Contact Tape Recording with a Flat Head Contour

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ABSTRACT

- **A row-bar of commercial, IBM thin-film disk heads, with $3.75\mu m$ wide, $2\mu m$ high, magnetoresistive read sensors, was evaluated on linear (Metrum 96) tape drive.**
- **The tape was wrapped $\sim 2^o$ over the hard $Al_2O_3{-}TiC$ leading corner of the bar and not wrapped at all over the relatively soft TF trailing corner.**
- **After more than 2000 hours of running in contact at $8m/s$ under $\sim 90N/m$ tension we can place an upper limit of $4nm$ on head wear.**
- **Output, hence spacing, was stable and independent of the tape speed in the range of $0.5 - 8m/s$ which is proof of contact with the substrate.**

◇ **A model of the head tape interface showed a very good match to the experimentally observed results. Air pressure becomes subambient in the tape-row-bar interface.**

◇ **The tape is "sucked" down into contact with the row-bar surface in the indicated speed range.**

◇ **The highest contact pressure region is near the wrapped (leading) edge.**

◇ **Contact pressure on most of the remaining flat part of the tape bearing surface is only $\sim 10\%$ of the ambient pressure.**

Wrap Geometry

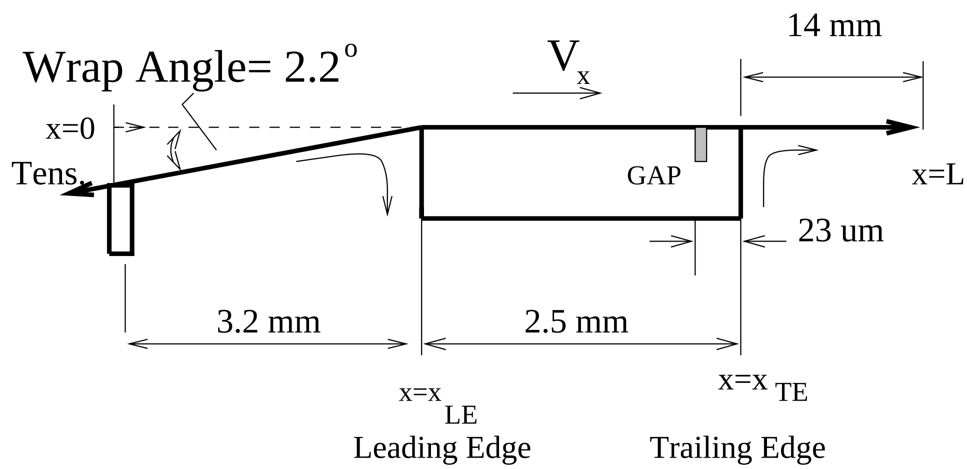


Figure 1: Row-bar wrap geometry.

EXPERIMENTAL RESULTS

1. WVHS and SVHS tapes were shuttled in contact for 120 and 2000 hours, respectively.
2. For the 2000 hours case shuttling was at $V = 8m/s$ and tape tension was at $T = 2.3N$.
3. During the same 4000 + hours of operation a ferrite head wore $10\mu m$.
4. No speed dependence was observed in the MR head output in the range $0 - 8m/s$ for the SVHS tape.
5. No change in the MR head resistance was observed during this time and no loss of output was seen either (SVHS tape recorded with $2.25fc/\mu m$ to within $0.5dB$).

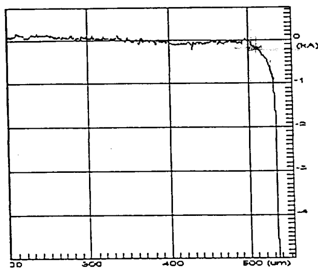
WVHS tape at 4.5 $fc/\mu m$ ($\sim 114kfci$) with $3.75\mu m$ MR

V (m/s)	S/EN (dB)	S/TN (dB)
0.5	51.5	43.5
1	51.5	45.5
2	51.5	45.5
4	51.5	46.5
8	49.5	46.5

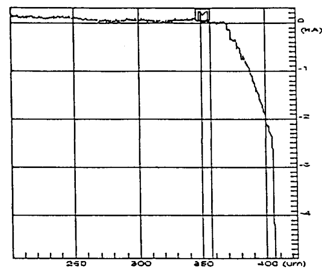
Table 1: Output variation with tape speed.

