Effect of Damping on the Time Variation of Fields Produced by a Small Pole Tip With a Soft Under Layer

Eric D. Boerner, Kai-Zhong Gao, and Roy W. Chantrell

***Abstract*—The time variation of magnetostatic fields generated by space and time varying magnetization configurations in small perpendicular pole tips is studied. The magnetization configurations are a response to external fields driving the pole tip and soft under layer (SUL). When the system damping is sufficiently small the magnetization excitations persist for a long time after reversal. The effects of damping parameter, position in the media, and discretization cell size on the magnitude of the time varying magnetostatic fields will be given. Decreasing the damping parameter increases the magnitude of the magnetostatic field variation.**

***Index Terms*—Damping parameter, head field, micromagnetic, perpendicular recording.**

I. Introduction

When a magnetic system is subjected to a rapid reversal of the applied field, dynamic magnetization excitations may be generated due to a transfer of Zeeman energy to magnetostatic and exchange modes [1], [2]. When the damping of the system is small and energy dissipation to the lattice occurs over a long time, these excitations allow the average magnetization to reverse in shorter times as compared to the coherent case, provided the field amplitude is sufficient [3]–[5]. As the damping parameter is decreased we observe an increase in the amplitude of the variation of the magnetostatic field about its equilibrium. Under conditions of smaller dissipation, this variation persists for longer times. These time scales are approximately inversely proportional to the damping parameter. In small magnetic writers, this results in fields in the media that have high frequency modes.

II. Model

Our three dimensional micromagnetic model is very similar to that described in [6]. The in-plane directions are discretized uniformly, and the out of plane (perpendicular) direction is discretized nonuniformly. In plane magnetostatic fields are calculated more rapidly using fast Fourier transforms [7]. The out of plane direction is treated by direct pairwise summation. The parallel model uses the Message Passing Interface (MPI), with each layer handled by a seperate process. Earlier simulations on lower memory machines with a faster interconnect required a seperate CPU for each layer. For a cluster of workstations with more memory per node but a slower interconnect, it becomes more favorable to run several MPI processes per node. This is because the magnetostatic field calculation requires communicating the information contained in the spin directions between all nodes. The pole tip and leading edge side of the soft under layer (SUL) are driven by long bar magnets with exponential rise times. We have made this simplification in the SUL to avoid requiring a large enough region to include the return pole. We are primarily interested in correctly modeling the magnetization variation in the pole tip and SUL near the pole tip, and we expect this will be a reasonable approximation for our purposes. The pole tip is driven by both magnetostatic and exchange fields from the long bar magnets. The SUL, hard layer (medium), and pole tip can all be discretized, but in this paper we will include only the SUL and write pole tip, and look at the fields from the pole tip and the SUL (not including the driving fields) where the hard layer would be. For the results presented, we have a nominal pole tip size at the ABS of 50 nm by 100 nm, total head to SUL spacing of 25 nm, driving field rise time of 200 ps, and pole tip and SUL saturation magnetization of 1600 emu/cm^3.

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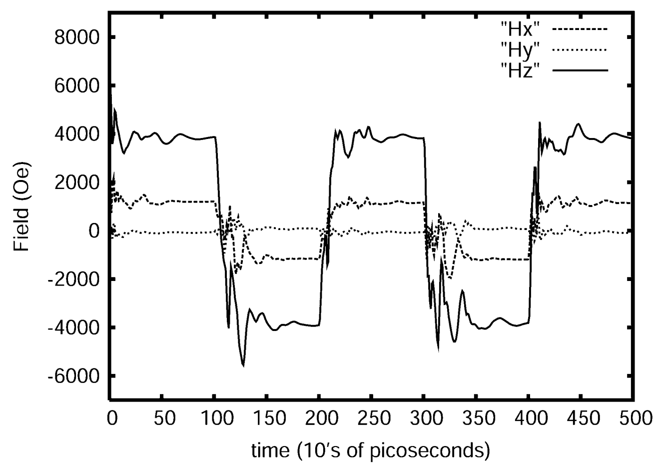

Fig. 1. Field in the medium at track center near the trailing edge due to a pole tip with $\alpha = 0.01$.

III. Results

Fig. 1 shows the time variation of the field in the media at track center near the trailing edge of the write pole. The damping constant is chosen to be $\alpha = 0.1$. The results show

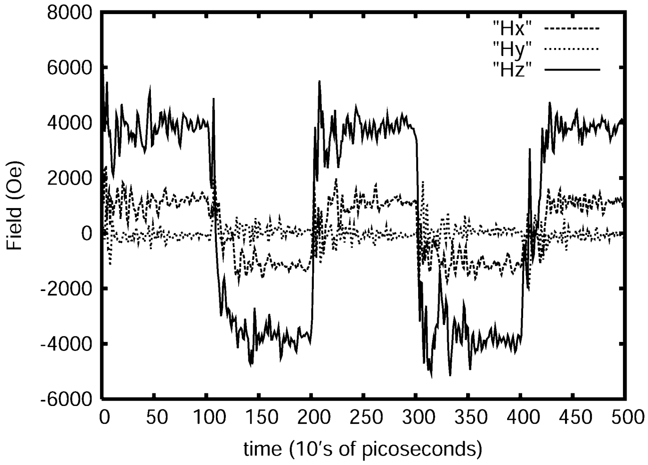

Fig. 2. Field in the medium at track center near the trailing edge due to a pole tip with $\alpha = 0.01$.

