T-MAG/25/5/1/32312

Flexible Magnetic Disk Image File System Using Perpendicular Magnetic Recording

Yoshihisa Nakamura
Setsuo Yamamoto
Hiromi Sakata
Shun-ichi Iwasaki

Reprinted from
IEEE TRANSACTIONS ON MAGNETICS
Vol. 25, No. 5, September 1989

FLEXIBLE MAGNETIC DISK IMAGE FILE SYSTEM USING PERPENDICULAR MAGNETIC RECORDING

Yoshihisa NAKAMURA, Setsuo YAMAMOTO, Hiromi SAKATA and Shun-ichi IWASAKI
Res. Inst. of Elec. Commun., Tohoku University, Sendai, JAPAN

Abstract *- The feasibility of application of perpendicular magnetic recording to a large capacity image file system has been investigated experimentally. It is predicted that the areal density of 3.3μm²/bit will be achieved for practical use at 100kFRPI and 1950TPI by introducing a sensitive single-pole type perpendicular head with a Fe-Si/SiO₂ multi-layered main-pole film and a durable Co-Cr/Ni-Fe medium with high squareness. The digital recording of still-pictures was tried by guardbandless recording with a flexible disk medium for which the durability over 10 million passes was ensured. It was confirmed that at present, the image data of 10MBytes can be recorded on one side of a 3.5-inch disk medium with bit error rate less than 1 x 10^{-5}.*

INTRODUCTION

We have already proved that perpendicular magnetic recording using a Co-Cr/Ni-Fe double-layer medium and a single-pole type perpendicular head possesses tremendous potential for high areal density recording [1,2, 3]. The potential shows that this recording technology is suitably applicable to a large capacity image file system in which enormous information must be recorded in a minute area of a disk medium.

In this paper, the feasibility of a large capacity magnetic disk system for digital image file recording is discussed, and the results of a trial to apply perpendicular recording to an image file system using a highly durable flexible disk is also described.

HIGH AREAL DENSITY RECORDING

Recording medium

The magnetic properties of a Co-Cr layer are improved by improving the crystalline orientation of a Ni-Fe underlayer because the Co-Cr layer grows epitaxially on the Ni-Fe underlayer in the sputtering process [4]. Fig.1(a) shows the M-H loops in perpendicular direction of the Co-Cr layer on the Ni-Fe underlayer. The loops (A) and (B) are for the media deposited by normal RF sputtering, and the loop (C) with the highest squareness is for the medium prepared by bias RF sputtering [5] to improve the crystalline orientation of the Ni-Fe and Co-Cr layers. Fig.1(b) shows the peakshift for NRZI 2-bit pattern versus recording density characteristics measured for the media

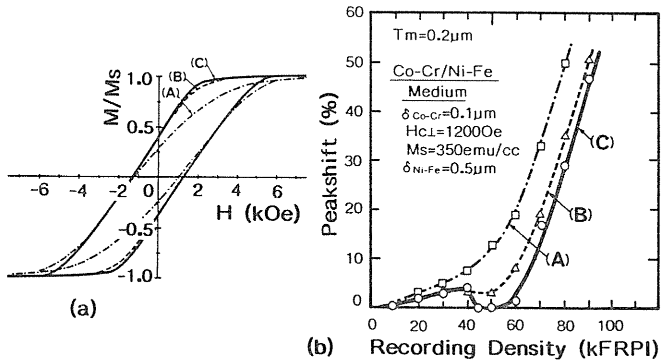

Fig. 1 *(a): M-H loops of Co-Cr layer on Ni-Fe underlayer. (b): Peakshift versus recording density characteristics.*

whose M-H loops are shown in Fig.1(a). It is found that the smallest peakshift is obtained for the medium (C) having the highest squareness.

