MR head reading characteristics in perpendicular magnetic recording

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MR Head Reading Characteristics in Perpendicular Magnetic Recording

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Abstract-- **Reading characteristics of an MR head for perpendicular magnetization are theoretically and experimentally examined. Higher output than with an ordinary longitudinal medium is obtained because of the higher M_st product of the perpendicular medium; D_{50} is comparable. The step function pulse is confirmed in this experiment too, which is well explained by the reciprocity theorem using numerically calculated head sensitivity function. Differentiation of the signal brings familiar single peak pulses, and improves D_{50} by about 30 %. Signal reproduction from a narrow track of 0.5 μm width is demonstrated with a MR head. Writing head comparison between a thin film ring head and a single pole head is also discussed for the perpendicular double layered medium.**

I. INTRODUCTION

Narrow track recording of less than a half-micron width has been demonstrated in perpendicular magnetic recording [1]. Such extremely narrow track width suffers from total reading flux reduction, even though high moment media of large M_st product can be utilized without resolution degradation [2]. The MR head will be therefore successfully adopted to the recording scheme because of its high sensitivity. Seagle et al. reported important results of the reading characteristics for perpendicular magnetization [3], but the shield gap and flying height seemed to be rather large comparing with today's MR heads.

In this paper, the fundamental read characteristics of the MR head is again examined with a current vertical MR head [4]. The isolated pulse obtained in experiments is compared with the theoretical calculation. We confirmed that the signal processing of differentiation, which was proposed by Seagle et al. [3] is effective to adapt the MR head to a conventional recording channel in perpendicular magnetic recording.

II. EXPERIMENTAL PROCEDURE

The vertical MR head was utilized as the reading head in the experiments, whose shield gap length and flying height are 0.4 μm and 0.05 μm. The read track width is 2.5 μm. The head-to-disk velocity is 5 m/s. A single pole writing head which has the main pole of 0.3 μm in thickness was separately attached on a spin-stand to optimize writing conditions for a Co-Cr/permalloy double layered medium. A thin film ring head merged with the MR head was also examined as a writing head; its gap length and track width are 0.6 μm and 3.5 μm, and the coil has 14 turns. These heads are schematically depicted in Fig 1.

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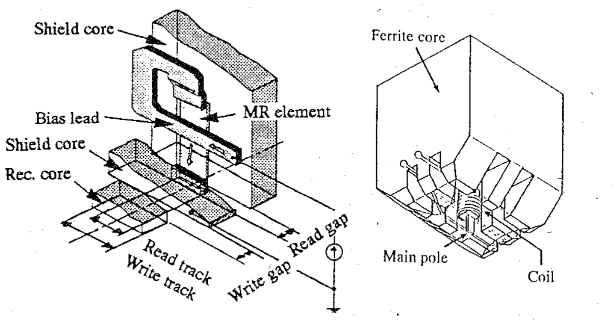

Fig 1. Schematic view of merged vertical MR head (left) [4] and single pole head (right).

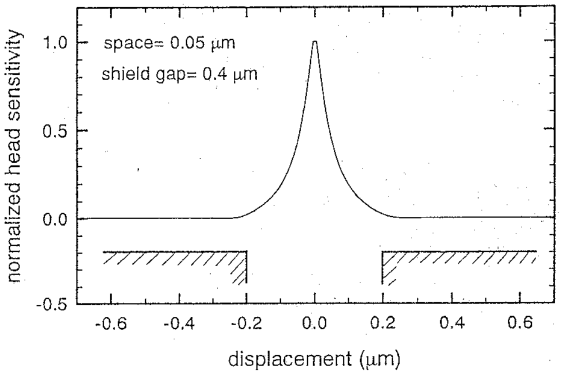

Fig 2. Calculated head sensitivity function. Head-to-medium spacing and shield gap are 50 nm and 400 nm. Distance between soft magnetic underlayer and head is 100 nm.

III. READ CHARACTERISTICS WITH MR HEAD

A. Isolated Readback Pulse

The readout waveform with a shielded MR head for perpendicular magnetization can be theoretically calculated according to Potter's equation [5]. It was assumed that the reading flux through the MR stripe is equivalent to the flux detected with a virtual coil wound around the stripe. This means that the sensitivity function of a head for perpendicular magnetization in the reciprocity can be determined by the normal component of the head field, which is excited with the virtual coil. The geometry of the shielded MR head with an soft magnetic underlayer does not make it very simple to know the accurate head sensitivity function. We calculated the head sensitivity function by a self-consistent FEM simulation, in which the underlayer of the double layered medium was considered as a part of the head. A typical sensitivity function is shown in Fig 2. Almost single peak sensitivity with very little undershoots is obtained within the shield gap of 0.4 μm. By

