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To : Distribution
Subject: **Evaluation of Phase-2, Part-1 Heads for the Thin-Film MR Head Project: Triple-Flat Assembly Contour Geometry Qualification Tests**

Abstract

The main tests of a partial prototype head assembly for Phase-2, Part-1 has now been completed. A triple bar assembly with flat contour design have been tested with the "thin" tape. These tests show that the interface provides robust head-to-tape contact for 0.25-8 m/s (10-320 ips) tape speed, under 0.88 – 3.52 N (4 – 16" H_2O vacuum) of tape tension in the Metrum transport. The contact is shown to be robust in both directions. Wrap angles of 0.8^o-1.5^o have been tested successfully. The tests also show a small increase with speed of a nearly white non-magnetic running noise. Assuming white electronic noise, this is currently attributed to frictional heating of the MR element. There is also a smaller but significant apparent increase in MR response with increasing speed.

1. Introduction

The main tests of Phase-2, Part 1 prototype head assembly have now been completed with excellent results that qualify the prototype contour geometry for implementation. In a previous memo the evaluation of Phase-1 dual-flat head assembly was reported [1]. Those tests had shown that a 0.56 mm wide flat bar with 2.5^o wrap angles has some difficulties in providing robust contact. Tests conducted here show that the wider 1.5-mm flats and somewhat smaller 1.5^o corner wrap angles of the new triple-flat head assembly, provide robust head-to-tape contact under a wide range of conditions. A schematic depiction of the geometry of the triple-flat head assembly can be seen in Figure 1.

Eight Phase-2, Part-1 prototype subassemblies were delivered in October 1998. In these heads:

- The write track width is X μm, the read track width is Y μm, the write-gap length is 1 μm, and the heads have MR read elements. As reported before, the relatively long write-gap length causes 6 dB recorded signal loss at band-edge (0.9 μm) relative to a VLBI head

writing a thin VLBI tape [1]. The write characteristics of these heads have not yet been tested.

- There is an 80-100 nm of pole-tip recession caused by initial flat lapping process. This results in a 6-dB signal loss at the band-edge wavelength 0.9 μm.

- While most channels in each bar are electrically good, each bar has a few read and/or write elements with open circuit, abnormal resistance, or short circuit between MR element and a shield.

The heads on each one-inch long bar are clustered at islands composed of Z heads. The island pitch necessitates a head-assembly consisting of three one-inch long bars containing 80 heads altogether, in order to utilize the one-inch tape span efficiently. Therefore, the triple-bar, flat head assembly shown in Figure 1 has been implemented. An extensive effort has been spent on mechanical work to design, build, and learn to use precision assembly and alignment tools and mounting modifications. The assembly was mounted in a Metrum tape drive, in place of a standard VLBI head-stack. The tests were made with a 15 μm thick Quantegy tape under 4, 5, 10 and 16" of water vacuum pressure (0.88-3.52 N) running in the speed range 10-320 ips (~0.25-8 m/s)

In what follows, Section 2 shows the results verifying speed insensitivity of the head-tape spacing. This section also shows that a small and nearly white, non-magnetic running noise, exists in the tape-noise-to-electronic-noise (TN/EN) spectra. Sections 3 and 4 show the results of direction, wrap, and tension insensitivities. Finally the appendix gives a summary of the method used to evaluate the read performance.

2. Speed Insensitivity

An increase in the head-tape spacing Δh, causes a loss L in the signal-to-noise ratio of the read-back signal. This loss is linearly proportional to Δh and inversely proportional to the wavelength λ of the signal, and it is calculated from the Wallace formula,

$$L = 55\ \Delta h/\lambda \text{ (dB)}.$$

Appendix 1 gives a brief explanation of the measurement technique used to determine spacing change. Measurements based on this technique show that; **no significant spacing change with speed from 10 to 320 ips can be inferred from either tape noise or read signal spectra.** A change of 4 nm, corresponding to ¼ dB difference at 0.9 μm wavelength, would have been detected.

