Nonlinear Transition Shift Measurement in Perpendicular Magnetic Recording

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Abstract--- **Transition-shift distortion for perpendicular magnetic recording is measured using a pseudorandom sequence and extracted dipulse analysis. The analysis reveals moderately low distortion at a high linear density of 318 kFRPI. Perpendicular recording is expected to give rise to transition-shift distortion in a direction opposite to that for longitudinal recording. However, very little transition-shift distortion is observed. The distortion that does occur appears to be predominantly a narrowing of 'following' transitions.**

I. INTRODUCTION

Perpendicular magnetic recording has been proven to show good high density response [1]. For good performance at high density, low nonlinear distortion is also essential. Linear superposition can well explain the roll-off curves for perpendicular recording up to 200 kFRPI [2]. Roll-off curves, however, cannot reveal transition-shift distortion. It has been previously shown that hard/easy transition shifts due to overwrite effects are not very large and can anyway be suppressed by utilizing a bi-layered single pole head [4]. However, 'nearest-neighbor' transition shifts have not been previously measured and recent predictions have suggested that relatively large 'nearest-neighbor' shifts may occur in perpendicular recording [3].

This paper reports experimental measurements of nonlinear transition-shift distortion for perpendicular recording at high density. Analysis by the "extracted dipulse" or pseudo random sequence technique reveals that the levels of distortion are in fact quite low.

II. EXPERIMENTS AND RESULTS

A single pole head and a double layered disk were used for the measurements. The head has a main pole of 150 nm thick used for both reading and writing in sliding contact recording. The thickness of recording layer of the disk is 50 nm. The head to medium velocity is 1 m/s and 2 m/s for writing and reading respectively. The write current for most of the experiments is 20 mA zero-to-peak. This head/medium combination shows a D_{50} of 150 kFRPI and a half pulse width of about 300 nm. To remove the influence of overwrite transition shift in the experiment, the medium was first ac-erased by writing an extremely high density of 450 kFRPI on the whole track. A 63-bit maximal-length pseudorandom sequence with characteristic polynomial x^6+x+1 was used. The reproduced waveforms were analyzed using the techniques described in the past literature [5],[6].

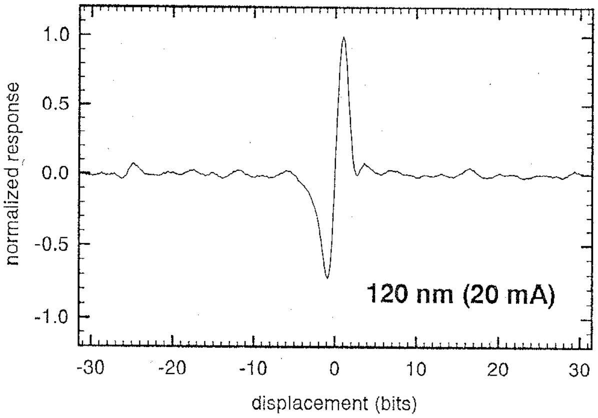

Fig 1. Experimental extracted dipulse response at 212 kFRPI. Characteristics polynomial for the sequence is x^6+x+1.

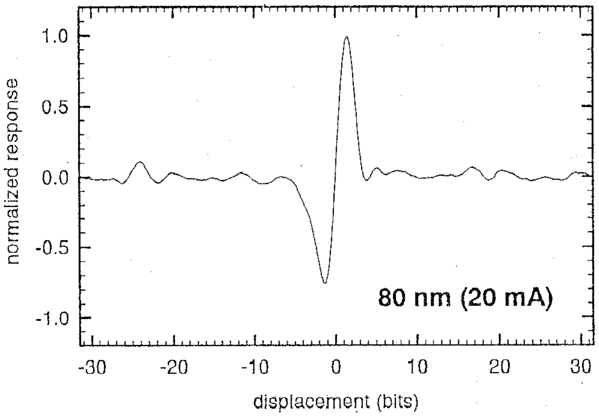

Fig 2. Experimental extracted dipulse response at 318 kFRPI.

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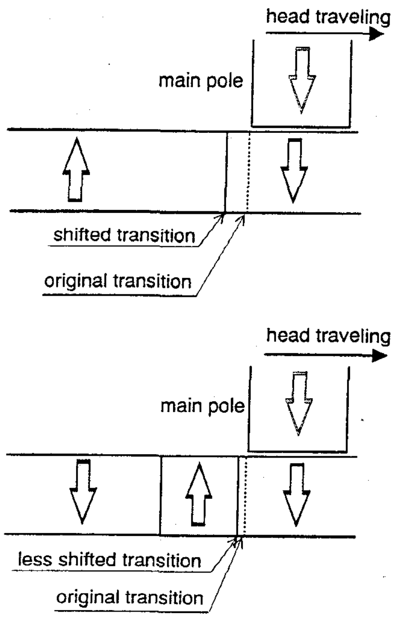

Fig 3. Schematic explanation on the magnetostatic interaction from the preceding bit to head field in dibit recording. Upper: the first transition without a preceding transition, Lower: the second transition with a preceding transition

Fig. 1 shows the extracted dipulse response at a bit separation of 120 nm (212 kFRPI, 60 ns separation at 2 m/s). Some slight distortions appear. The largest one of these is at the -24.5 bit position which is associated with the nearest neighbor interaction. The echo at position -24.5 can be seen more clearly when the recording density increases to a bit separation of 80 nm (318 kFRPI, 40 ns separation at 2 m/s) as depicted in Fig. 2. The echo is not a simple dibit response but is fairly symmetric positive peak with slight undershoots.