The MR sensor outperformed a $38\mu m$ ferrite head. Output signal (S) to tape noise (TN) is high enough to project the feasibility of $20,000tpi$ recording at $18dB$ SNR with SVHS- and WVHS-like tape at 3 and $6fc/\mu m$, respectively.

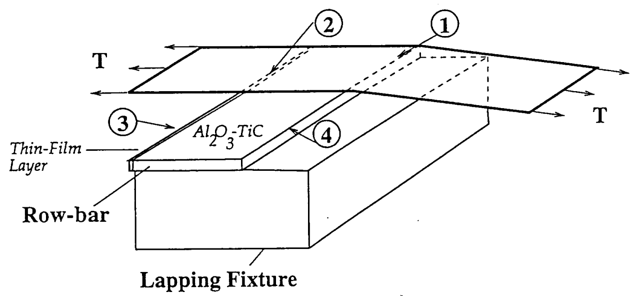
Experimentally Measured Wear Contours



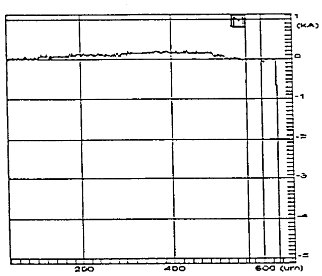
Ave. Depth = $83nm$
Ave. Width = $29\mu m$

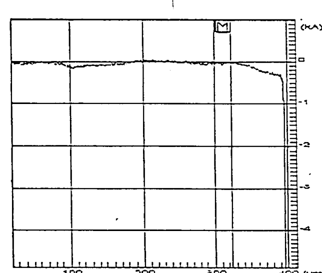


Ave. Depth = $248nm$
Ave. Width = $35\mu m$



Ave. Depth = $30nm$
Ave. Width = $67.5\mu m$





Model of the Head-Tape Interface

$$
\begin{aligned}
&\underline{\textbf{Tape Eqn.:}} & r_t &= D\frac{d^4w}{dx^4} + (\rho_a V_x^2 - T_x)\frac{d^2w}{dx^2} - (p - P_a) - P_c = 0 && (a)\\
&\underline{\textbf{Reyn. Eqn.:}} & r_p &= \frac{d}{dx}[ph^3\frac{dp}{dx}(1 + 6\frac{\lambda_a}{h})] - 6\mu V_x\frac{d(ph)}{dx} = 0 && (b)\\
&\underline{\textbf{Contact P.:}} & P_c &= \frac{P_{max}}{\sigma_t^2}(h - \sigma_t)^2 H(-(h - \sigma_t)) && (c)\\
&\underline{\textbf{Spacing:}} & h &= w + \delta && (d)\\
&\underline{\textbf{Disp. BC:}} & w &= w_o, \frac{dw}{dx} = m \text{ at } x = 0 && (e)\\
& & w &= 0, \frac{dw}{dx} = 0 \text{ at } x = L_x && (f)\\
&\underline{\textbf{Pressure BC:}} & P &= P_a \text{ at } x = L_{LE}, L_{TE} && (g)
\end{aligned}
\tag{1}
$$

x	Coordinate axis	P_c	Contact pressure
w	Tape displacement	$P_{max} = 10MPa$	Contact pressure at $h = 0$
h	Head-tape spacing is	$\sigma_t = 24, 48nm$	Asperity engagement height
$D(=\frac{Ec^3}{12(1-\nu^2)})$	Bending stiffness	H	Heaviside step function
T_x	Tape tension	$E(= 4GPa)$	Modulus of elasticity
V_x	Tape speed	$\nu(= 0.3)$	Poisson's ratio
p	Air pressure	$c(= 15\mu m)$	Tape thickness
$P_a(= 101.3kPa)$	Ambient pressure	w_o	Tape disp., $x = 0$
$\lambda_a(= 63.5nm)$	Molecular mean-free path	$m = \frac{w_L}{x_{LE}}$	Tape slope, $x = 0$
$\mu(= 18.5\mu Nsm^{-2})$	Air viscosity	r_t, r_p	Residuals

The Wear Relation

According to Archard's wear law the wear volume is proportional to the applied load;

$$V_{wear} = kl\frac{W}{H} \tag{2}$$

where,

V_{wear}	Wear volume
k	Wear Coefficient
l	Sliding distance $(56,000km)$
W	Normal load
H	Hardness of the material $(450GPa$ for $Al_2O_3 - TiC)$