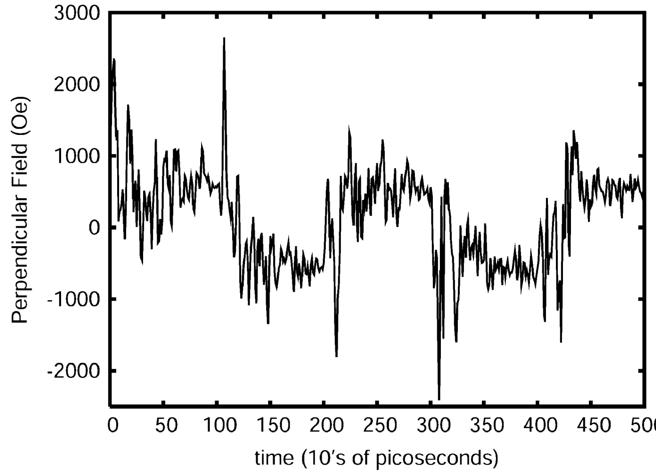

Fig. 4. Time variation of field further downtrack with $\alpha = 0.01$.

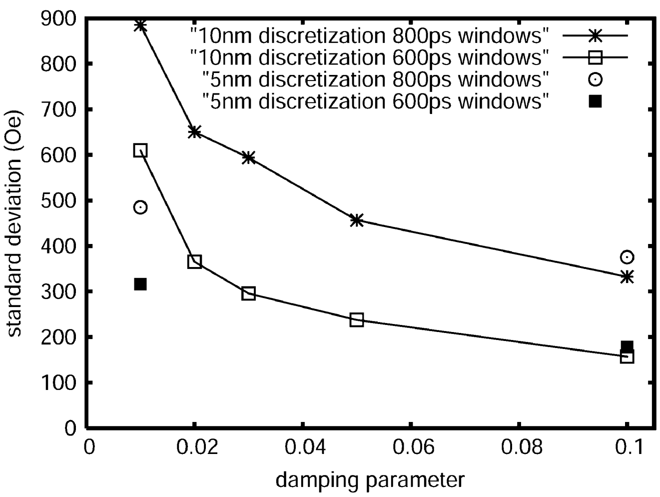

Fig. 3. Standard deviation of the field versus damping parameter.

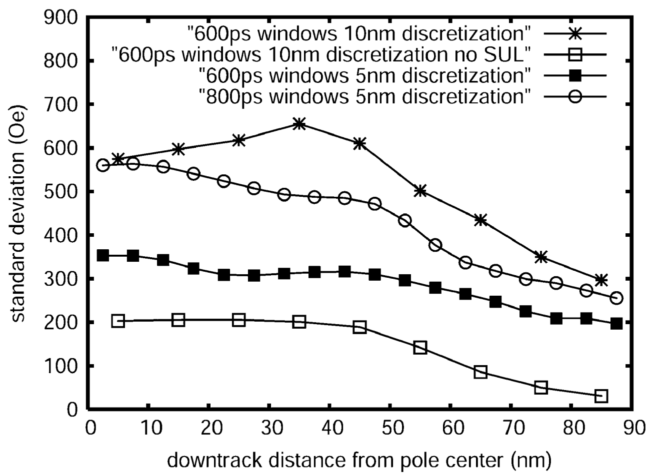

Fig. 5. Standard deviation of field versus downtrack position.

a relatively smooth field variation with oscillations, due to larger scale nonuniform dynamic reversal processes. Higher frequency modes that may be initially excited are damped out within 0.5 ns.

In Fig. 2, the time variation of the field for the same case as shown in Fig. 1, but smaller damping, $\alpha = 0.01$, is plotted. The results show that the high frequency excitations are large compared to the $\alpha = 0.1$ case and persist for a longer time compared to our reversal period. For both cases, the magnetostatic field may exceed the mean (saturation) field before the equilibrium state is reached.

To get an estimate of the magnitude of the field variation, first we define a window of certain length ending at the end of a bit period. We then compute the standard deviation of the absolute value of the magnetostatic field in this window and average over each bit (the windows ending at 2 ns, 3 ns, 4 ns, and 5 ns). In Fig. 3 the standard deviation of the field is plotted versus damping parameter. The results show that the magnitude of the field variation decreases monotonically with increasing damping parameter. The results also show the effect of window length: longer windows capture more of the field variation present at earlier times when there was more energy in the spin system, and hence have a larger standard deviation. Different discretizations are compared. There is a weaker dependence on damping parameter for the smaller discretization cells. For larger discretization cells, the normalized exchange fields are weak [8], allowing larger excursions of the spins after excitation for small damping.