2.1 Detection of a Small, Nearly Wavelength Independent Noise

Neither signal nor tape-noise-spectra scale as expected. As explained in Appendix 1, in the simplest model, the tape-noise to electronic-noise (TN/EN) or the signal to electronic-noise (S/EN) ratios are expected to increase by 3 dB for each halving of the tape speed. Instead, the

tests show a change of approximately 2 dB per each halving of the tape speed, nearly independent of wavelength.

Figures 2 and 3 show the difference of the S/EN and TN/EN spectra between 10 and 160 ips, (~0.25-4 m/s), respectively. The horizontal axes of these figures span the wavelength $\lambda = V/f$ range of 8-0.8 μm. In both of these figures the thicker line represents the $\Delta(s/N)_{10\text{-}160}$ between the two speeds, where "s" stands for either signal S or tape-noise TN. In Figure 2, it is seen that $\Delta(S/EN)_{10\text{-}160}$ changes between 10 and 11 dB, over the 4-1 μm (62-280 kHz at 0.254 m/s) range, respectively. Similarly in Figure 3, the $\Delta(TN/EN)_{10\text{-}160}$ variation is only 9.5±0.3 dB over the same range. The $\Delta(S/EN)_{10\text{-}160}$ and $\Delta(TN/EN)_{10\text{-}160}$ noise values measured here deviate 1.5 and 2.5 dB, respectively, from the expected 12-dB power loss[1]. The measurements from Figures 2 and 3 are summarized in Table 1.

The deviation of the measurements from the expected 12 dB, indicated by the symbol $\delta_{V1\text{-}V2}$, cannot be attributed to spacing loss. As indicated by the Wallace formula, a spacing change produces a spectrum difference which is linearly proportional to the wavenumber $\nu = 1/\lambda$. The data is inconsistent with such dependence. A closer look at the data can be found in Tables 2 and 3 where the deviations per octave of tape speed as a function of wavelength is given. The deviation is defined as follows,

$$\delta_{V1\text{-}V2} = \{\Delta(s/EN)^{exp.}_{V1\text{-}V2} - \Delta(s/EN)^{meas.}_{V1\text{-}V2}\} / \{\log_2 (v2/v1)\} \quad \text{[dB/(speed octave)]}$$

$$\text{for } V2>V1,$$

where V1 and V2 indicate the tape velocities, and the expected a speed dependence of s/EN is,

$$\Delta(s/EN)^{exp.}_{V1\text{-}V2} = 3 \text{ x } \log_2 (v2/v1).$$

Tables 2 and 3 show that,

- Deviation $\delta_{V1\text{-}V2}$ is significantly wavelength-dependent for S/EN, but not for TN/EN. The extra noise is therefore not purely additive in nature; that is, it may have a multiplicative component.

- The S/EN deviation is larger at smaller wavenumbers, but <u>not</u> proportional to wavenumber as must be the case for a spacing change.

- Neither S/EN nor TN/EN deviations significantly depend on the speed ratio.

At this point, this nearly white running noise is attributed tentatively to frictional heating of the MR element. Some thermal effects due to asperity contact are reported in the hard-disk literature. More work on investigating this effect is necessary. The assumption of white electronic noise made throughout this analysis also needs to be more vigorously checked.

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[1] As explained in the Appendix, four octaves in speed change for 3dB/octave gives 12 dB total change.

3. Direction and Wrap Insensitivity

No difference in tape noise spectrum or read signal spectrum between forward and reverse tape motion was detected from 10 to 320 ips. This is in spite of fairly large known corner wrap angle variations in this assembly. One tested bar has one corner wrapped only 0.8 degrees, that is, about half the design value.

4. Tension insensitivity

Neither the tape noise spectrum nor read signal spectrum depends on tension. These were measured at 0.88, 1.1, 2.2 and 3.52 N tension (4, 5, 10 and 16" vacuum) at 10 to 320 ips. Audible noise, probably due to stick-slip on the wide contact area over the triple bar assembly, was noted when the tension was increased to about 18” vacuum.

Reference

[1] Hinteregger, H.F. “Progress Report on Thin Film Head Development - (as of 7 April 1998),” M.I.T. Haystack Observatory, Westford, MA, January 14, 1999.