Using the apparent area of contact, A_a, this equation can be transformed into the following form;

$$\delta_{wear}(x) = CP_c(x) \tag{3}$$

where,

$C(= 10^{-14} - 10^{-15})$	Wear coefficient chosen arbitrarily
δ_{wear}	Wear depth
P_c	Apparent contact pressure

The Numerical Solution

The governing differential equations (1.a,b) are discretized with $O(\Delta x^2)$ accurate finite difference approximations. The residuals are linearized using the Newton-Raphson approach. Equations are solved iteratively;

The tape equation

$$[J_t]\{\Delta w\}^{I_t+1} = -\{r_t\}^{I_t} \tag{4}$$

The Reynolds equation

$$[J_p]\{\Delta p\}^{I_p+1} = -\{r_p\}^{I_p} \tag{5}$$

where,

I_t,	I_p	Iteration counters for the tape and pressure solutions
$\{r_t\}^{I_t}$,	$\{r_p\}^{I_p}$	The residuals defined by (1.a,b)
$[J_t]$,	$[J_p]$	The non-linear Jacobian matrices for the tape and Reynolds eqns.
$\{\Delta w\}^{I_{t+1}}$,	$\{\Delta p\}^{I_{p+1}}$	The correction vectors

Coupling is provided by a relaxation coefficient, C_{relax}. The tape equation is updated at the end of each iteration step;

$$\{w\}^{(I_t+1)} = \{w\}^{(I_t)} + C_{relax}\{\Delta w\}^{(I_t+1)} \tag{6}$$

The relaxation coefficient is set initially to $C_{relax} = 0.8 - 1$ and it is cut by 1/2 every time the Euclidean norm, l_2, of the tape residual grows;

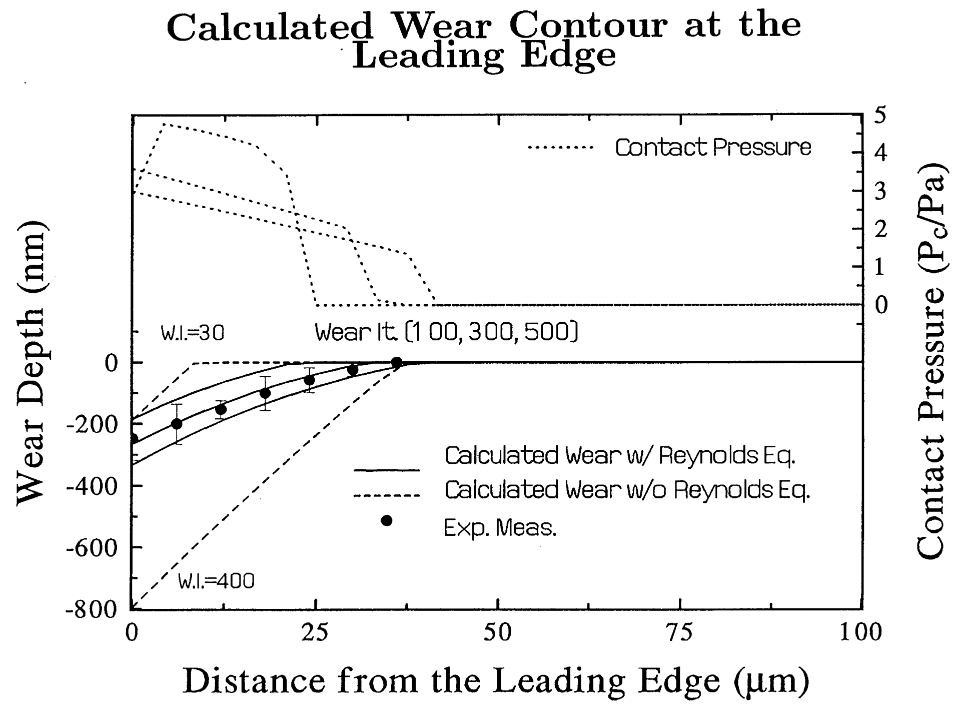
$$l_2^{(I_t)}(w) = \left(\sum_{k=1}^{NN} r_{t_k}^2\right)^{1/2} \tag{7}$$

