VLBA ACQUISITION MEMO #266

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To: VLBA Data Acquisition Group

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Subject: Thermal Calculations for High Tape Speeds

At the suggestion of Hans Hinteregger, I have investigated the thermal experience of the tape edge as it passes through the vacuum buffers.

Heat input

The heat input to the tape edge is

$$P = f\mu V = 160\ mW$$

where

f	=	edge force (0.04N - see memo 124)
μ	=	coefficient of friction (assume 0.5)
V	=	velocity (8m/s)

Temperature rise of bearing surface

The tape edge bears against the precision plate with a contact arc length of about 500 microns (see VLBA Acquisition Memo #141) and thereby acts as a line source for which the temperature rise (assuming at this point that heat is only lost by conduction) will be

$$\Delta \sim P(\ln(R_2/R_1)/(K\pi L) + \ln(R_3/R_2)/(K_a\pi L)) \sim 4°C$$

where

P	=	input power (160mW)
K	=	thermal conductivity of alumina (30 watts/m/°C)
K_a	=	thermal conductivity of aluminum (221 watts/m/°C)
L	=	contact arc length (5×10^{-4}m)
R_2	=	depth of alumina (~ 25μm)
R_3	=	depth of aluminum (~ 1cm)
R_1	=	contact width (~ 16μm)
Δ	=	temperature rise

Heat carried away by the tape

The tape passing over the contact area sees a pulse of heat and using an approximate solution to the diffusion equation

$$\frac{\partial T}{\partial t} = \left(\frac{K}{ps}\right)\frac{\partial^2 T}{\partial x^2}$$

the heat will propagate in a distance

$$l = \left(\frac{K}{ps}\right)^{1/2} tp^{1/2} \sim 2\ microns$$

where

T	=	temperature
t	=	time
p	=	density (2500 Kg/m^3)
s	=	specific heat (835 J/Kg/°C)
tp	=	pulse duration = L/V ~ 62 microsec
K	=	conductivity of tape (0.14 watts/m/°C)

and the heat carried out is

$$Pout = p\, l\, V\, d\, s\, \Delta \sim 0.5\ mW/°C$$

where

d	=	tape thickness (16 μm)

This calculation shows that the dominant heat loss is via conduction into the precision plate - unless deposits insulate the contact area. If this is the case, and the heat carried away by the tape is the only loss, then the temperature rise will most likely be controlled by the conduction in the contact area.

Edge damage model

At high speed enough heat is generated by friction to heat the edge above the plastic flow temperature of the tape. Since the thermal pulse is very short only a very thin layer is affected and the damage accumulates with every pass.

If the temperature rise is limited by conduction it will be proportional to velocity. Since the conduction is almost proportional to contact area one would expect the temperature rise to be inversely proportional to tape thickness. Also the thin tape is less able to carry significant heat away through its motion.

Tests and observations

The edge heating can be clearly observed by constructing a front vacuum door out of a stainless steel foil (13 microns thick), a liquid crystal film (changes from green at room temperature to blue at 100°F) and a plexiglass sheet. All three were laminated together with double sided adhesive tape

(120 microns thick). The presence of hot spots at places where the tape edge runs against the stainless steel are clearly seen by the color change of the liquid crystal film. Spots are not visible below 135 IPS and become extremely intense at 320 IPS.

Qualitatively the hot spot intensity is proportional to speed and vacuum. However, increased vacuum tends to increase the number and extent of the spots rather than the intensity. Breathing humid air on the entry to the vacuum column increases the heating but not as dramatically as smearing some sticky deposit on the steel foil in the contact area.

To get a handle on the temperatures involved the tape is run against a plexiglass door. At low speeds no marks are left on the plexiglass (even running for many passes) while above the critical speed of about 160 IPS marks start to appear very rapidly (within seconds) that are almost certainly the result of raising the temperature above the 160°C plastic flow temperature of plexiglass.