	Expected	Measured	
ν (μm^{-1}) / λ (μm)	$\Delta(s/EN)_{160\text{-}10}$ (dB)	$\Delta(S/EN)_{160\text{-}10}$ (dB)	$\Delta(TN/EN)_{160\text{-}10}$ (dB)
1.00 / 1	12	11	9.5
0.50 / 2	12	10.5	9.8
0.25 / 4	12	10	9.2

Table 1. The measurements of the change in signal-to-noise ratio when the speed is changed from 160-10 ips as a function of wave number ν and wavelength λ.

	Measurements					Average of Columns 1-4
ν (μm^{-1}) / λ (μm)	$\delta_{10\text{-}20}$	$\delta_{20\text{-}40}$	$\delta_{40\text{-}80}$	$\delta_{80\text{-}160}$	$\delta_{10\text{-}160}$	$\delta_{10\text{-}160}$
0.25 / 4	1.0	0.5	0.7	0.8	0.7	*0.75*
0.50 / 2	0.4	0.5	0.7	0.7	0.55	*0.58*
1.00 / 1	0.8	0.7	0.3	0.8	0.63	*0.65*

Table 2. The deficit δ values between expected and measured **TN/EN** noise values at the speeds indicated as subscripts, as a function of wave number ν and wavelength λ.

ν (μm^{-1}) / λ (μm)	$\delta_{20\text{-}80}$	$\delta_{10\text{-}160}$
0.50 / 2	0.5	0.38
1.00 /1	0.25	0.25
1.50 / 0.66	0	-

Table 3. The deficit δ values between expected and measured **S/EN** noise values at the speeds indicated as subscripts, as a function of wave number ν and wavelength λ.

