

## HEAD-TO-MEDIA SPACING LOSSES IN PERPENDICULAR RECORDING

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**Abstract** - The perpendicular recording process is essentially demagnetization-free at high bit densities, and the head-to-medium spacing losses become perhaps the most constraining factor in realizing the ultimate capabilities of this technology.

In this study we investigated the recording losses resulting from head-to-medium spacing for a double layer medium using a single-pole head and a narrow gap ring head. The spacing was introduced by sputtering Ti overlayers onto the CoCr film in the range of 0.02 microns to 0.18 microns. The recording experiments were performed using a tape deck and a closed tape loop running at low speed.

For a spacing  $d$  and a wavelength  $\lambda$ , the spacing loss when writing and reading with the single pole head was found to be  $-99d/\lambda$  (dB) for any bit density up to 4Kb/mm (kilobits per mm). The spacing losses for the ring head, however, depend on bit density, and are much larger at lower bit densities. In an attempt to separate the writing from the reading spacing losses, we recorded with the single pole head and read back with the ring head. The results of this experiment show that the large spacing losses observed with a ring head at the lower bit densities are primarily incurred during the writing process.

## INTRODUCTION

In longitudinal recording, the read spacing loss calculated by Wallace<sup>1</sup> is  $-55 d/\lambda$  (dB). A recent estimate of the write spacing loss by Bertram and Niedermeyer<sup>2</sup> places it at  $-44 d/\lambda$  (dB). Therefore, in longitudinal recording, the total recording (write/read) spacing loss is  $-99 d/\lambda$  (dB).

For perpendicular recording, Dugas et al<sup>3</sup> performed a large scale model experiment employing a probe head and observed spacing losses comparable to the above for writing and for reading at a given head-to-tape spacing. However, when a narrow gap ring head was used by Tatsuta<sup>4</sup> to write and read on a rigid disk coated with a CoCr layer, significant problems were encountered in the writing process (poor overwrite characteristics). By varying the speed of the disk, Tatsuta was able to vary the flying height over the range 0.065 microns to 0.15 microns, and to measure the reproduced signal vs bit density response over this range of flying heights. If we analyze this data we find enormous spacing losses of several hundred dB per wavelength increase in head-to-disk spacing, particularly at the lower bit densities. Furthermore, a recent theoretical analysis by Middleton and Wright<sup>5</sup> concluded that the magnetization transition lengths are much stronger functions of head-to-medium spacing for the case of a ring head and a perpendicular anisotropy medium than for either of the cases of a single pole head and a perpendicular aniso-

tropy medium or a ring head and a longitudinal anisotropy medium.

In this study we conducted an experimental investigation of head-to-medium spacing losses in perpendicular recording employing a double layer medium with a single pole head and a narrow gap ring head.

## DESCRIPTION OF EXPERIMENT

The experiments were performed on a Teac recorder modified to run as a closed loop system using 0.635 cm wide tape, with a writing speed of 4.75 cm/s and a reading speed of 9.5 cm/s. The double layer film was deposited by sputtering onto a 50 micron PET base. The underlayer NiFe film had thickness of 0.4 microns, saturation magnetization ( $M_s$ ) of 700 emu/cc, and easy axis coercivity of 0.3 Oe. The hard magnetic layer of CoCr had thickness of 0.29 microns,  $M_s$  of 500 emu/cc, perpendicular coercivity of 980 Oe, anisotropy field ( $H_k$ ) of 3.7kOe, and easy axis dispersion ( $\Delta\theta_{50}$ ) of 9.6°.

