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Subject: Wear Rates, Head Flying and Performance of the Current Head Design at Various Operating Tensions

Introduction

As a continuation of our study to determine the best operating vacuum for the VLBA recorder, we have measured the equivalent spacing loss and head contouring rates at various operating tensions of 5", 7.5", and 10" of water.

Spacing Loss at 5" and 10" of Water

We measured the spacing loss by measuring the head output while playing back recordings with wavelength of 1.35 and 0.9 microns. In order to make the playback of the two wavelengths at the same tape speed, we first calibrated the frequency response of the head and equalizer by playing back at 0.45 microns wavelength recording at various speeds. The calibrated signals were taken at a forward direction. The equivalent spacing is calculated from the following expression based upon the theoretical response of an inductive "ring" head (see H. Bertram, *Proc. IEEE*, vol. 74, pp.1494-1512, 1986)

$$V(k) = \underbrace{EQ(f)}_{\text{(equalizer)}} \; \underbrace{\frac{\sin(1.11kg/2)}{(1.11kg/2)}}_{\text{(gap loss)}} \; \underbrace{e^{-kd}}_{\text{(spacing loss)}} \; \underbrace{\frac{1 - e^{-k\delta}}{k\delta}}_{\text{(record depth)}}$$

where
- $EQ(f)$ = equalizer + head response at frequency f
- g = gap length (assume 0.3 μm)
- δ = record depth (assume 0.3 μm)
- k = wave number = $2\pi/\lambda$
- d = equivalent spacing
- $V(k)$ = voltage response to wavenumber k

We used a constant playback speed to avoid confusion of the wavelength variation with variations produced by flying. As mentioned previously the method required the additional step to calibrate the frequency response due to the equalizer.

Spacing d is calculated by assuming the record depth as 0.3 μm; however, the depth might be as high as 0.4 μm since the signals were recorded at a higher current. That would only reduce the spacing loss by 0.02 μm.

Two separate headstacks were used, one in the upper and one in the lower position. The upper headstack was the one using a spacer material made of MN130 and the lower headstack was one using the fotoceram spacer material in the current design. Measurements were made in forward as well as the reverse direction and on track 14 of both headstacks. Figure 1 shows the spacing loss vs. playback speed at a vacuum of 4.75" of water. The vacuum was set at 5" of water but as time went on, the vacuum decreased slightly, falling to 4.75" and head output was measured at that tension. The spacing loss is equivalent to the calibrated playing response at 1.35 μm relative to the response at 0.9 μm wavelength. In the reverse direction there is a large spacing loss from the upper headstack at higher speeds which is evidence for a significant amount of head flying. Prior to taking the data in Figure 1, the heads were contoured for 5" by running a thick tape at a tension which produces the same characteristic bending length P according to the relation (see Timoshenko, *Strength of Materials*, Volume II, pp26-56)

$$P = (Yt^3W/(12T))^{1/2}$$

where

Y = Young's modulus (4.54×10^9 Pa)
t = tape thickness (16 microns)
W = tape width (2.54 cm)
T = tape tension (2.2N at 10")

The reason for the flying could be a result of an asymmetric head mount from the inchworm motor housing or viscous drag in the vacuum columns (see VLBA Acquisition Memo #257). The marginal performance, could in part be due to a poor head contour (too small a radius of curvature).

The vacuum was then increased to 6" and spacing loss vs. speed is graphed in Figure 2. The reverse direction of the MN130 headstack has improved its spacing loss since its maximum spacing loss is 0.25 μm at 180 ips. The fotoceram headstack in both directions and the MN130 headstack in the forward direction have reduced spacing loss as well compared to the 4.75" vacuum.

Figure 3 shows the spacing loss at 10" vacuum for various tape speeds. At this tension the performance is uniform, within the measurement and calibration errors, and there is no evidence of flying. The spacing loss at this tension is even less than at 6". Also at this vacuum the performance is maintained without degradation as the heads wear.

Performance Maintenance

Following the measurements at 10" we reduced the vacuum to 5" and owing to the relatively small contour radius developed by running at 10", we immediately developed a very large spacing loss even at speeds as low as 80 ips. The large amount of head flying is explained qualitatively by the presence of a gap opening for air to enter at the head entrance as illustrated in Figure 4. [The flying was extensively studied in the previous work of VLBA Acquisition Memo #264 , 273, and 282.]

We attempted, without success, to condition the heads for 5" by running at this tension at 80 ips for a week. Even though some of the running time included humidities around 40-55%, we saw no sign of any signal recovery and eventually concluded that the flying even at a speed of 80 ips was so severe that the wear rates on both headstacks had been reduced to zero.