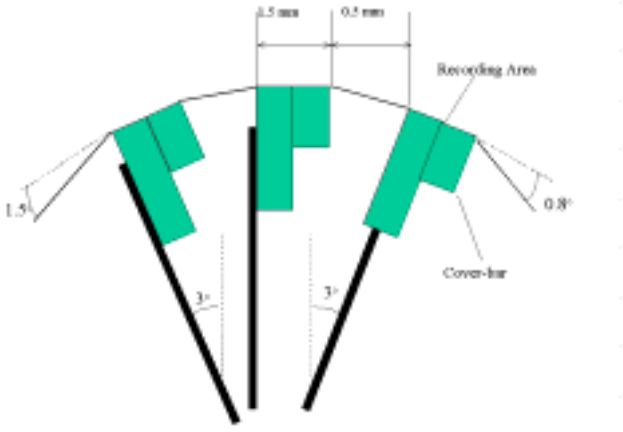


Figure 1. Schematic depiction of the triple-bar assembly**.**

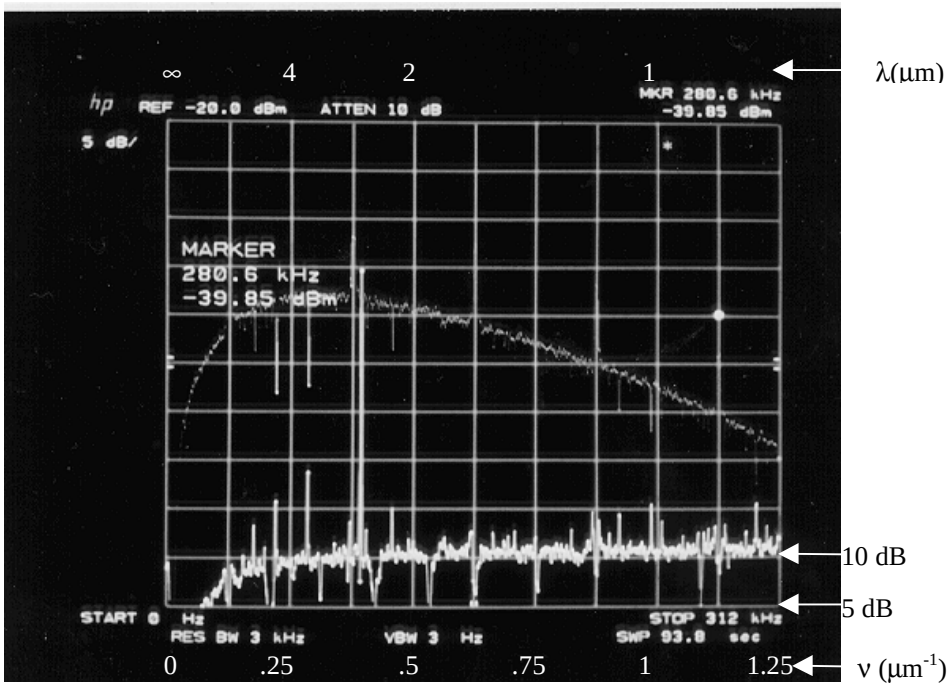


Figure 2. The difference of the S/EN power spectra of 160 ips and 10 ips. Note that the thicker line represents the S/ER difference. The horizontal axis is linear in wavenumber, using $\nu=1/\lambda = f/V$, where V = 0.254 m/s (10 ips).

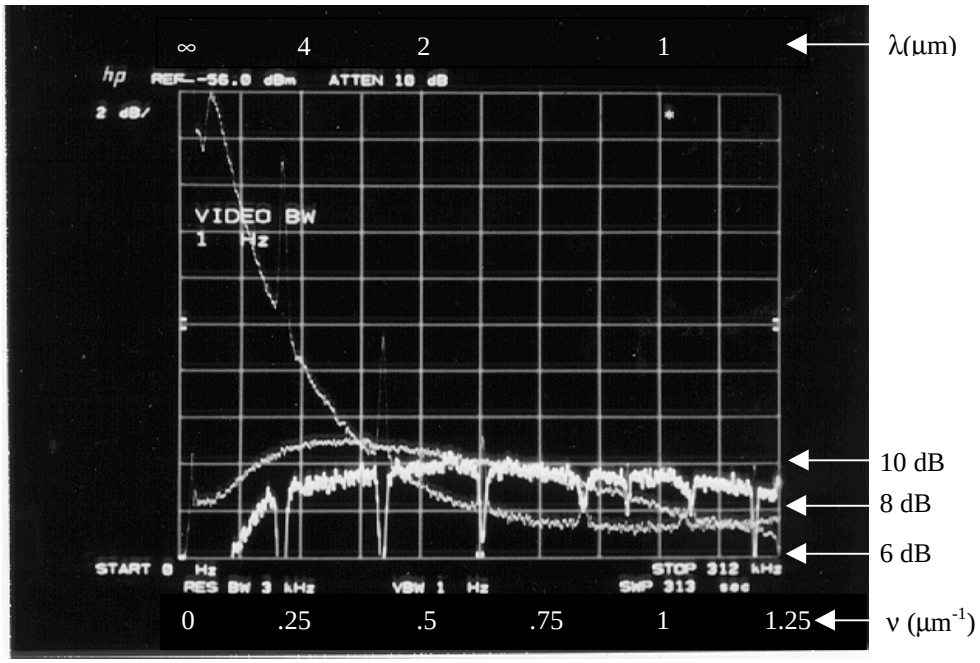


Figure 3. The difference of the TN/EN power spectra at 160 ips, 10 ips. Note that the thicker line represents the TN/NR difference.

Appendix: Evaluation of the Read Performance

An MR head is a magnetically sensitive resistor. When a constant "sense" current is passed through the MR element moving over a variable magnetic field, changes in its resistance are detected as voltage changes. As such, the response of an MR element is independent of tape speed. Electronic noise is inherent to all circuits and it also is independent of tape speed.

Electronic noise is dominated by the resistance of the MR element and is assumed to be perfectly white over the entire range of frequencies in this analysis. Data at frequencies where this assumption is clearly violated due to electronic interference are not used, but low-level broadband interference may still be a small source of systematic error.

Two easy ways to measure the response of an MR head to a wide range of wavelengths is either to use a tape recorded with a broad-band signal, or a degaussed tape. In the latter case, the magnetic particles are most simply modeled as magnets with random-sign, longitudinal magnetization.

Any pure frequency-dependence of gain in the channel[2] is removed by subtracting the electronic noise spectrum from the recorded signal or tape noise spectrum. For the case of a tape written with a broad-band signal, the signal to electronic-noise ratio is indicated by S/EN. Similarly, for the case of a degaussed tape, the tape-noise to electronic-noise ratio is indicated by TN/EN.