Fig. 4 shows the time variation of the field in the hard layer for a position further downtrack (away from the pole tip). The results clearly show that further downtrack, a larger percentage of the field is composed of high frequency modes as compared to the case near the trailing edge.

Fig. 5 plots the standard deviation versus downtrack position. The result under the pole tip is complicated and depends on the window size. Beyond the pole tip the standard deviation then decreases, but still more slowly than the decrease in the absolute field magnitude generated from the pole tip as will be shown later. Fig. 5 also shows the 10 nm discretization case with and without an SUL. The absence of the SUL decreases the standard deviation because a smaller percentage of the solid angle contains pole tip or SUL excited spins.

Fig. 6 plots the standard deviation relative to the mean field versus the downtrack position. We see that without an SUL the amplitude of the field variation scales with the field. With an SUL, however, the field variation increases relative to the field

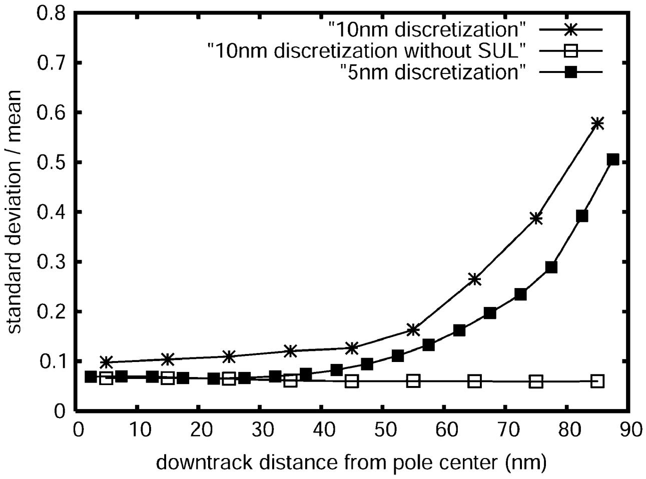

Fig. 6. Normalized standard deviation of field.

further from the pole tip. This is believed to be due to excitations in the SUL which are not localized directly underneath the pole. One would expect significant ringing in the SUL due to fast reversal, and this would give a significant contribution to the fluctuations in the field. Including a larger region of the SUL may result in a reduction of the field variation because the excitations in the SUL would no longer be confined to a fairly small region.

We will not discuss results of parameter variations with a 10 nm discretization in any detail but point out several observations obtained using this discretization. A relatively small effect was observed due to crystalline anisotropy in a soft material over a fairly large range. This would appear reasonable since magnetostatic fields generated near the edges and corners would dominate crystalline anistropy. Also with a 10 nm discretization a small change in the standard deviation relative to the mean was observed over a fairly limited range of head to media spacings.

IV. Discussion

We have studied the fluctuations in the field from a pole tip produced by high frequency magnetization fluctuations. The characteristic time for damping is inversely proportional to the damping parameter. For our case this characteristic time is longer than the driving field rise time and we are able to excite high frequency modes. It was found that the results were strongly dependent on the discretization. From an exchange length argument one would expect a 5 nm discretization to be small enough to describe the reversal process fairly accurately, however, smaller discretization allows higher frequency modes to be excited [9], but it is not yet clear how significant this will be for the time variation of the field. Parallel models which scale better due to how they calculate the magnetostatic interaction will allow more accurate examination of the effects of smaller discretization and larger head structures [10]. In the long term, multilength scale models which allow one to study the effect of very small discretization cells [11] may become necessary.

But how important is the field variation on noise due to playback of recorded transitions? Simple slope models might suggest the possibility of a nontrivial contribution from this field variation. But because the spins are not responding instantaneously to the recording field, the effect on noise is expected to be much smaller. The model used is capable of including the hard layer, but for simplicity of examining the effects shown in this paper it was not included. To accurately model the effect of the hard layer, the hard layer needs to be included self-consistently and if performing micromagnetic simulations one will probably need to run enough cases to understand the statistics due to variation in the media conditions present at each recorded transition.

V. Conclusion

The amplitude of higher frequency oscillations in the field from a pole tip and SUL was characterized in terms of effective damping parameters. A similar study can be done for other structures. This suggests a way to estimate effective damping parameters through measurements of variation in the magnetostatic field near test structures after reversal.

Higher frequency modes imposed on the typically assumed smooth time varying field from modeled pole tips was observed. The amplitude of the higher frequency modes increased with decreased damping parameter. It was seen that an appropriate discretization was necessary to avoid overestimating the amplitude of the field variation. The field variation relative to the mean field increases further downtrack, while the absolute variation decreases further downtrack.

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