The head-to-medium spacing was introduced by sputtering different overlayers of Ti over the CoCr film, of thickness 0.02 microns, 0.05 microns, 0.1 microns, and 0.18 microns. Several different single pole heads of sputtered CoZr were used with main pole thickness of 0.3 microns, 0.6 microns, and 1.0 microns. From the null in the output signal vs bit density response, the corresponding effective main pole thickness was 0.7 microns, 0.89 microns and 1.43 microns, respectively. All were auxiliary pole driven, had a track width of 2mm, used 100 turns for writing and 500 turns for readback and gave comparable results. The ring head was made of hot pressed MnZn ferrite, with a gap of 0.3 microns, track width of 0.5 mm, and 100 turns for writing and reading. Square wave recording was performed, optimized at short wave lengths. At the optimum write current, the deep gap field was estimated to be under 60% of the saturation induction of the ferrite core material; consequently, no significant pole tip saturation should occur.

In this experiment we measured the combined write/read spacing loss since the overlayer was placed on the medium. In a follow-up experiment we plan to deposit the overlayers on the heads so that we can separate the writing losses from the reading losses.

## EXPERIMENTAL RESULTS

The write current response was obtained for each value of the separation parameter  $d$  and for a number of different recording densities. Typical results are shown in Figs. 1 and 2 for the single pole (SPT) head and the ring (RT) head, respectively.

Some recording demagnetization with increasing write current was observed for the ring head, and the writing MMF was set to minimize this effect at each value of head-to-medium separation.

The frequency response curves for the different head-to-medium separations are shown in Figs. 3 and 4 for a single pole head with 0.9 micron shim thickness and a ring head with 0.3 micron gap length, respectively.

Manuscript received April 15, 1983

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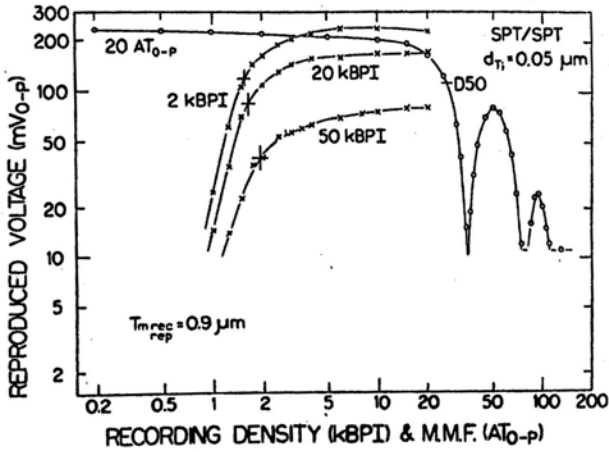


Fig. 1. Output signal vs write current (x) and bit density (o) for single pole head at a spacing of 0.05 microns.

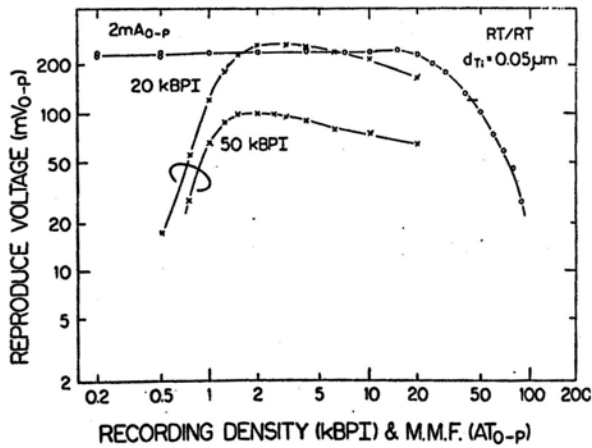


Fig. 2. Output signal vs write current (x) and density (o) for ring head at a spacing of 0.05 microns.

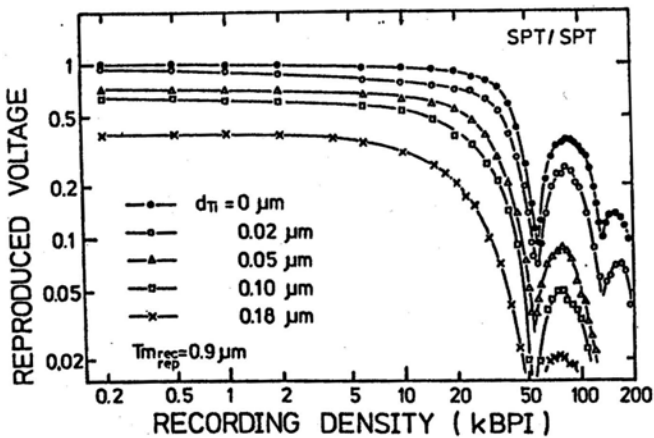


Fig. 3. Bit density response of single pole head with spacing as a parameter.