Perpendicular magnetic head

Until quite recently, we used a Co-Zr-Nb film for the main-pole material because of its high saturation flux density (12.5kGauss). However we have developed a new main-pole material with a higher saturation flux density of 20kGauss [6]. The new main-pole is composed of four Fe-Si films stacked with three non-magnetic SiO_2 layers alternately to obtain a high permeability. Fig.2 shows the relationship between the recording density, D_{ps20}, at which the peak-shift reaches to 20%, and the overwrite value, which is defined as the reduction of the reproduced voltage of 40kFRPI signal after 90kFRPI signal is overwritten on the prior recorded 40kFRPI signal. Two heads with a 0.2μm thick main-pole were used in the measurement. The circles are for the head with a Fe-Si/SiO_2 main-pole, and the triangles are for that with a Co-Zr-Nb main-pole. In the hatched zones, the overwrite value less than -26dB is obtained. As the magneto-motive-force increases, not only the overwrite value but also the D_{ps20} are improved because the sharp magnetization transition is formed in a recording medium when the medium is magnetized strongly enough to saturate. The Fe-Si/SiO_2 multi-layered main-pole realizes saturation recording easily and can achieves a higher D_{ps20} than the Co-Zr-Nb main-pole.

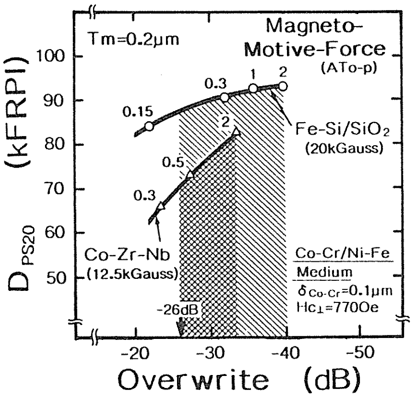

Fig. 2 *D_{ps20} versus overwrite value measured by perpendicular heads with Fe-Si/SiO_2 multi-layered main-pole and Co-Zr-Nb main-pole.*

High linear bit density characteristics

Fig.3 shows the bit-density response curve (open circles) and the peakshift versus recording density characteristics (solid circles). In this measurement, a perpendicular head with Fe-Si/SiO_2 multi-layered main-pole of 0.2μm in thickness was used with a Co-Cr/Ni-Fe medium with a high squareness Co-Cr layer. The signals were reproduced up to 640kFRPI, and D_{50} and D_{50}^* were 125kFRPI and 170kFRPI respectively, where D_{50} is the recording density at which the reproduced voltage becomes a half of that at low densities, and D_{50}^* is defined as the D_{50} on the envelope connecting the maxima of the reproduced voltage in the bit-density response curve. In this measurement, the peak shift was less than 20% up to 100kFRPI.

Side fringing effects

We have already found that the recorded magnetization transition at the track edge in the transverse direction is very sharp, and the recorded trackwidth almost coincides with the trackwidth of a main-pole used in recording. It was also found that the cross-talk in reproduction is small in perpendicular recording compared to longitudinal recording [2].

Fig.4(a) shows the displacement curves measured with the three heads with trackwidth of 100μm, 48μm and 12μm at 63.5kFRPI. The displacement curve shows the reduc-

0018-9464/89/0900-3372$01.00©1989 IEEE

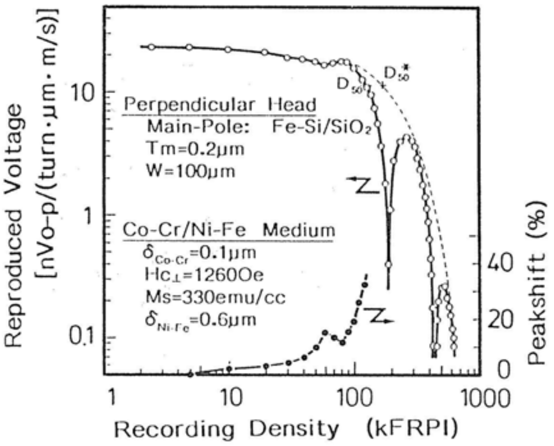

Fig. 3 Bit-density response curve (open circles) and peakshift versus recording density characteristics (solid circles) measured by perpendicular head with 0.2μm thick Fe-Si/SiO2 main-pole.