This could have resulted from staining, formation of friction polymers on the head surfaces that could only be removed by abrasive tapes. The production of these polymers causes head-to-medium separation, hence flying, and reduces the tape head wear. (Bhushan, *Tribology and Mechanics of Magnetic Storage Devices*, pp.442-444)

Recovery(Wear) Rate at 7.5"

Following our inability to restore performance at 5" we increased the vacuum to 7.5" and measured the rate of signal recovery at various speeds. The amount of material that needs to be removed to convert a 10" contour to a 7.5" contour can be calculated from the theory of a stable contour for which the radius of curvature is simply given by

$$R = (p + L)/\theta$$

where,

p = characteristic bending length
L = head step half length (150μm)
θ = tape wrap half angle 5°

For the 16 μm 3M tape being used for these tests,

at 10", $p_1 = 134\ \mu m$, $R_1 = 3238\ \mu m$
at 7.5", $p_2 = 154\ \mu m$, $R_2 = 3489\ \mu m$

The cross-sectional area segment shown in Figure 4 is

$$\frac{2}{3} L^3 \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$$

or an equivalent wear depth of

$$\frac{1}{3} L^2 \left(\frac{1}{R_1} - \frac{1}{R_2} \right) = 0.17\ \mu m$$

Figure 5 shows the time vs. the signal(dB) for 80 and 160 ips in the forward and reverse direction. The signals recovered at a higher rate in the reverse direction. The tape was shuttled for about 7 days to reestablish the 7.5" contour but even after this time the signals still has not fully recovered. If we assume the contour would have fully recovered in about 500 hours, which is approximately consistent with figure 5, the calculated wear rate for the removal of 0.17 μm is approximately 0.0003 μm per hour or a headlife (assuming a 38 μm depth of gap) of 10^5 hours.

Conclusion

5" of water is too low a tension for a reliable operation. There were just no sign of any contour recovery. At this tension the head will not establish a contour which results in low spacing loss. A reasonable contour can be established, at least with the fotoceram headstack, by using an abrasive thick tape but if this contour is degraded it will not reestablish itself. Operating at 7.5" is a real possibility but the re-conditioning rate is extremely slow. If the current operating vacuum of 10" results in an unacceptable headlife, we should consider lowering the vacuum to around 8" as a means of extending the headlife without significantly degrading the performance. More tests will be needed to be sure that the lower vacuum will have sufficient performance margin under all operational conditions.

Figure 1: Flying at 4.75" Vacuum (with a 5" contoured head)

