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RECORDING ON FLEXIBLE MAGNETIC SHEETS

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SOME DESIGN CONSIDERATIONS FOR SHORT TERM AUDIO
RECORDING ON FLEXIBLE MAGNETIC SHEETS

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An actual sheet recorder will not be described in this paper. Instead five different design areas which deviate from those of regular reel-to-reel machines will be covered. The five areas are:

1. Head Design,
2. Head Placement,
3. Mechanical Drive System,
4. Dropouts,
5. Equalization.

HEAD DESIGN

The head design criteria were that it should:

- 1) playback 1/3 mil wavelength signal with minimum gap loss;
- 2) record tape into saturation without saturating the head using 100 kc bias frequency at a reasonable bias current;
- 3) have long life, considering the type of head to tape contact;
- 4) be replaced easily without critical adjustments;
- 5) have low hum pick-up from extraneous fields;
- 6) have minimum head bumps;
- 7) have minimum crosstalk between tracks.

A 100 micro-inch gap was chosen as the best compromise between output and gap loss. Since a narrow gap record head may require excessive bias because of the shunting effect of the pole tips being close together, especially for large gap depths, 100 micro-inch was also considered the smallest gap that would not give pole tip saturation using a 0.4 mil oxide-coated tape. Ten mil gap depth was chosen as a good compromise between head life and pole tip saturation. Figure 1 shows head wear versus time. The slope of the curve approximates 5.5 micro-inch per hour which gives a $10,000/5.5 = 1800$ hours lifetime. After 200 hours use, a more abrasive magnetic coating was tested for 50 hours. It showed a 50-micro-inch per hour slope which is almost ten times that of the original tape. If two machines are used 24 hours a day operating 1/3 of total air time, the total use will be $24/3 \times 2 = 4$ hours per machine. A 1000-2000 hours head life would then demand head replacement every 250-500 days or approximately once a year.

The magnetic head structure is symmetrical in order to balance out stray hum fields and a Mu-metal can is reducing the hum sensitivity further.

The pole pieces protrude through the head shield by approximately 10 mils, so the proximity between the shield and the oxide is close enough to considerably reduce the long wavelength track-to-track crosstalk. Figure 2 shows track-to-track crosstalk as measured with a wave analyzer. It is evident that the curve flattens out at low frequencies and is below the broadband noise at frequencies above 150 cps.

The pole tips are shaped for minimum head bumps. The head is designed to be easily exchangeable. It is a fixed base head with close tolerance mounting surfaces so no azimuth adjustment is necessary or possible.

Heads can be exchanged without tools in less than a minute. Two knurled nuts must be removed and the head slides off its mounting pins. A new head will slide right in place on the pins and the two nuts must be re-installed.

HEAD PLACEMENT

The basic difference between a reel-to-reel machine and a sheet recorder is the method of scanning the tape medium.

A reel-to-reel machine has to maintain a fixed head centered on a linear track, maintaining correct azimuth.

A sheet recorder has to maintain a moving head centered on an established spiral track, maintaining correct azimuth and a correct fore and aft and radial position.

To illustrate the interaction between azimuth and fore and aft position, four different conditions prevail:

- 1) A head with its gap on a line through the center of the sheet.
- 2) A head as in 1) but with a fixed azimuth error.
- 3) A head with its gap on a line parallel to but spaced away from a line through the center of the sheet.
- 4) A head as in 3) but with an added azimuth error.

The first case represents the optimum condition. The second case will result in high frequency losses varying with the recorded radius; in other words not a condition that can be corrected for with a fixed treble boost as in a reel-to-reel machine. The third case is illustrated in Figure 3. It shows the resulting azimuth error at the inside of the spiral track (B).

In Case 4) an azimuth adjustment may partly correct for the fore and aft error, but never completely. If azimuth is adjusted to maximum output at the beginning of the spiral track, the error at the inside would be the angle A in Figure 3. If this were carried further, the error could be divided between the inside and outside track but could never be eliminated across the whole sheet. To approximate the optimum

conditions in 1), the head is designed with the mounting surfaces and the gap manufactured to tolerances sufficiently close to make the azimuth error an order of magnitude lower than the fore and aft error.

The fore and aft position is pre-set in a jig within ± 2 mils. The Case 3) azimuth error can then be a maximum of 2 mils in 2.8 inches or with a 50 mil wide track: $\frac{x}{50} = \frac{2}{2800}$, $x = 36$ micro inches.

The gap is 100 micro inches long which gives a 1.5 db loss at 1/3 mil wavelength. An effective gap of $100 + 36 = 136$ micro inches would result in a 2.5 db loss at this wavelength.

The radial position of the head on the sheet is governed by a piece of Mylar tape similar to the sheet material which is connected between the head and a rotating drum. The drum is digitally connected to the rotating sheet in the play mode. The Mylar tape draws the head across the sheet and provides some compensation for thermal and humidity expansion of the sheet. Actual heat cycling showed track displacements to be less than 3 mils when recordings made at 30°F and 120°F were played back at room temperature, which results only in approximately 1/2 db of signal attenuation.