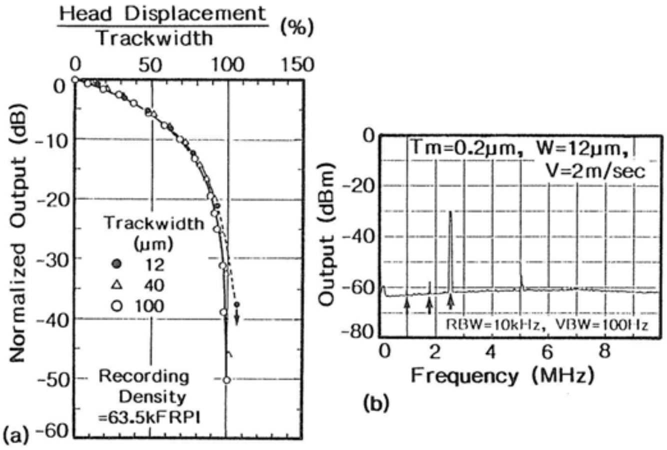

Fig. 4 (a): Displacement curves for perpendicular heads with trackwidth of 12μm, 48μm and 100μm.
(b): Frequency spectrum of reproduced signal in narrow track recording. Trackpitch is 12.5μm with including guardband width of 0.5μm.

tion of reproduced output as a function of the displacement of a reproducing head with respect to the recorded track. Greater reduction in reproduced output for a given head displacement indicates less crosstalk. In this figure, the head displacement was normalized by the trackwidth of each head. The heavy solid curve for the trackwidth of 100μm and 48μm shows that the contribution of a side-reading to the reproduced voltage is negligibly small. However the heavy broken curve for the trackwidth of 12μm shows that the output of -29dB remains when the head is in complete off-track (i.e. at head displacement of 100%) because of the side-reading effect. Therefore, the crosstalk in reproduction is not negligible for the trackwidth less than about 12um. Fig.4(b) shows the frequency spectrum of 63.5kFRPI (2.5MHz) signal reproduced by the head with trackwidth of 12um when the 25.4kFRPI(1.0MHz) and 45.7kFRPI (1.8 MHz) signals were also recorded on the neighbouring tracks with a guardband of 0.5μm in width. The C/N was 27dB, here C is defined as the amplitude of 63.5kFRPI signal and N is that of crosstalk of 45.7kFRPI component. When the guardband width was increased to 1 μm, the C/N was more than 30dB, which is large enough to perform the digital recording.

High areal density recording

As described above, the linear bit density which gives peakshift less than 20% exceeds 100kFRPI and the narrow track recording with a trackpitch of 13μm including a guardband width of 1μm gives a C/N of over 30dB. Therefore, we conclude that the high areal density of 3.3μm^2/bit can be expected for a practical use at a linear bit density of 100kFRPI and a trackpitch of 13μm by using a sensitive single-pole type perpendicular head with a Fe-Si/SiO$_2$ multi-layered main-pole and a medium with a high squareness if only the sufficiently high C/N is obtained in such a narrow track recording. With respect to C/N, Numazawa et al. have already proved that the main-pole driven type perpendicular head with a 3.8μm trackwidth gives C/N of 22.5 dB(rms/-rms) which is large enough to perform digital video recording [7].

APPLICATION TO IMAGE FILE SYSTEM

Specifications

A large capacity disk drive system was built as a trial experiment for a image file recording. The disk drive has a function to exchange the data with a 16-bit desktop host computer through a SCSI interface at a data transfer rate of 5Mbits/sec. As the encoding scheme, modified frequency modulation (MFM) was used. The reproduced signals through the low-pass filter with cutoff frequency of 7.5MHz was detected by peak detection. The function of error correction was not utilized to evaluate the raw performances of recording and reproducing. Table 1 shows the geometrical dimensions and the magnetic properties of the main-pole driven single-pole type perpendicular heads and the 3.5-inch Co-Cr/Ni-Fe double-layer flexible disk medium loaded in this system. The medium had a protective overlayer to ensure the durability more than 10 million passes and was supported by the inner and outer carbon rings in a hard plastic disk cartridge [8]. Additionally, the clean air passed through an air filter was splayed around the head to remove the dust.

