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To: VLBA/Mk4 Recording Group
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Re: Performance Maintenance and Head Wear

Introduction The design of heads, tapes, and of their interface should assure consistent optimum read/write performance and also an adequate head life.

Minimize Spacing In general, optimized performance is achieved by minimizing the effective spacing between head and tape.

Spacing is minimized by reducing as much as possible the mechanical and magnetic roughness of the tape and head surfaces, and by maintaining the best possible contact under all necessary operating conditions.

Adequate tolerance and/or control of environmental variations, and other changes caused, for example, by wear, must also be provided.

Headlife Tradeoff In practice, there is a tradeoff between guaranteed optimized performance (minimized spacing loss) and headlife. Headlife is limited by the finite depth of gap and by the finite head wear rate implied by true (mixed) contact recording.

The efficiency of a head, and hence its read performance, increases as depth of gap is reduced, and truly optimized performance is not obtained until the head is nearly worn out.

This is why flying head applications (hard disc sliders) use shallow, roughly 3 um deep, gaps. Another reason is that, for a thin film head (because of the thinness of the pole tips), the efficiency drops much more sharply with increased depth of gap than it does for a bulk ferrite head.

Depth of Gap, Current Design For well-made ferrite heads of the current design (with a sufficiently long gap) a 60 um initial depth of gap could be used for uncompromised recording of the current 900 Oe tape.

Little loss in read performance is observed (less than 2 dB) in going from 30 minspec to 50 um depth of gap. Some stacks recently delivered with 50 um depth of gap have exceeded our 24 dB min SNR performance spec by 4 dB. SNR spec is for thick FujiH621 tape at 135 ips (33.3kfci) but otherwise as described below for thin tape at 80ips (56kfci).

Efficient Use of Headstacks with Reliability Bonus If headstacks are transferred from write-monitor (data acquisition) to read-only (data processing) operation at approximately midlife (30 um = suggested midlife gap depth), they should, at that time, exceed the read performance spec by about 6 dB and only get better as they continue to wear.

Such a programmatic use of headstacks is efficient because it effectively doubles headlife.

Such use also improves system reliability. Write performance is most consistent with a deep gap, read performance is optimized on the processor (where it counts), and unanticipated wear-out in read mode can cause no harm (loss of data).

Acceptable Life For the VLBA, an average wear rate of 6 nm/hour (30 um in 5000 hours or 1 year of 50% duty-cycle use) is thought to be acceptable.

This wear rate implies replacement in the field of 20 half-used headstacks per year with new 60 um gap depth stacks (and replacement of 20 worn-out stacks per year at the processor with half-used ones from the field). At $6.5K per headstack the operational cost of heads is then quite comparable to that of shipping tape (assuming 40 reels per day at $10 per reel shipped). If a 5-year tape life is budgeted the cost of maintaining the tape supply is at least $200K/year in addition to $140K/year for shipping and it may be more appropriate to compare the sum, $340K/year, with $130K/year for head replacement.

Can Performance be Maintained at 6 nm/hr Wear Rate or Less? In principle, the answer is yes and probably in more than one way. For example, a so-called proximate contact recording scheme has been developed and applied to disc drives by Lemke et.al. at VisqusInc (now part of Conner, which is about to market a product using this technology). A non-Newtonian fluid lubricant is applied to the medium which allows the head to fly in the fluid with extraordinarily small spacing, 25 to 12 nm, without actual (mixed) contact. (A non-Newtonian fluid has a non-linear stress vs. strain-rate curve which for the fluids of interest flattens out at sufficiently high velocity.)

In practice, with the tape and head options currently at our disposal, the answer is a much more ambiguous maybe. Experimental results are summarized below. The interpretation of these results is also somewhat ambiguous.

Both the calcium titanate and Fotoceram spacer materials appear to be far from an optimum choice. With calcium titanate optimum performance is not easily or consistently obtained. With Fotoceram the head wear rate (which in the current design is dominated by wear rate of the spacer material) seems excessive even below 30% RH in the tape path, and is certainly excessive at 50%. The tribological behaviour of the (mechanically sound) Sony and 3M tapes, on which the last statement is based, was very similar. That of the (low Tg binder, mechanically questionable) Ampex tape, however, was quite different; the Ampex tape appeared to wear the Fotoceram spacer headstack very much more slowly and a blue film is evident on the Fotoceram after shuttling.

At Hv=920 and 500, 3M851D calcium titanate and Corning Fotoceram are respectively harder and softer than the Hitachi single-crystal ferrite at Hv=650. From the four fringe deep worn-in Fotoceram spacer saddle shape, Alan Rogers inferred in Memo#342 that the Fotoceram is only about 1/5 as abrasion resistant as the ferrite.

A closer tribological match is needed. Hitachi MN130 with Hv=550 has been incorporated in an experimental headstack which is about to be tested.

An even better match is probably the newly developed Hitachi MN-2 whose thermal expansion coefficient also matches that of ferrite and can therefore be used in a glass-bonded construction such as Roger Mersing's. 3M861D with Hv=820 (the only version of calcium titanate now available from 3M) may also be worth trying since the relation between hardness and abrasion resistance is not an exact one. A future head design will try to use a harder than ferrite alloy such as the FeTaN developed by NEC that has Hv> =1000 and a Sendust-tempco-matched Hv=820 spacer/substrate (calcium titanate - nickel oxide compound) which exhibits 4 times the abrasion resistance of MN130.

