and track density.[1] In longitudinal thin-film recording, as the linear bit density increases, the transition region, which is a noise source, occupies a larger fraction of the bit cell, and the rms noise increases.[2] Similarly, as tracks are narrowed and track densities increase, the track edge regions do not scale and occupy a greater fraction of the recorded track; irregularities of the written track edge generate an increasing fraction of the total medium noise. However, transition and track edge noise need not be simply related.[3] Investigations into both noise sources need to be conducted.

Extensive research has helped to formulate strategies for reducing the adverse effects of transition noise (e.g., Refs. 2 and 4–6). In contrast, a relatively small amount of literature exists on track edge fluctuations.[3–9] In this study we are investigating methods of minimizing track edge noise as well as utilizing it; for example, written track edges have been used as a narrow source to enable the precision measurement of head sensitivity functions.[10] In addition, track edges could be useful in future servo systems.[11]

The medium- and write-process-dependent jitter of a dc track edge has been studied by Muller *et al.*, using a technique insensitive to width fluctuations.[3] In the present work we extend that study to determine an effective interaction distance between two dc track edges. The basis of the experiment is the hypothesis that adjacent track edges do not interact significantly until they reach a critical distance. This measurement allows us to infer information about the recording process, the actual track edge width, and the microstructure and micromagnetics of the medium.

EXPERIMENTAL PROCEDURE

We write two track edges on a longitudinal thin-film medium by the method of Ref. 3 as depicted in Fig. 1, where s is the edge spacing. First, we dc band erase an area wider than the head (write 1), return to the original position, perform a dc erase, and read the dc erase noise power spectrum.

A pair of track edges is written so that they are centered under the original head position. To write the first edge, we move the head, apply a direct current of opposite polarity (write 2), remove the current, and move the head the desired edge separation. The second edge is written by applying a direct current to write a dc track with magnetization in the original direction (write 3). The read transducer is then returned to its original position so that it is centered over the pair of track edges to read the track edge noise power spectrum. Our net track edge noise power spectrum is calculated by a point-by-point subtraction of the dc noise spectrum from the track edge noise power spectrum. The result is integrated to provide a single number as the output of each test. With our present apparatus, the track edge separation can be varied in 0.06-μm steps. It should be noted that even if there is significant side writing, the first edge will not be simply overwritten since we use the same side of the head to write the second edge. Side writing on the first edge will be compensated by equal side writing on the second edge.

RESULTS AND DISCUSSION

Pairs of edges were written with wide, equal spacing on longitudinal thin film media. Figure 2 shows that the total noise power increased linearly with the number of edges. A single track edge produced exactly one-half the noise power of a pair. This is experimental evidence supporting our hypothesis that adjacent track edges are uncorrelated noise sources when they are sufficiently far apart. Initially, the track edges were written for 10 s each, so that even if nonrepeatable spindle runout were present, the track edges would have the desired separation because each track edge would have been displaced by the same maximum radial excursion. The possibility of nonrepeatable runout errors during read was eliminated by writing even numbers of edges. Additional tests performed by writing the track edges for only one revolution of the disk produced data which correlated with the tests in which edges were written for 10 s each. Signal envelope modulation tests demonstrated that the nonrepeatable bearing runout of our spindle is smaller than our measured interaction distances.

When adjacent track edges are written several micrometers from each other, their total noise power adds as the number of track edges, implying that at this distance track edges are uncorrelated noise sources. By writing two track edges at smaller and smaller spacing, a region is reached in which the dc track edge noise power is smaller

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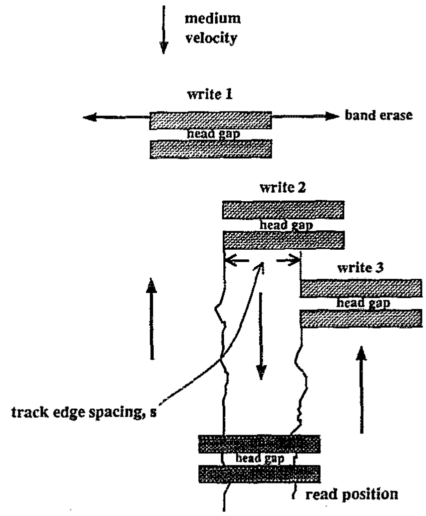

FIG. 1. dc track edge pair write schematic.