These experimental results reveal that the distortion is moderately small even at high density. Also the nature of the distortion is different from that familiar in longitudinal recording [5]. The shape of the echo suggests that 'following 'transitions becomes narrower rather than being shifted towards or away from the first transition. In the context of a thick recording medium, Yeh et al. have described a similar single peak echo which they also attributed to narrowing of following transitions [7].

III. DISCUSSION

A. Extracted Dipulse Analysis

Theoretically, for perpendicular recording, we expect the demagnetizing field from the medium to be lower if there is an immediately preceding transition. Fig. 3 schematically explains this effect. Considering the demagnetizing field at the writing point which corresponds to the magnetostatic interaction from the preceding bit, the left side of the transition in the figure, aids the writing of the new transition because of its anti-parallel magnetization configuration, as indicated in the upper part of the figure. Here, the dotted line shows a reference position where a transition would be written if there were no demagnetizing field present, i.e. the amplitude of the preceding magnetization is zero. When the preceding bit is close to the transition, the demagnetizing field becomes weaker. Thus, an immediately preceding transition will cause the new transition to be written closer to the head. This transition shift is in the opposite sense to that familiar for longitudinal recording.

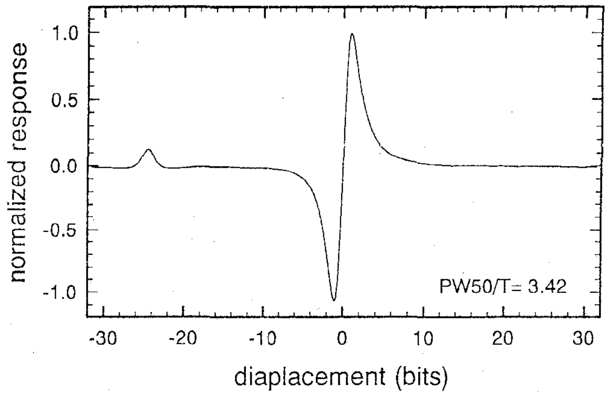

Fig 4. Extracted dipulse for a simulation with a Lorentzian pulse PW50/T= 3.42, transition which are immediately preceded by another transition are 8 % narrower.

The head field gradient at a writing point can be interpreted as a sum of the intrinsic head field and the demagnetizing field from the preceding magnetization. A sign of the demagnetizing field gradient is opposite to that of the head field gradient at a writing point, which means that the field from the preceding anti-parallel magnetization tends to degrade the head field gradient. The effective head field gradient is therefore steeper by the weaker demagnetizing field. We might expect to see some pulse narrowing rather than pulse broadening.

The measurements, however, show very little evidence of pure transition-shift. To better establish the nature of the distortion observed, a simulation was performed with a simple Lorentzian at PW50/T= 3.42, which matches the measurement. The simulation assumes only that all following transitions are 8% narrower. The extracted dipulse response from this simulation, Fig. 4 shows a similar echo very close to the correct location. It is believed that the undershoots of the echo would be matched more closely if a real pulse-shape were used and if second

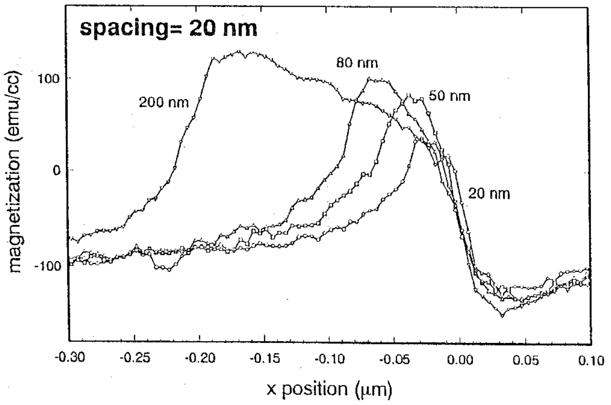

Fig 5. Recorded magnetization in the double layered medium for a self-consistent FEM simulation. A head-to-medium spacing of 20 nm was assumed.

derivative slimming rather than time- contraction were used to narrow the pulses.

B. FEM simulation

The recorded magnetization of dibit recording was calculated with a self-consistent FEM simulation for various transition separations under the assumption of a main pole thickness of 180 nm and a recording layer thickness of 50 nm with a sufficiently thick soft magnetic underlayer. A spacing of 20 nm was assumed, which is close to the measured spacing of about 30 nm. Fig. 5 shows the results, in which the recorded magnetization of the perpendicular component is plotted for bit separations of 200 nm, 80 nm, 50 nm, and 20 nm. Since the transitions has rather complicated magnetization distribution, transition points can not be precisely determined. However, if the distance between the steepest gradient points of the recorded transitions can be considered as the transition points, it becomes gradually wider than the current reversals as bit separation is shorter, which is expected in the model of the magnetostatic effect.

C. Finite Rise-Time Effect of Writing Current

The transition shift itself was not clearly detected in our measurements. Following transitions are expected to be shifted slightly late based on the above magnetostatic interaction model and FEM simulation. We suspect that risetime effects [8] may be affecting our experimental results. The expected magnetostatic transition shift away from the preceding transition may be almost cancelled by the risetime effects in the head/medium which cause a transition-shift toward the preceding transition, because the nonlinear effect of the poor risetime moves the following transition early [5].

IV. CONCLUSION

The extracted dipulse analysis shows that up to relatively high linear densities perpendicular magnetic recording obeys superposition well. Surprisingly, the small distortion that is seen does not correspond well with a transition-shift away from the preceding transition, as predicted by magnetostatics. The distortions are better explained by changes in transition width. We speculate that field risetime effects in the head/medium may be cancelling much of the expected magnetostatic transition shift.

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