Experimental Results and Discussion A time-ordered list of experimental results is given on the next page. Apparent wear rates in nm/hr are calculated according to WR = (ds/dt)/(ds/dh), where ds/dt is signal recovery rate in dB/hr and ds/dh = .061 dB/nm is the spacing loss for a 900 nm wavelength test recording. Tests were done in June/July 92. Tension was fixed at 2.2N (10"vac). Noise (head/preamp, tape stationary) and signal (Mk3 formatted noise) levels were measured at 80ips in 30kHz bandwidth at 2.2 MHz with a spectrum analyzer.

It is unclear why apparent wear rates are not nearly constant after moderate flattening of the contour peak by a thick, abrasive tape. The much higher initial apparent wear rates suggest that flattening roughens the head surface and that the roughened surface is smoothed quickly compared to steady wear.

There is evidence that signal recovery is sometimes not complete, especially at humidity below 30% and even with the Fotoceram spacer head and the more abrasive tapes. The effect is worse but not much worse for a low abrasivity tape (as the Ampex seems to be). The unwanted 30-50 nm extra spacing may or may not mean that wear has ceased when it exists, but the extra spacing probably means a film of stable thickness has formed on the head which is able to sustain itself. The 3M and probably the Sony tape appears to be able to quickly remove such a film fully when RH approaches 50%, but only partially when RH is below 30%. The Ampex tape seems to be able to maintain performance at 320 ips when RH is in the upper 40s range but not when it is below 30%; at 135 ips the Ampex tape even maintained slightly spoiled performance below 30%RH (contour spoiled 3dB=50nm by V16) -- that the tape's ability to maintain performance may be speed dependent, as this result hints, is puzzling. The 30to45% range is unexplored and some point within it probably is the best compromise for now.

	WR	RH	V	ds	dt	Tape	Comment
	nm/hr	%	ips	dB	hr	Tape	Comment
Fotoceram Spacer Headstack							
*	5	53	160	5	16.5	500'Sony	3000 prior passes
*	44	47	160	2	.75	18K'Sony	compare w burnished above
	>1.3	46	330	1.3	16.3	" 3M	
*	7	<30	135	6.7	16	"	
*	7	"	"	1.2	3	"	consistent
*maint	<.1	"	"	<.1	16	18K'Ampex	3dB=50nm spoil maintained
	20	"	160	1.8	1.5	" Sony	
	140	43	"	3.2	.375	" "	first pass, after V16
	60	"	"	1.3	"	"	second
	14	"	"	.3	"	"	third
	55	47	320	.5	.375	Ampex	first F&R, after V16
*	3.3	45	160	.3	1.5	"	4 more passes
	0	42	"	0	3	"	8 more
	0	46	80	0	18	"	many more
	100	48	320	2.2	.375	Sony	2 after Ampex
*	50	51	"	1.1	"	"	2 more
	17	50	"	.4	"	" "	
*film	-	<30	"	-2	15	Ampex	33nm spacing increase
*clean	20	"	"	.9	.75	3M	stalled at 15nm partial recovery, 30nm short of 'super', needs hiRH
	-	"	"	-7.7	.1	V16	flatten head
	67	"	"	1.6	.375	3M	first 2 passes
	33	"	"	.8	"	"	2 more
*wear	7	"	"	.6	1.5	"	passes 10-18, -4.7dB
*	64	45	"	2.9	.75	"	quick recovery @ hiRH
	>22	60	"	.5	.375	"	full recovery, superSNR=26.5dB
	-	50	160	-7	-	H621	flatten head
	27	"	320	1.2	.75	Ampex	initial hiRH rate
	140	47	"	3.2	.375	3M	"
*wear	56	"	"	1.3	"	"	2 more
*	.8	49	"	.7	15	Ampex	superSNR=26.5dB maintained
	670	"	80	-5.5	.17	H621	flatten head, F200'R
*	3.5	"	320	.7	3.3	Ampex	passes 3-20
*film	<.3	"	"	<.2	12	"	64 more, -3.3dB
*clean	90	"	"	2	.375	3M	near full recovery
	-	"	"	.6	24	"	full recovery
Titanate Spacer Headstack E40							
	-	50	320	-1.3	1.5	3M	21nm spacing incr., not recoverable
	260	47	80	-2.6	.17	H621	F200'R, WR=.4xfotoceram
	27	"	320	.6	.375	3M	2 passes, after H621
	16	"	"	.7	.75	"	4 more
	7	"	"	.3	.75	"	4 more
*wear	2.2	"	"	.2	1.5	"	8 more
	2.2	"	"	"	"	"	8, recovery to 21nm from 'super'
*wear	1.3	51	"	1.3	15.7	Ampex	after H621 F800'R 4.4dB loss
	280	52	"	6.4	.375	Sony	2p, after 9db H621 flattening loss
	43	50	"	1	.375	"	2 more passes
*wear	30	53	"	2	1.12	"	6 more
*wear	6.6	41	"	.3	.75	"	4 more, falling humidity