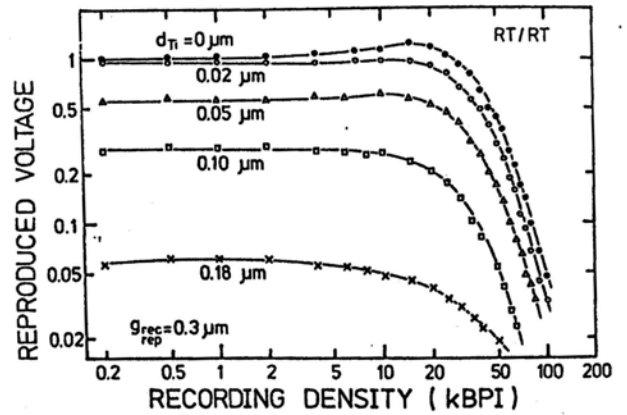


Fig. 4. Bit density response of ring head with spacing as a parameter.

From these results we computed the reduction in output signal at each spacing normalized to the output signal at zero spacing. For the single pole head, the spacing loss in dB as a function of the parameter  $d/\lambda$  is a straight line of the form  $-99 d/\lambda$  (dB), as shown in Fig. 5.

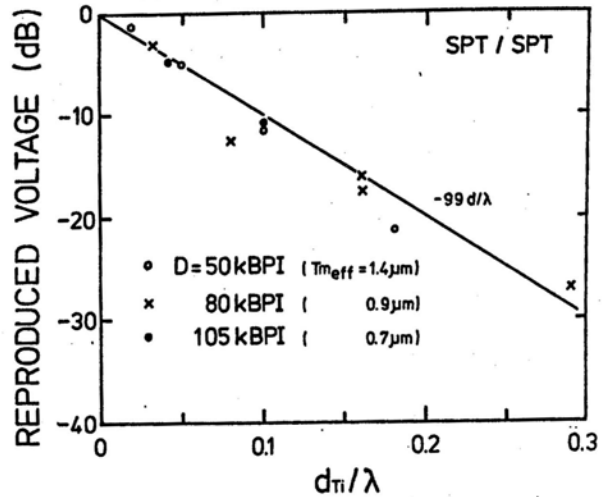


Fig. 5. Spacing loss vs  $d/\lambda$  for the single pole head.

For the ring head, however, the spacing loss depends on bit density and it is much larger at the lower bit densities, as shown in Fig. 6.

As additional confirmation of the large spacing loss observed for the ring head, we repeated the experiment with a different ring head and obtained very similar results.

It was not possible in this experiment to separate the writing from the reading spacing losses because the Ti overlayers were deposited on the recording media. However, in an attempt to gain some insight regarding the large differences in spacing losses between the single pole head and the ring head, another experiment was performed writing with the single pole head and reading with the ring head, and the results are shown in Fig. 7.

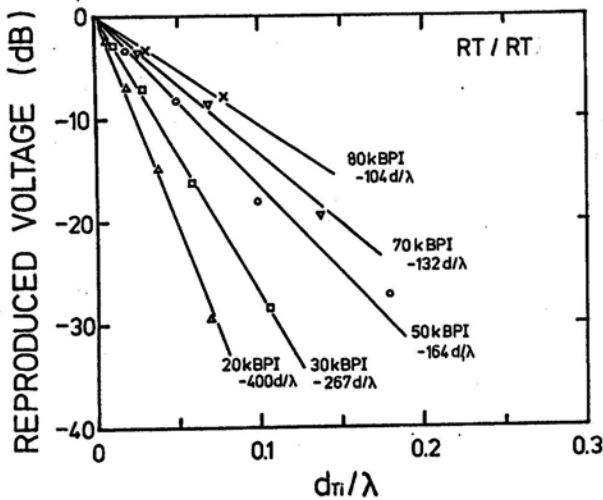


Fig. 6. Spacing loss vs  $d/\lambda$  for the ring head.

