Recording and Reproducing Efficiency of Main-Pole Driven Perpendicular Magnetic Head

S. Yamamoto, Y. Nakamura, and S. Iwasaki

Abstract

The reproducing efficiency of a perpendicular magnetic recording head was investigated. Miniaturization and adoption of a head construction with a closed magnetic circuit and coil wound close to the main pole are very effective ways to improve the readout efficiency. We have designed and fabricated a main pole-driven perpendicular head with a thin film coil wound around the main pole film in addition to the wire coil. The readout voltage per turn of the thin film coil was confirmed to be double that of the wire coil, and the same readout voltage as from a thin film perpendicular head with a double-sided return path core can be obtained when the two coils of this head are used in series.

I. Introduction

In the past single-pole type (SPT) perpendicular magnetic heads [1] were used in read/write experiments at high linear recording densities in excess of 600 kFRPI, and verified that perpendicular recording is possible at high densities near the physical resolution of the medium [2]. We have also verified that there is almost no blurring in the magnetization near the track edges, and that track densities can be raised without difficulty [3]. In order to implement magnetic recording systems with high linear and track densities which make use of these features of perpendicular recording, the record and reproduce efficiencies of the perpendicular head, and especially the reproduce efficiency, must be improved.

In this paper we describe finite element analysis of the relation between the structures of perpendicular heads developed to date and their readout efficiencies. Based on the results obtained, we examined the structures of perpendicular heads enabling higher recording densities.

II. Analysis of the Reproduce Efficiencie of Existing Perpendicular Heads

A. Analysis model and method

We first employed the finite element method in analyses of the readout efficiency of perpendicular heads developed to

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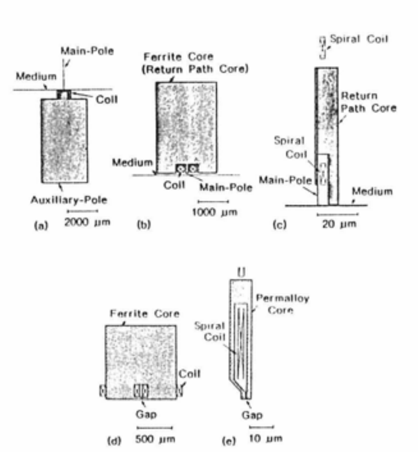

Fig. 1. Models of various SPT heads for analysis. (a) Auxiliary pole-driven head; (b) main pole-driven head; (c) thin film head with return path core on one side; (d) ferrite ring head; (e) thin film ring head.

Table 1. Geometric dimensions and magnetic properties of heads and media.

SPT Head		
Thickness of Main Pole:	0.4	µm
Thickness of Co-Cr Layer:	0.1	µm
Thickness of Ni-Fe Layer:	0.5	µm
Head to Medium Spacing:	0.02	µm
Permeability of Main Pole:	5000	
Permeability of Auxiliary Pole:	1000	
Permeability of Return Path Core:	1000	
Permeability of Co-Cr Layer: ⊥	10	
∥	1	
Permeability of Ni-Fe Layer:	1000	
Ring Head		
Gap Length of Ring Head:	0.4	µm
Thickness of Core of Thin-Film Head:	5	µm
Permeability of Ferrite Core:	3000	
Permeability of Permalloy Core:	3000	
Permeability of Longitudinal Medium:	1	

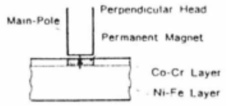

Fig. 2. Relative position of the magnetic flux source.

date. The constructions of these heads appear in Fig. 1. Here (a) is an auxiliary pole-driven perpendicular head, (b) is a main pole-driven perpendicular head with a ferrite core [1], and (c) is a thin film perpendicular head with a spiral coil [4]; these were studied in combination with Co-Cr/Ni-Fe double-layer film media. For purpose of comparison with perpendicular heads, we also performed analyses of (d), a ferrite ring head for video signal recording, and (e), a thin film ring head, in combination with longitudinal media. These heads were treated using linear two-dimensional models assuming an infinitely great track width. Table 1 gives the dimensions and magnetic properties of the heads and media. In the models employed in analyses, the readout process was approximated by positioning a source of flux in that part of the medium facing the head as shown in Fig. 2, and the distribution of lines of flux was calculated. In this paper, the "head readout efficiency" is defined as the proportion of the total flux flowing from the medium which is linked with a single turn of the readout coil (expressed in percent).