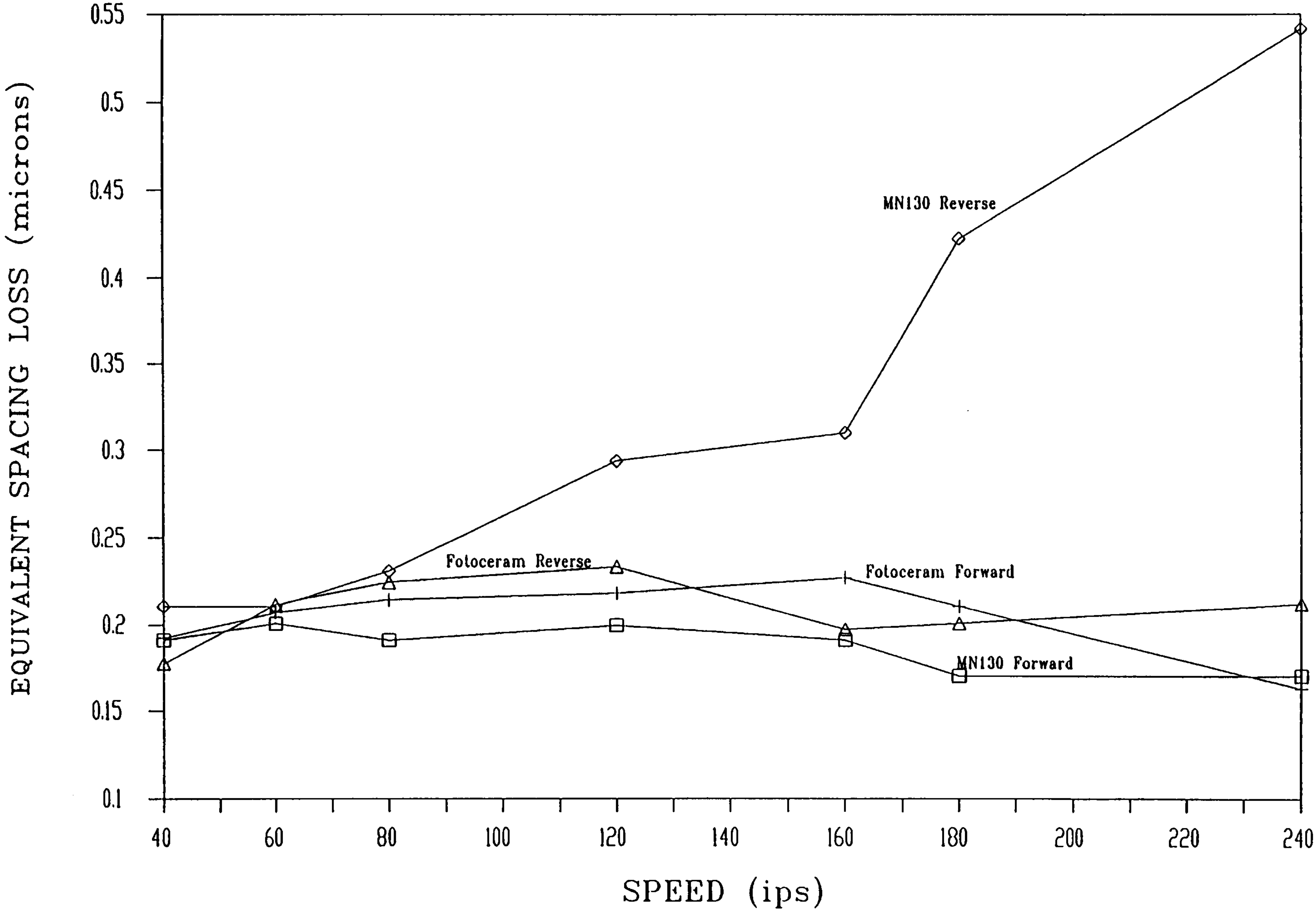


Figure 2: Flying Height at 6.0" Vacuum

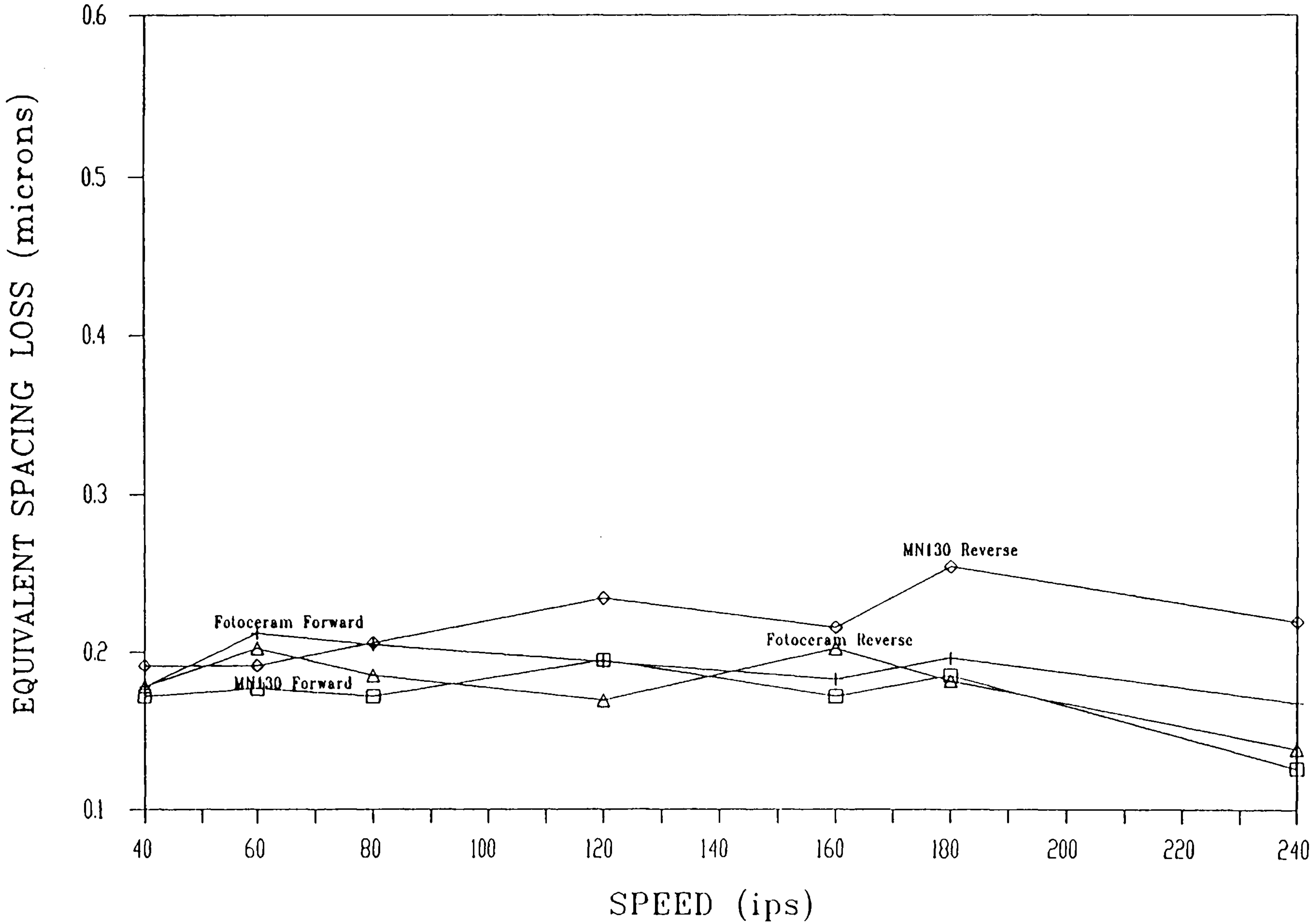


Figure 3: Flying Height at 10" Vacuum