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

PERPENDICULAR MAGNETIC HEAD	3.5-INCH FLEXIBLE DISK MEDIUM
(a) Main-pole (Co-Zr-Nb)	Co-Cr Layer
Thickness: 0.3 μm	Thickness: 0.14 μm
Trackwidth: 48 μm	Coercivity: 530 Oe (perpen.) 370 Oe (in-plane)
Bs: 12.5 kGauss	Magnetic Anisotropy: 2.2 kOe
Coil: 50 turns	Ni-Fe Underlayer
(b) Main-pole (Fe-Si/SiO$_2$)	Thickness: 0.47 μm
Thickness: 0.2 μm	Coercivity: 1.2 Oe
Trackwidth: 100 μm	Protective Layer
Bs: 20 kGauss	Thickness: 0.021 μm
Coil: 50 turns	

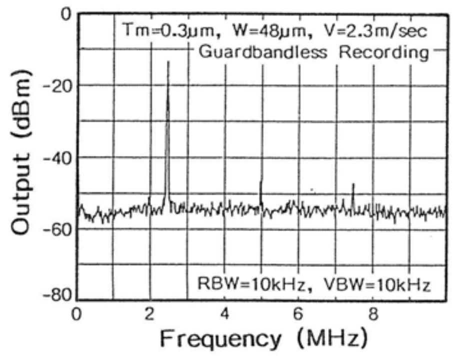

Fig. 5 Frequency spectrum of reproduced signal when guardbandless recording was performed with perpendicular head of 48μm in trackwidth.

Track density

As described above, in principle, the track density is easily increased in perpendicular recording. Therefore, the influence of the crosstalk from the adjacent tracks was measured prior to recording of still-picture. After the signals of 22.1kFRPI (1MHz), 44.2kFRPI (2MHz) and 55.2kFRPI (2.5MHz) were recorded on the neighbouring three tracks without guardband, the head was positioned on the central track in reproduction. Fig.5 shows the frequency spectrum of the reproduced signals. It is found that the crosstalk from the adjacent tracks is so small that the C/N of 40dB is obtained, here C is defined as the amplitude of 22.1 kFRPI signal and N is for that of 44.2kFRPI component. If we suppose that the recorded data can be demodulated without error when this C/N is larger than 26dB similarly to overwrite, it was found that the tracking error less than 1 μm is permissible and is within the positioning accuracy of this system. Therefore, the digital recording of still-picture was performed without guardband.

Linear bit density

The influences of peakshift and C/N on the bit error rate were measured to clarify the criterion of operation in this system. In the measurement, the peakshift for NRZI 2-bit pattern was varied with changing a bit density, and C/N was changed by adding a white noise to the reproduced signal at the input terminal of a reproducing amplifier. In Fig.6, the contour lines of bit error rate of 10^{-2} and 10^{-5} are drawn with light solid lines. In the hatched zone, the bit error rate less than 10^{-5} is obtainable. Based on these results, the linear bit density and the track width in the still-picture recording were set. The heavy solid lines show the raw peakshift and C/N measured with changing bit density. The bit error rate less than 1×10^{-5} was obtained at 65kFRPI by using a perpendicular head with a main-pole of 0.2μm in thickness and 100μm in track width. The same bit error rate was also obtained at 50kFRPI by using a head with with a main-pole of 0.3μm in thickness and 48μm in trackwidth.

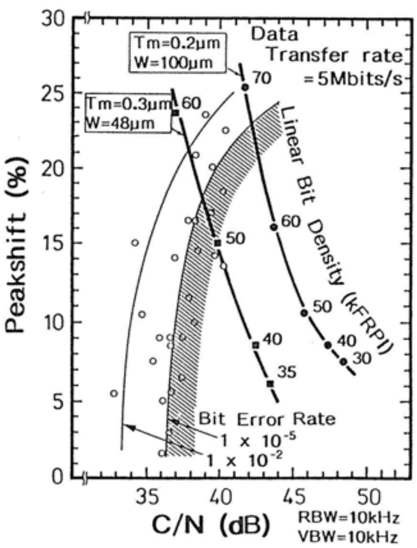

Fig. 6 Effects of peakshift and C/N on bit error rate (light solid line), and peakshift and C/N measured with varying recording density (heavy solid lines). In hatched zone, error rate less than 1×10^{-5} is achievable.