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assuming the magnetization vector in the reciprocity equation as the ideal sign-function of the perpendicular component, the head response is given by the equation below. Herein, e(τ) and φ(τ) represent output voltage and read-flux respectively. The d and δ are spacing and medium thickness.

$$e(\tau)=\phi(\tau)=\int_{-\infty}^{\infty} dx \int_{d}^{d+\delta} M_y(x-\tau,y)\cdot H_y(x,y)dy$$

After substituting the sensitivity function, H_y, and magnetization distribution, M_y, numerical integration produced results, where uniformity along the medium thickness was assumed. A result of the calculation is plotted in Fig 3 with a dotted line, in which the observed signal for the condition is also shown. Since an ideal step function was assumed as the magnetization, the readback pulse directly corresponds to the simple convolution of the head sensitivity and the isolated transition. The calculated waveform agrees well with the observed one. In physical meaning, the head detects the normal component of stray field on the medium which is continuous to the perpendicular flux density distribution in the medium.

B. Differentiation

For some applications a familiar single peak response may be required. A differentiation transforms the transfer function into a single peak response for step-magnetization, because the head response is roughly equivalent to the integration of that for perpendicular magnetization component. The raw head output were processed with a differentiation circuitry whose bandwidth covers up to 20 MHz, or about 200 kFRPI in this experiment. Fig 4 shows the result. The original raw isolated pulse and differentiated one, and an example of longitudinal disk with the same head are plotted. The longitudinal medium has M_rt of 150 Gμm and H_c of 1800 Oe. About 40 % reduction of half-pulse-width against the longitudinal medium was observed even with the same head.

Recent high density recording channels usually utilize differentiation-type partial response signaling. The differentiating-equalizer for the MR head, in some cases combined with other pulse shaping, in perpendicular magnetization may fit these sorts of read-channel.

C. Roll-off Characteristics

Roll-off characteristics for the MR head is plotted in Fig 5. The calculated response by reciprocity is also plotted in the figure; again the ideal square-wave-like magnetization was assumed. A D_{50} of 117 kFRPI was obtained which well agrees with 120 kFRPI from the calculation. This fact means that the D_{50} is restricted by the read-head. The differentiation improves D_{50} by about 30 % because of its high-frequency boost effect. This improvement is slightly larger than that pointed out by Seagle et al. [3].

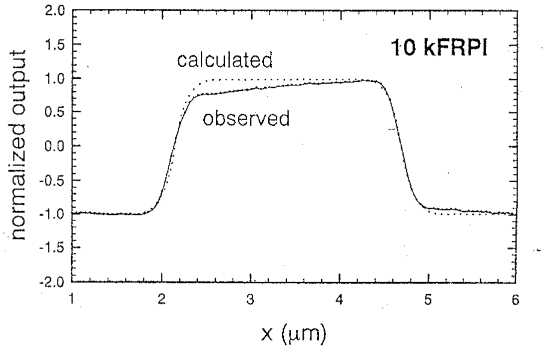

Fig 3. Calculated readback pulse in comparison with calculation. Density: 10 kFRPI.

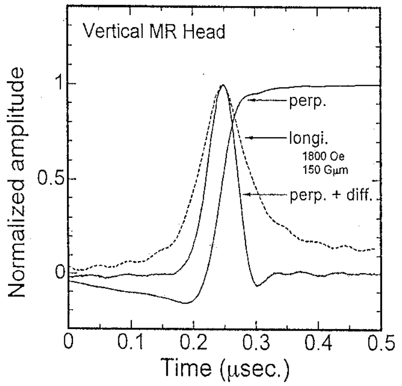

Fig 4. Pulse shape comparison among raw output pulse, differentiated one, and longitudinal pulse.

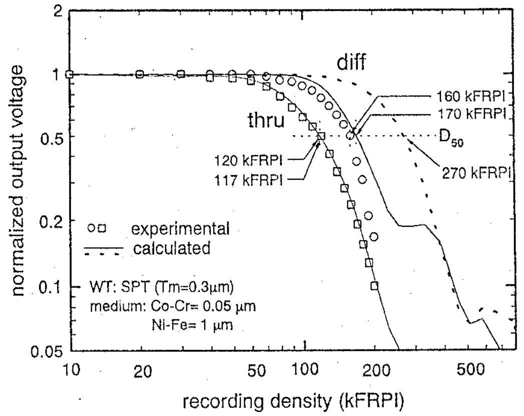

Fig 5. Roll-off curves for raw output and differentiated one. The dotted line shows an estimation for shield gap length of 0.2 μm with the differentiator.