Signal frequency f, wavelength λ, and tape speed V are related by:

$$\nu = 1/\lambda = f/V\,.$$

The wavenumber ν is the reciprocal of the wavelength and indicates the spatial frequency of the recording or media noise. For a given recorded wavelength, it will be seen from this relation that halving the tape speed will halve the associated frequency. Therefore, halving the tape speed causes the S/EN to increase by 3 dB[3]. Thus, in the absence of other speed dependent noise, signal sources or losses, when the TN/EN or S/EN is plotted as a function of the wavenumber and tape speed a plot similar to that given in Figure 4 is expected.

In practical applications the head-tape spacing causes a loss in the read signal power. This loss L is estimated by the Wallace formula, is proportional to the spacing change Δh, and inversely proportional to the wavelength of the recording. However, for the discussion that follows it is easier to give the Wallace formula in terms of the wave number:

$$L(\nu,\Delta h) = 55\,\Delta h \nu \text{ (dB)}.$$

[2] Such as that due to fixed equalizer used.
[3] True as long as neither S nor TN is colored within the resolution bandwidth of the measurement.

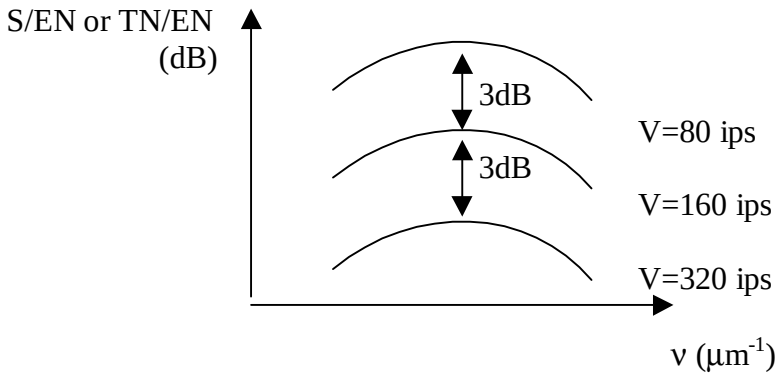


Figure 4. This picture shows a schematic depiction of the S/EN or TN/EN variation as a function of wavenumber ν and tape speed *V*, in the absence of spacing changes and other unmodeled signal losses.

If there is a change in signal level due to spacing change, the difference between the S/EN or TN/EN spectra associated with the two speeds will no longer be the 3dB per speed octave constant, but will depart from that value in proportion to Δh and in proportion to ν. Figure 5 gives a schematic depiction of the effect of a hypothetical increase or decrease in spacing when speed is reduced by a factor of 4 from 320 to 80ips for example.

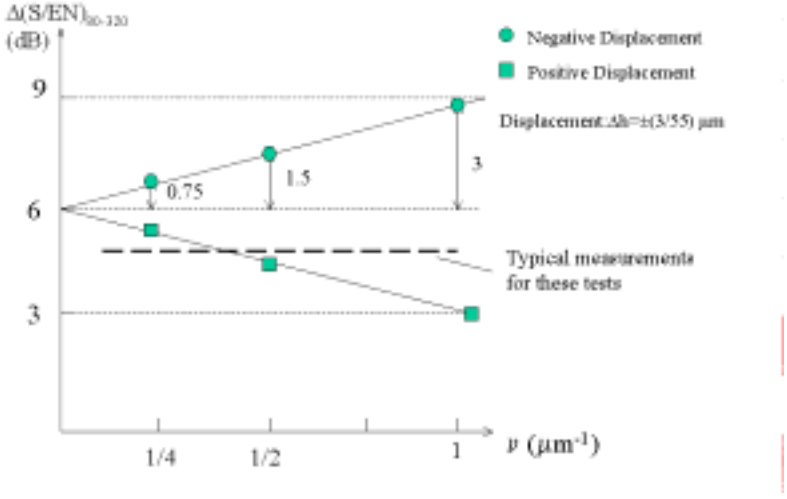


Figure 5: Schematic depiction of the effect of spacing change on the signal spectrum as a function of wave number ν. Also shown is the schematic depiction of the test results obtained.