Digital recording of still-pictures

We tried to record the 8-color graphics displayed on the monitor of the desktop computer by guardbandless recording. The quantity of information of a color image is about 100kBytes (640 lines x 400 dots x 3 bits for color). Fig.7 shows an examples of the reproduced picture. In this experiment, a perpendicular head with trackwidth of 100μm was used at the 2F density of 65k FRPI. No error is found in this picture, and the bit error rate was estimated to be less than 10^{-6}.

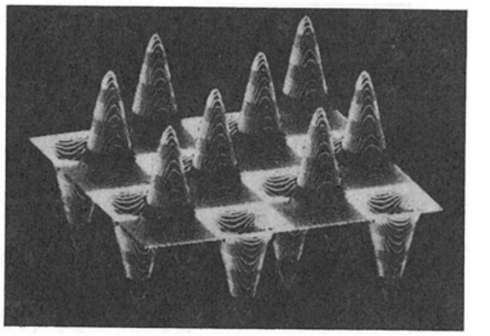

Fig. 7 An example of reproduced picture.

We have also succeeded in still-picture recording by using the head with the track width of 48μm at 50k FRPI. The unformatted capacity of this image file system on these conditions is estimated to be about 10 MBytes per surface of a 3.5-inch flexible disk.

CONCLUSIONS

We have developed the single-pole type perpendicular head with the 0.2μm thick Fe-Si multi-layered main-pole and found that the perpendicular medium with Co-Cr layer of high squareness realizes high density recording. It is predicted that the areal density of $3.3 \mu m^2$ /bit will be achieved for practical use at linear bit density of 100kFRPI and track density of 1950TPI if the combination of this perpendicular head and this medium is introduced. In this case, the estimated unformatted capacity is 80MBytes per surface of the 3.5-inch disk medium.

Currently, we have confirmed experimentally that the image file system with the recording capacity of 10MBytes per surface of 3.5-inch flexible disk can be realized by using the highly durable medium and the perpendicular head with bit error rate less than 1×10^{-5}.

We would like to express our appreciation to Mr. G. Ishida in Fujitsu Limited, Mr. Y. Miura in Fujitsu Laboratories Ltd. and Mr. S. Hanabusa in Fujitsu Automation Ltd. for their assistance to construction of the disk drive system. Acknowledgment is also due to Mr. S. Kadokura in Teijin Ltd. for supplying the durable flexible disk media. And we wish to thank to our colleagues: Dr. K. Ouchi and Mr. S. Tadokoro for fabricating the disk media, and to Mr. I. Watanabe and Mr. N. Tani for preparing the perpendicular heads.

REFERENCES

[1] S. Yamamoto, Y. Nakamura and S. Iwasaki, IEEE Trans. Magn., MAG-23, 5, 2070-2072 (1987).

[2] S. Iwasaki, Y. Nakamura, S. Yamamoto and K. Yamakawa, IEEE Trans. Magn., MAG-19, 5, 1713-1715 (1983).

[3] Y. Nakamura and I. Tagawa, IEEE Trans. Magn., MAG-24, 6 2329-2334 (1988).

[4] S. Iwasaki, K. Ouchi and N. Honda, Digest of Tohoku Regional Branch Joint Convention of the Electrical engineers and Related Societies, 1F-6, p.250 (1979) (in Japanese).

[5] J. S. Logan, IBM J. Res. Develop. 172-175 (1970).

[6] N. Tani, Y. Nakamura and S. Iwasaki, Report of Technical Group on Magnetic Recording, MR88-47, 45-52 (1988) (in Japanese).

[7] J. Numazawa, Y. Yoneda, F. Aruga and T. Horiuchi, 1988 Spring National Convention Record, The Institute of Electronics, Information and Communication Engineers of Japan, C-20, 2-20 (1988) (in Japanese).

[8] M. Yamaura, T. Yatabe, H. Matsuzawa, S. Kadokura and S. Sobajima, IEEE Trans. Magn., MAG-22, 5, 349-351 (1986).