The Solution Algorithm

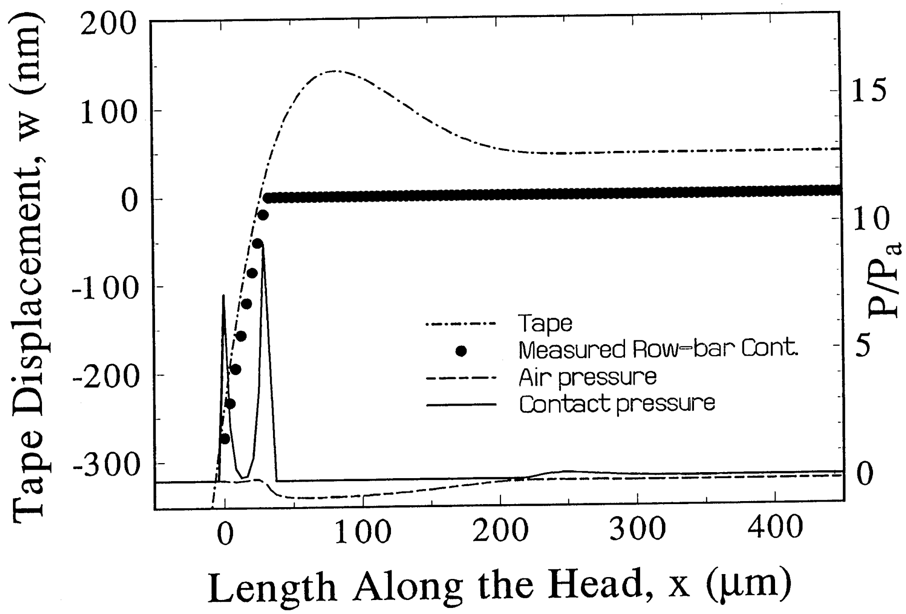
0. Start with "initial conditions"
   1. Start wear iterations $I_w = I_w + 1$

      $I_t = 0$
   2. Start tape iterations, $I_t = I_t + 1$
      (a) If $h \geq 0$ in the contact zone then,
          Solve Reynolds eqn. using NR-method
          $I_p = 0$
          i. Start pressure iterations, $I_p = I_P + 1$
          ii. Solve $[J_p]\{\Delta p\}^{I_p+1} = -\{r_p\}^{I_p}$
          iii. Calculate the new residual, r_p
          iv. If $r_p < 1 \times 10^{-2}$ goto step 2.(b),
              otherwise goto step 2.(a)i.
      (b) Calculate the contact pressure
      (c) Solve $[J_t]\{\Delta w\}^{I_t+1} = -\{r_t\}^{I_t}$
      (d) Calculate tape eqn. residual, r_t
      (e) Update $\{w\}^{I_t+1}$, $\{h\}^{I_t+1}$ and check C_{relax}
      (f) If $r_t < 1 \times 10^{-2}$ goto step 3
          otherwise goto step 2
   3. Calculate wear amount, δ_{wear}
   4. Calculate the new head shape, $\delta^{I_w+1} = \delta^{I_w} + \delta_{wear}$
   5. Calculate the new spacing, h
   6. If I_w limit is reached then stop