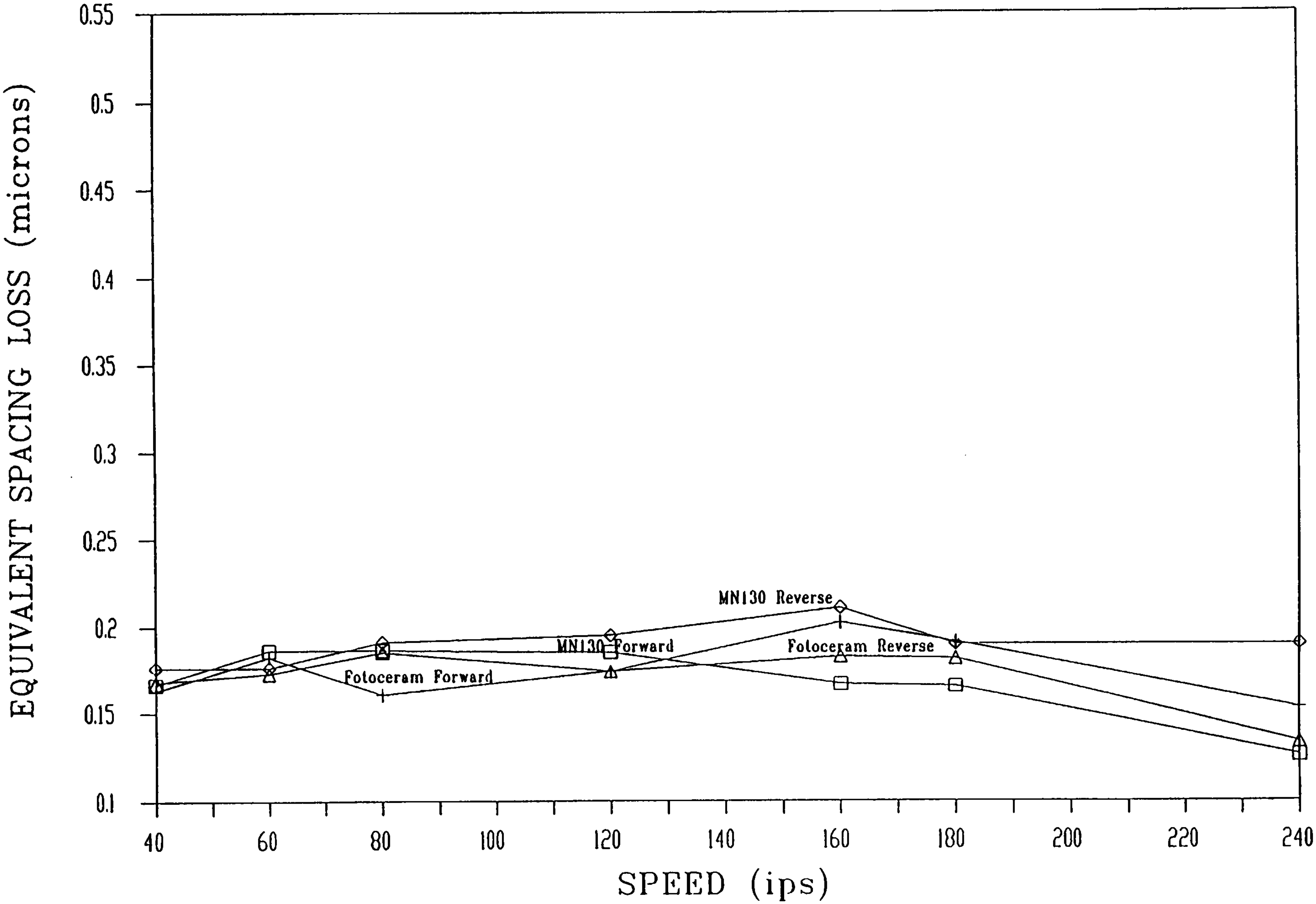
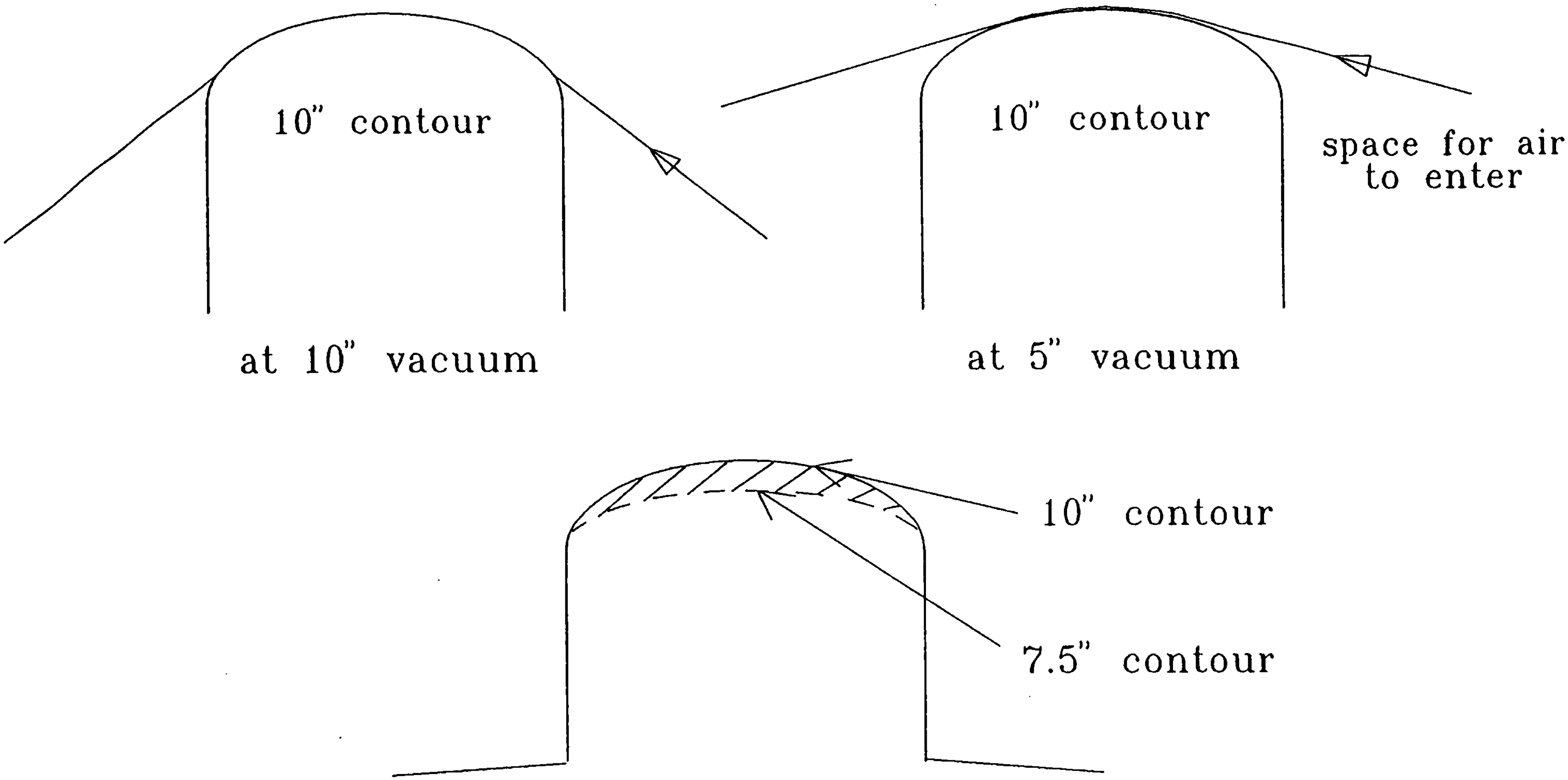


Figure 4: Gap Forming Due to Head Not Contoured



The shaded area is the amount of material to be removed from a 10" contour to a 7.5" contour.

Figure 5: Recovery Rate at 7.5" Vacuum From a 10" Contour