In the experiment, the larger readback amplitude than a current longitudinal medium by about 40 % was also confirmed, as reported by Sonobe et al. [6], which is thought to be caused by the large M_st of 300 Gμm of the perpendicular medium. D_{50} was same for both. Both media exhibited second harmonic distortion of less than -25 dB for the same bias current in the experiment.

An estimated result for narrow shield gap of 0.2 μm by the calculation is indicated in the figure. The higher D_{50} of 270 kFRPI is predicted, holding the flying height of 50 nm.

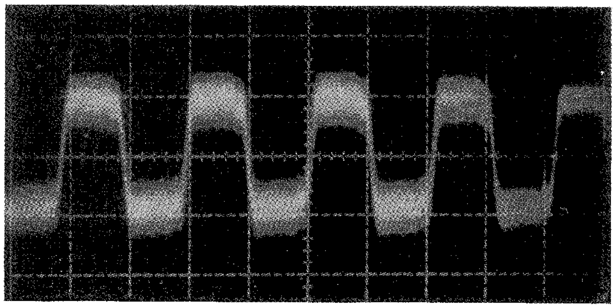

Fig 6. Readback waveform for 0.5 μm-width-track with MR head. Density: 10 kFRPI, velocity: 5 m/s, 20 mV/div, 0.5 μs/div.

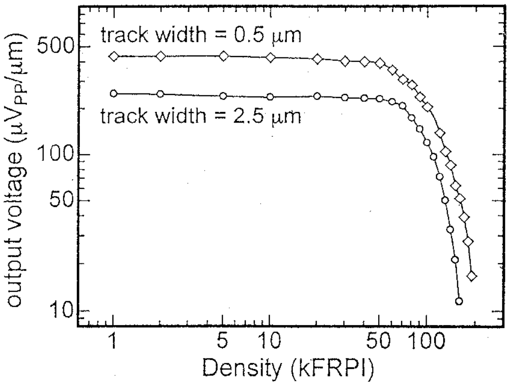

Fig 7. Roll-off curve for the submicron trackwidth recording. The trackwidth is 500 nm.

D. Submicron Trackwidth Readout

Submicron-width track of 0.5 μm was written with a lateral single pole head [1] on a double layered medium. A signal observed at 10 kFRPI is shown in Fig 6. The same pulse as shown above was observed, which meant perpendicular magnetization certainly recorded in the medium. Its roll-off characteristics is plotted in Fig 7. The larger normalized output at low density is measured than the case of wider trackwidth. The track narrowing into such extremely small width may reinforce magnetization because of reduction of demagnetization in perpendicular magnetic recording.

E. Ring Head Writing

Design of a writing head associated with an MR head is one of the critical issues. Fig 8 indicates roll-off curves for both writing of a single pole head and a ring head. The single pole head attains moderately higher D_{50} than the ring head, which suggests the ring head parameters mentioned above should be optimized in order that dominant perpendicular head field is applied to a recording layer. If its gap broadens, strong in-plane field near gap will be suppressed. In addition, by making either pole be much thinner, concentrated perpendicular field will be generated at the front of the pole. The write pole optimization will thus improve the writing resolution of the ring head.

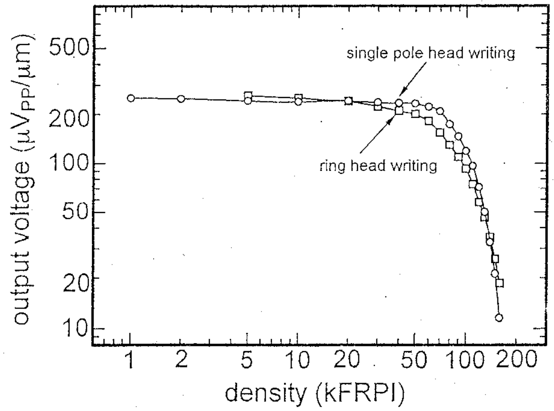

Fig 8. Comparison between ring head writing and single pole head writing for perpendicular double layered medium.

IV. CONCLUSION

The high sensitivity of the MR head will be an advantage in perpendicular magnetic recording, in particular, submicron trackwidth recording. It shows large output amplitude with the step function pulse which corresponds to the perpendicular magnetization distribution. By differentiation, the pulse is transformed into familiar single peak response, and D_{50} of 160 kFRPI was attained with the shield gap of 0.4 μm. Further D_{50} up to 270 kFRPI is predicted by narrowing a shield gap into 0.2 μm. The pole design on the writing head associated with the MR head will be one of the principal issues for perpendicular magnetic recording.

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