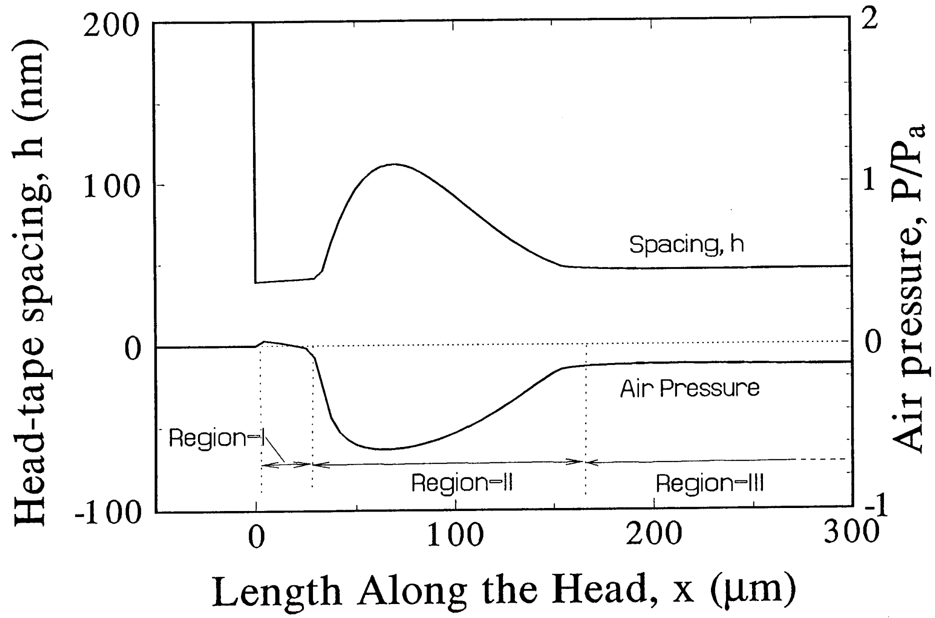
      otherwise goto step 1


Calculated Wear Contour at the Leading Edge
Contact Pressure
W.I.=30
Wear It. (1 00, 300, 500)
Calculated Wear w/ Reynolds Eq.
Calculated Wear w/o Reynolds Eq.
Exp. Meas.
W.I.=400
Wear Depth (nm)
0
-200
-400
-600
-800
Contact Pressure (P_c/Pa)
5
4
3
2
1
0
0
25
50
75
100
Distance from the Leading Edge (μm)

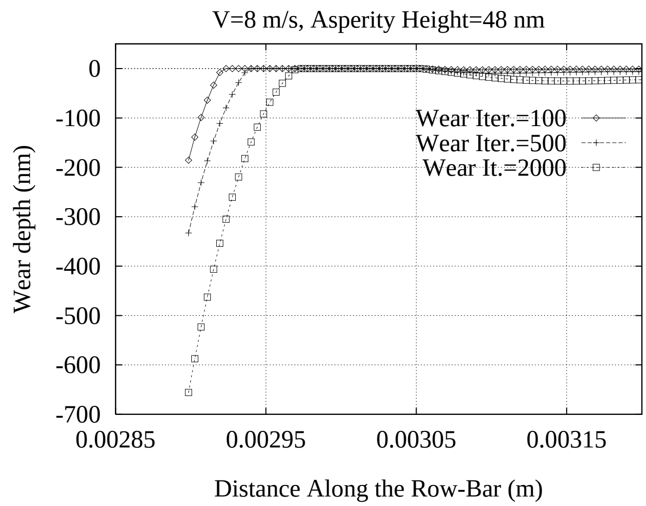
Calculated Tape Displacement and Pressure Profiles Using the Experimentally Measured Contour

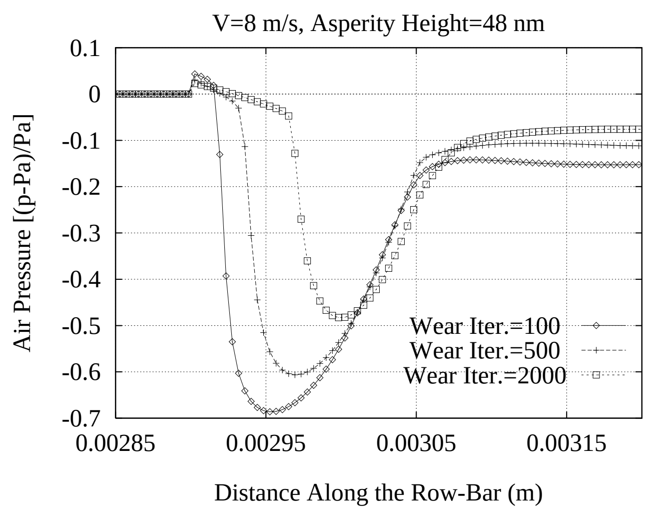


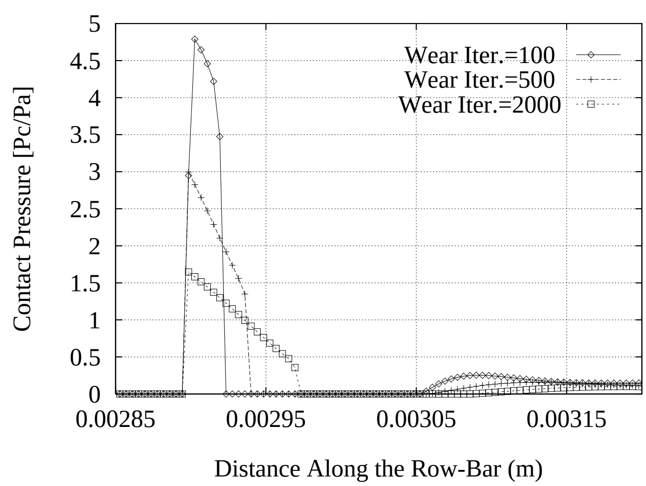
The Head-Tape Spacing, h and the Air Pressure, p