B. Results of analysis of the readout efficiencies of perpendicular heads

Fig. 3 indicates the distribution of lines of flux near the main pole tip during data readout, as obtained in FEM analyses. For head (b), the main pole-driven perpendicular head, the readout efficiency is 15%,

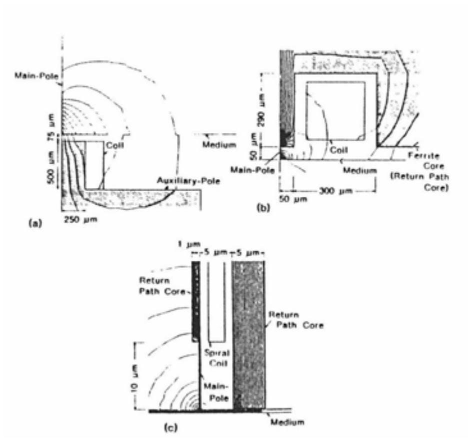

Fig. 3. Magnetic flux line distributions. (a) Auxiliary pole-driven head; (b) main pole-driven head; (c) thin film head with return path core on one side.

more than twice the efficiency of (a), the auxiliary pole-driven perpendicular head. This improvement in readout efficiency has been observed for actual heads as well [1]. An even higher readout efficiency of 46% was obtained for the thin film perpendicular head (c), with a return path core on one side. However, we see that half the flux leaves the medium on the side of the main pole on which there is no return path core. On the other hand, ring heads afford extremely high readout efficiencies compared with other heads--74% for the ferrite video head, and 83% for the thin film ring head.

These differences occur because the main pole films of perpendicular heads are thinner than the cores of ring heads by an order of magnitude or more, so that the magnetic reluctance of the main pole film is higher, adding to the tendency for flux to leak out from the path through the main pole film.

Hence, in order to improve the readout efficiencies of perpendicular heads, two measures are expected to be effective: (1) adoption of a construction with a closed magnetic circuit, with a small overall head size, enabling flux to pass more easily through the head; and (2) winding of the readout coil as close to the main pole tip as possible, so that flux can be detected before it leaks from the circuit.

III. Perpendicular Heads with High Readout Efficiencies

A. Methods for improving readout efficiencies

Specific methods for improving the readout efficiencies of perpendicular heads include the following. (i) A thin film head construction may be adopted, thereby miniaturizing the entire head. (ii) As the main pole-driven perpendicular head which the authors are using has the advantage of being very easy to fabricate, the same basic construction may be employed, but with a readout coil wound near the main pole tip in a hybrid configuration.

B. Thin film perpendicular heads with flanking return path cores

The construction of a perpendicular head adopting the above method (i) of improving the readout efficiency, appears in Fig. 4(a). This is a thin film head with a helical coil, and with return path cores positioned on both sides of the main pole film, in order to effectively capture the flux which, in the case of a thin film head with a single return path core, would leak away on the opposite side. The

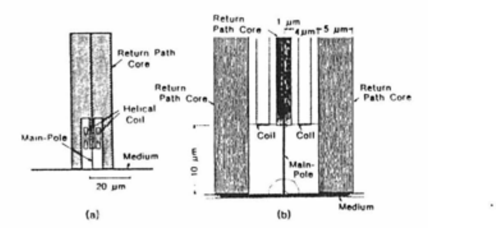

Fig. 4. Thin film head with return path core pieces on both sides of the main pole. (a) Head construction; (b) magnetic flux line distribution.

distribution of lines of flux during readout, as determined by FEM analysis, appears in Fig. 4(b). In this head, the amount of flux which in Fig. 3(c) returns directly from the side of the main pole to the medium can be reduced, so that a high readout efficiency of 88% is attained.

In order to actually construct such a head, the precision machining techniques used in fabricating thin film ring heads are necessary; and it cannot be denied that the fabrication processes involved are more complex than in the case of ordinary main pole-driven perpendicular heads.

C. Main pole-driven perpendicular heads with a thin film coil

On the other hand, when method (ii) is employed, an improvement in the readout efficiency can be expected. The head construction proposed here, and illustrated in Fig. 5(a), is based on a main pole-driven head [1], but in addition to the usual wire coil wound around the ferrite core, an additional thin film coil of helical shape is wound around the main pole film, for use exclusively in readout.

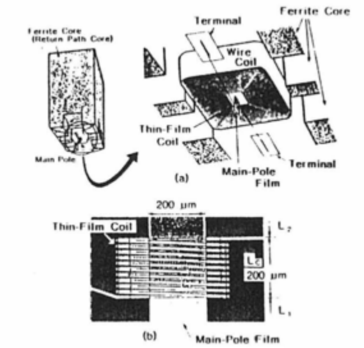

Fig. 5. Main pole-driven head with thin film coil wound around the main pole film. (a) Head construction; (b) photograph of main pole film and thin film coil.

We trial-fabricated one such head, and investigated the improvement in the readout efficiency. In the process of producing the main pole film of the head, photolithography was used to fabricate a helical-shape thin film coil around the main pole film, separated from the latter by an insulating layer. The resulting main pole film/thin film coil was bonded to the ferrite core of an ordinary main pole-driven perpendicular head with a 50-turn wire coil. The main pole film and thin film coil were fabricated as follows. After first fabricating the coil lower layer, the latter was flattened and then an insulating layer was formed on top; following this the main pole film was deposited. Another insulating layer was formed on top of this, and holes were then opened to connect the upper and lower coil layers. The main pole film was then subjected to anneal in a magnetic field, and finally, the upper coil layer was formed. Fig. 5(b) is a photograph of the main pole film and thin film coil of the prototype head. The pitch of the thin film coil is a large 20 µm, to facilitate head production; there are 10.5 coil turns, the coil length L_c is 200 µm, and the length L_2 from the coil to the ferrite core (the return path core) is 80 µm. The main pole film was of thickness 0.3 µm, and the track width was 200 µm; the film was of Co-Zr-Nb, with an anisotropy field H_k of 5 Oe and an initial permeability μ_i of 2500. The thin film coil material was copper, and SiO_2 was used as the insulator between the thin film coil and the main pole film.