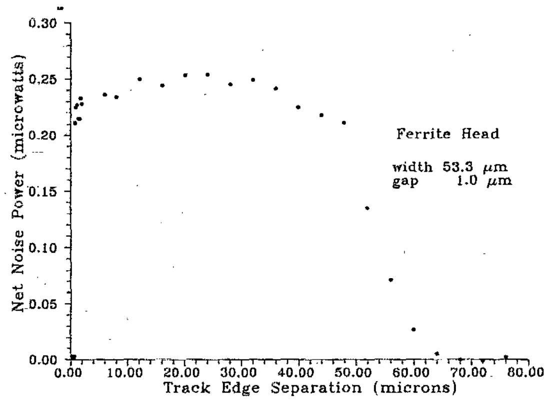

FIG. 3. Net noise power vs track edge separation s using a 53-μm ferrite head.

but nonzero. This correlation between the two track edges is not erasure; our experimental method eliminates the possibility of overwriting by writing the two edges with the same side of the head. In addition, track edges written by our experimental technique appear as opposing (repelling) magnetic line dipoles and have the same chirality. Since adjacent edges of the same chirality cannot readily annihilate by unwinding, they can be written side by side at small separations. Two track edges written with our technique have the same chirality as the edges of a dc track created by a single pass of a head.

One test of net noise power versus track edge separation for a 53-μm-wide ferrite head is shown in Fig. 3. We have concluded that the roll-off for edge spacing about two-thirds of the head width is an effect of the head field function's decay in the track-width direction, as observed in other measurements.[10,12,13]

The other interesting aspect of Fig. 3 is the transition to a very low noise power for spacings of less than about 2 μm. Figures 4 and 5 are from similar experiments, expanding the view of the transition region. The data in Fig. 4 are for track edges written on a 650-Oe coercivity medium using a ferrite, a metal-in-gap, and a thin-film head. The track edges were always fully written and noninteracting when the spacing was greater than 1.5 μm; there was a transition region between about 0.5 and 1.5 μm, and below 0.5 μm the track edge noise power was small but larger than noise from a dc-erased track. When no track edges were written, the measured noise power (less dc erase noise) varied evenly to both sides of zero, such that the mean of many data points was zero. The noise power of two correlated edges, in contrast, was nearly always positive. This indicates that the track edge interaction of very closely spaced edges is not a complete anticorrelation or erasure of the edges, but rather some magnetic structure of the track edge pair remains.

There is a transition region between the uncorrelated and interacting edge regions in which the track edges are sometimes interacting and sometimes not. Our measurements show that the location of this transition region is not repeatably dependent on head geometry or head type, as evidenced in Fig. 4. Changes in the write field also have no effect on the location of the transition region, as long as the write field is sufficient to saturate the medium.

The noise power of two edges written at large spacing is not correlated with the head type. The 650-Oe disk ex-

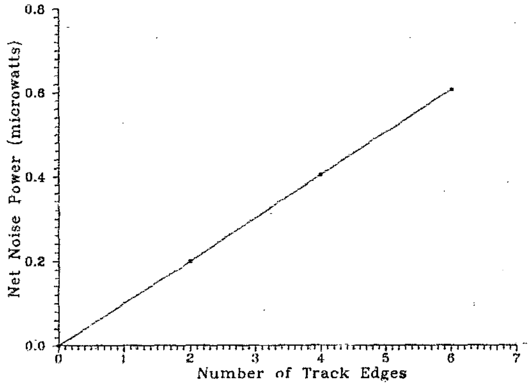

FIG. 2. Net noise power vs number of track edges.

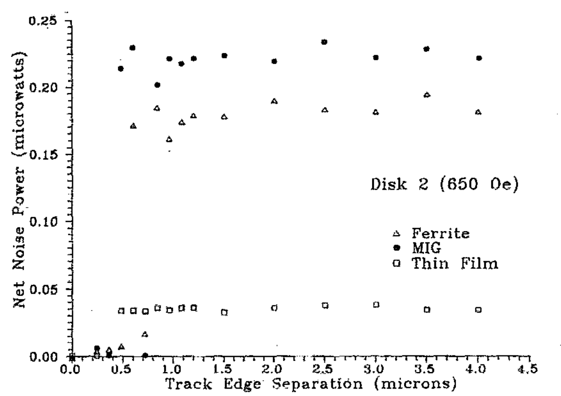

FIG. 4. Net noise power vs track edge separation for various heads using a 650-Oe coercivity disk.

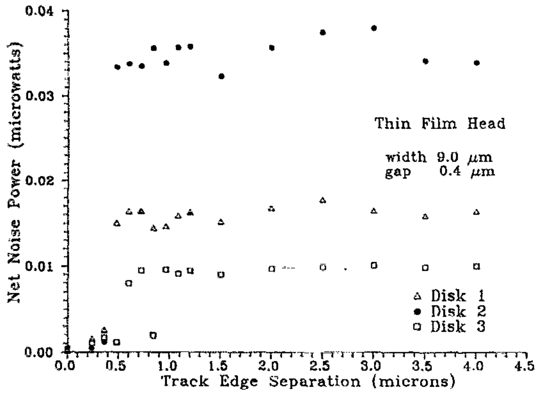

FIG. 5. Net noise power vs track edge separation for various media using a thin-film head.

hibits a greater noise power for edges written with the metal-in-gap head than the ferrite; whereas, when using the 900-Oe coercivity disk, the difference in the magnitudes of the noise power for these two heads has changed sign. This phenomenon necessitates further study.