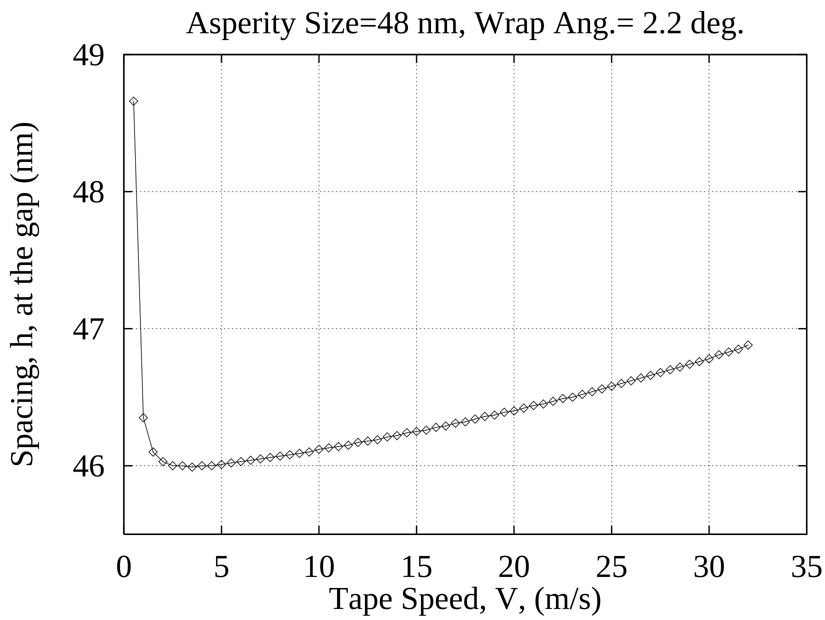
The Edge Wear and Corresponding Pressures