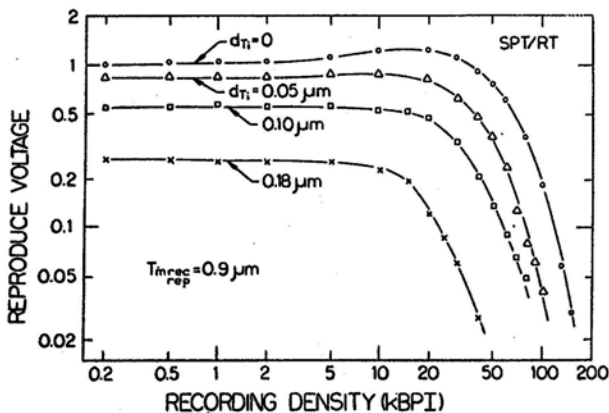


Fig. 7. Bit density response writing with a single pole head and reading with a ring head.

#### DISCUSSION AND CONCLUSIONS

Comparing the results of Figs. 5 and 6, it is clear that the spacing losses with the single pole head are smaller than the losses with the ring head at all spacings and frequencies, and this difference becomes increasingly larger as the bit density decreases. Since it is known that the ring head is very good for reading, we attribute the major part of this large spacing loss to the difficulty of writing with a narrow gap ring head on perpendicular anisotropy media. This conclusion is supported by considering the results of Fig. 7 and comparing them with the results shown in Figs. 3 and 4. The spacing losses when writing with a single pole head and reading with a ring head are a lot closer to the spacing losses of the single pole head than to the spacing losses of the ring head, confirming the conclusion that the main problem is introduced during the writing process with the ring head.

The large write spacing losses of the ring head result from the poor vertical field gradient and the rapid decrease of the vertical field with spacing. Theoretical simulations by Beardsley<sup>6</sup>, and experimental measurements of the depth of penetration of a ring

head field into a perpendicular anisotropy medium by Yamamoto and Kobayashi<sup>7</sup>, clearly point to the difficulty of writing with a ring head. Since the vertical field of the ring head is inadequate to write through the entire thickness of the CoCr layer, large demagnetization losses at the lower bit densities would result. Increasing the head-to-medium separation would greatly aggravate this effect.

Furthermore, at short wavelengths the demagnetizing field of the previous bit aids the head field in writing the next bit, but at longer wavelengths this aiding effect decreases rapidly.

The effectiveness of the ring head in producing a high degree of perpendicular magnetization is a strong function of the magnitude of the anisotropy field  $H_k$  of the CoCr layer<sup>8</sup>. Furthermore, the vertical coercivity, the thickness of the CoCr layer, the gap length, and the presence or not of the soft magnetic back layer will also influence the ring head performance, and we expect to investigate these effects in future studies.

In a model of the reading process for a ring head and a perpendicular medium of thickness  $\delta$ , Bloomberg<sup>9</sup> derived a read spacing loss of the form  $\sinh k\delta/\sinh k(d+\delta)$  which is not Wallace-like, and in the limit of long wavelengths predicts that the log of the output vs  $d/\lambda$  varies linearly with  $\lambda$ , as the results of Fig. 6 also indicate. However, the slopes are very different as a result of the writing deficiencies of the ring head.

The single pole head is superior to the ring head with regard to the losses resulting from head-to-medium separation. The single pole head produces a sharp transition in the vertical magnetization of the recording medium, whereas the ring head encounters considerable difficulty in switching through the recording medium and in producing sharp magnetization transitions<sup>10</sup>.

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