This prototype head was used together with Co-Cr/Ni-Fe double-layer media in actual read/write experiments. Fig. 6 plots the ratio of the readout voltage from the thin film coil to that from the wire coil, normalized by the number of coil turns, against the distance L_1 from the main pole tip to the thin film coil. The solid line represents the measured results for the prototype head, and the broken line was obtained by FEM analysis, setting the initial permeability of the main pole film equal to 2500, in conformance with the parameters of the prototype head. While there is some difference between the measured and calculated results, we see that the readout efficiency of the thin film coil rises in comparison with that of the wire coil as the distance L_1 is decreased, the ratio of the two reaching 1.7 when L_1 is 10 µm, thus confirming that adding a readout coil to the main pole film does improve the readout efficiency.

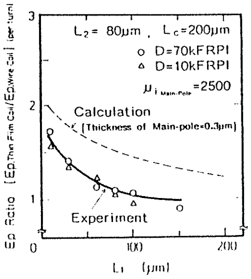

Fig. 6. Ratio of readout voltages vs distance L_1.

However, because the head trial-fabricated in this work has a large thin film coil pitch of 20 µm, the distance from the main pole tip to the ferrite core is at least 290 µm, and the absolute value of the readout efficiency of the thin film coil was 15 $nV_{0-p}/(\mu m\cdot(m/s)\cdot turn)$. The main pole-driven heads we are currently using mostly have a main pole length of from 50 to 100 µm. As the thin film coil of the head we are considering here is exclusively for use in readout, it should be possible to reduce the coil pitch to about 3.6 µm or so. If both L_1 and L_2 are 5 µm, then it would be possible to wind a 25-turn thin film coil about a main pole of length 100 µm. Moreover, the authors ordinarily use main poles with an initial permeability μ_i of about 5000. Under these conditions, FEM analyses reveal that the readout efficiency per turn of the thin film coil is 30%, or about double the efficiency of the wire coil.

IV. Readout Voltage from Perpendicular Heads

Fig. 7 shows measured values of the normalized readout voltage (normalized by the number of coil turns, speed and track width) for perpendicular heads discussed in the literature, versus the readout efficiency predicted by the above-described FEM analysis. In Fig. 7, the results are broadly divided according to the type of head, whether auxiliary pole-driven, main-pole driven, or thin film head with a return path core on one side. The solid circles and triangles are the results of measurements by the authors. We see that a relationship of proportionality, represented by the solid line, exists between the two. If we place on this straight line the readout efficiency of 88% predicted by FEM analysis for a thin film perpendicular head with dual return path core pieces, as well as the 30% predicted for a main pole-driven perpendicular head with a thin film coil wound round the main pole piece (the solid and empty stars respectively), then the normalized readout voltages are inferred to be 270 and 92 $nV_{0-p}/(\mu m \cdot (m/s) \cdot turn)$ respectively. The actual readout voltage from the coil will be proportional to these figures times the number of coil turns. If we assume that a thin film head with return path core pieces on both sides will have little space to accommodate the coil, so that the coil can only have about 20 turns or so, then the readout voltage becomes 5.4 $\mu V_{0-p}/(\mu m \cdot (m/s))$. On the other hand, a main pole-driven perpendicular head with thin film coil wound around the main pole piece may have 50 and 25 turns respectively in the wire coil and the thin film coil; hence the readout voltage when these two coils are cascade-joined will be 4.6 $\mu V_{0-p}/(\mu m \cdot (m/s))$. Hence, both these perpendicular heads can be expected to deliver essentially the same high readout voltage.

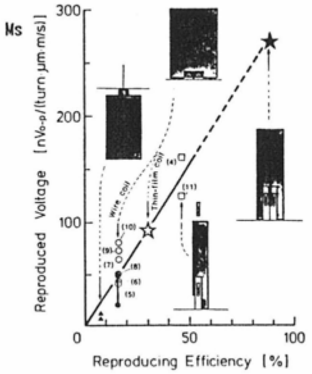

Fig. 7. Readout voltage at low densities vs. calculated readout efficiency (numbers in parentheses are reference numbers).

V. Conclusion

It was found that adoption of a miniaturized thin film head construction with a closed magnetic circuit design which includes return path core pieces on both sides of the main pole, is an effective means of greatly enhancing the readout efficiency of perpendicular heads. If such a head can be put into practical use, a high readout efficiency of nearly 90% can be expected.

On the other hand, when using conventional main pole-driven perpendicular heads, it was found that if the ferrite core is left as is, but a thin film coil exclusively for use in data reproduction is wound around the main pole film, then the thin film coil provides a per-turn readout efficiency double that of the wire coil. Such a head is easy to construct; moreover, if both the thin film coil and the wire coil are used together, a high readout voltage, essentially of the same magnitude as that obtained from the above thin film perpendicular head, can be expected.

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