When the write field changes, the measured noise power from a pair of dc track edges does not change, as long as the write field saturates the medium. The head field gradient at the medium surface may be different for different write fields, but the noise from the resulting pair of track edges is equivalent. From this we infer that a change in the write field does not affect the track edge interaction.

This and other experiments have shown that the net noise power obtained from a dc erase and a "half-edge," namely, the writing of two overlapping dc tracks of the same polarity, are not distinguishable from each other with the method of this work. This result is important to verify that the band erase performed in these tests yields the same noise power as a dc-erased track.

The noise power data we have obtained fit into discrete levels. All measurements yield a noise power at the level of two uncorrelated edges or at the low level observed at track edge spacing of less than 0.5 μm. This quantization implies that in our experiment two track edges cannot be correlated around a portion of the disk; they are distinct or they are not. Our results also suggest a minimum realizable proximity for two adjacent dc tracks. Measurement of track edges written on three different media with the same head demonstrates a direct relation of the noise power of two uncorrelated edges to the dc noise of each medium. However, as before, the location of the transition region between uncorrelated and interacting edges is not repeatably dependent on the medium type or coercivity.

The data we present here are only for dc-recorded tracks. The micromagnetics of the track edges may change for tracks having written transitions, and therefore the track edge interaction may be different; this needs to be investigated.

CONCLUSION

Measurement of the integrated noise power due to track edges which are several micrometers apart shows that the noise power is linear in the number of track edges. At spacing of greater than 1.5 μm, two written edges always produce the same noise power; they act as uncorrelated noise sources. Between about 0.5 and 1.5 μm track edge spacing, there is a region of uncertainty in which the edges sometimes completely correlate and sometimes do not. Under 0.5 μm, the edge noise is always small, but larger than noise from a dc-erased track. The track edge noise power is quantized into the uncorrelated and interacting levels; we infer that two dc track edges are interacting around the complete revolution of the disk, or not at all. The region where track edges are interacting produces a low-track-edge-noise situation.

The head-medium combinations tested in our experiments exhibit a direct relation of the magnitude of noise power due to two uncorrelated track edges to the dc noise of the medium. The magnitude of the noise power was independent of the head used. The location of the transition region between high and low noise powers was not repeatably dependent on head geometry, head type, medium, or write field, as long as the write field was sufficient to saturate the medium.

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[1] C. Tsang, M.-M. Chen, T. Yogi, and K. Ju, IEEE Trans. Magn. **MAG-26**, 1689 (1990).
[2] R. A. Baugh, E. S. Murdock, and B. R. Natarajan, IEEE Trans. Magn. **MAG-19**, 1722 (1983).
[3] M. W. Muller, R. S. Indeck, E. S. Murdock, and R. Ornes, J. Appl. Phys. **67**, 4683 (1990).
[4] T. C. Arnoldussen and H. C. Tong, IEEE Trans. Magn. **MAG-22**, 889 (1986).
[5] J.-G. Zhu and H. N. Bertram, IEEE Trans. Magn. **MAG-24**, 2706 (1988).
[6] M. W. Muller and E. S. Murdock, IEEE Trans. Magn. **MAG-23**, 2368 (1987).
[7] P. S. Alexopoulos, R. H. Geiss, I. A. Beardsley, and D. E. Heim, MMM-Intermag Conference, Vancouver, 1988; paper GE-03.
[8] T. A. Nguyen, P. S. Alexopoulos, C. Hwang, S. E. Lambert, and I. L. Sanders, IEEE Trans. Magn. **MAG-24**, 2733 (1988).
[9] E. J. Yarmchuk, IEEE Trans. Magn. **MAG-22**, 877 (1986).
[10] R. S. Indeck, M. W. Muller, S. C. Reising, and J. R. Hoinville, paper presented at the Magnetic Recording Conference, San Diego, CA, 1990.
[11] R. S. Indeck, NSF Grant MIP-9020883, 1990.
[12] G. S. Mowry, P. K. George, K. M. Loeffier, and N. R. Belk, IEEE Trans. Magn. **MAG-22**, 671 (1986).
[13] S. E. Lambert and M. L. Williams, IEEE Trans. Magn. **MAG-24**, 2832 (1988).