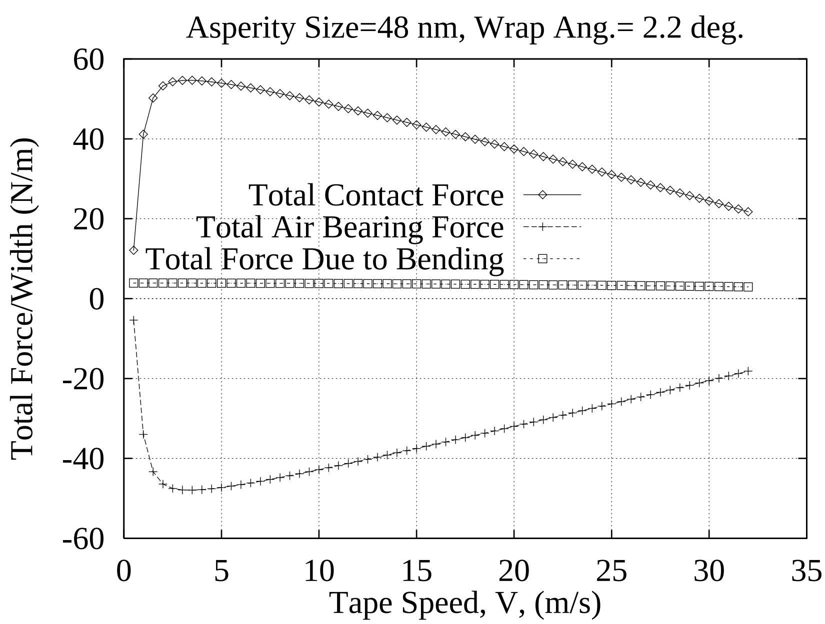




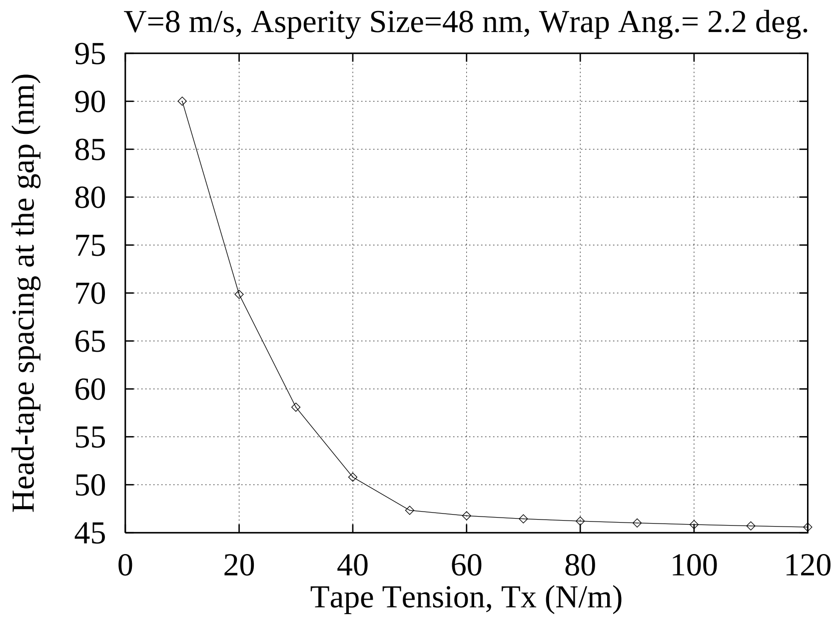


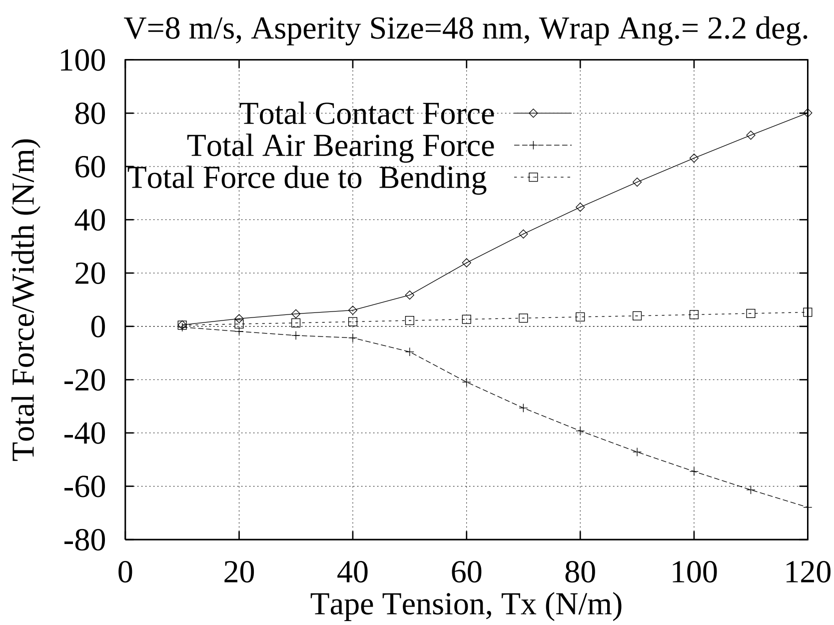
Spacing on the Gap as a Function of Tape Speed
$T_x = 2.2N$, Leading Edge Worn to 300 Its.





The Effect of Tape Tension at $V_x = 8m/s$
Leading Edge Worn to 300 Its. (Exp. Value)





SUMMARY AND CONCLUSIONS

- **As shown here by experiment and theory, contact between a tape and a flat bearing surface can be maintained at high speeds, due the sub-ambient air pressure in the interface.**
- **Wear of the wrapped corner does not lead to flying for a wide range of tape speed and tension provided that the leading edge is worn to equilibrium.**
- **The necessity of incorporating the Reynolds equation into the wear calculations was shown.**
- **We have seen no experimental evidence of significant wear on the flat part of the $Al_2O_3 - TiC$ substrate, nor of the softer layers near the trailing corner. The latter area which contains the TF heads is protected from wear because of the low contact pressure due to the combination of no-wrap and as-lapped TF recession.**

FUTURE WORK

Test and model symmetrically-wrapped bi-directional contact configurations. These can be produced by capping a row-bar with substrate material or perhaps by just reducing the wrap angle to $\sim 0.5^o$.