MECHANICAL DRIVE SYSTEM

The basic drive system consists of a hysteresis synchronous motor, an intermediate flywheel and a turntable. The motor is coupled to the flywheel with an elastic belt and the flywheel shaft--or capstan--engages a compliant rim on the turntable.

To obtain maximum speed stability and minimum wow and flutter, the compliant turntable rim should be as thin as possible--the optimum condition being no compliance at all.

In equipment of this type this is not recommended due to the necessary tight tolerances and total dust protection. One little hard speck of dust would change the speed momentarily and introduce high frequency flutter.

When a compliant rim was applied at the periphery of the turntable, the high frequency flutter was reduced somewhat. Different materials, hardnesses, and thicknesses were tried but to obtain a rubber moulding that was sufficiently homogeneous and independent of environment was a difficult, if not impossible, task. Flutter measurements indicated random irregularities in the rubber as the largest disturbing factor. Readings averaged 0.15% with frequent peaks up to 0.4 - 0.6%.

The speed of the turntable is determined by the circumferential speed of the capstan and the effective circumferential speed of the turntable surface in the contact area. Since the penetration of the capstan into the compliant rim causes the surface to stretch, the effective circumferential length is increased and the turntable speed will decrease.

Increased penetration will result in further surface stretch and still lower speed of the driven member. The lower curves in Figure 4 confirm this. They represent measured speed deviation versus penetration. This is a steady state condition, but it appears logical to use the findings for short deviation pressure variation also--which will then illustrate the relationship between rubber inhomogeneities and flutter.

If the rubber were compliant in a plane through the center of the turntable but very still in a tangential plane, a system with high speed constancy and low wow and flutter would be obtained!

This was accomplished by placing a seamless Mylar belt around the rubber rim on the turntable.

Flutter measurements on this system confirmed the improvement. Readings averaged 0.05 - 0.08% with low values down to 0.02% and no significant peaks.

The top two curves in Figure 4 show how little the speed varies with different pressures.

The two top curves are also closer together than the two bottom ones, indicating less sensitivity to varying load (head rub against tape sheet and friction in the associated sheet clamping device).

Addition of the 3 mil thick Mylar belt which would have decreased the turntable speed by 0.05% if the rim had not been compliant, actually increased the speed approximately 5.0% at the standard operating force used (Figure 4).

It is also apparent that the setting of the penetration force is much less critical with the Mylar belt in place.

DROPOUTS

The head-to-oxide contact in a sheet recorder is just as critical as in a reel-to-reel machine, because the same negligible spacing losses are desired.

Since the sheet is 3 mils thick, which is twice or more the thickness of tape normally used on reel-to-reel machines, the necessary head-to-oxide contact is more difficult to obtain due to the reduced compliance of the medium.

Small irregularities in the base stiffness may result in more momentary spacing losses than if a thinner tape were used.

Purely magnetic inhomogeneities may produce momentary level variations.

Small particles imbedded in the oxide will act as momentary spacers between the head and the oxide. To illustrate the orders of magnitude involved, let us assume that the spacing equals the oxide coating

thickness (0.4 mil). If the bias level is set for optimum long wavelength output, the critical field just penetrates 0.4 mils into the oxide. When the "spacer" comes along, the critical field will hardly penetrate the oxide at all and an almost complete loss of signal will result due to the insufficient biasing. The length of this dropout depends on the length of the "spacer" and the pole piece-oxide contact area.

The length of the contact area between the head and the oxide for a head at half life is approximately 100 mils and assuming the "spacer" to be of negligible length, the length of the dropout will be $100/7500 = 0.0133$ sec (13.3 milliseconds) at the 7.5 ips speed at the outside tracks and twice as long at the inside of the sheet. When the "spacer" starts moving in under the head, the gradually reduced bias will result in a gradual attenuation of long wavelength signals but an attempt of an increase of short wavelength signals. The spacing, however, will also deteriorate the definition, so no increase can actually be observed. When the "spacer" moves away from the head, the opposite procedure takes place.

If the same 0.4 mil "spacer" exists in playback only, a total signal loss will not occur but a frequency dependent attenuation ($54.5 \times S/\lambda$ db) will exist. (S is the head-to-tape spacing and λ the wavelength).

A 1 kc tone will be attenuated $\frac{.4 \times 54.5}{7.5} = 29$ db.

A 100 cps tone will be attenuated $\frac{.4 \times 54.5}{.75} = 2.9$ db.

Subjective listening tests have shown that dropouts as long as 13 milliseconds are not very audible even if the level drop is 100%.

If groups of particles are imbedded in the oxide, a more complicated and more audible disturbance will result.

To eliminate dropouts from loose particles such as dust, a thin Mylar sheet is touching the sheet in front of the head and loose particles are removed from the track.

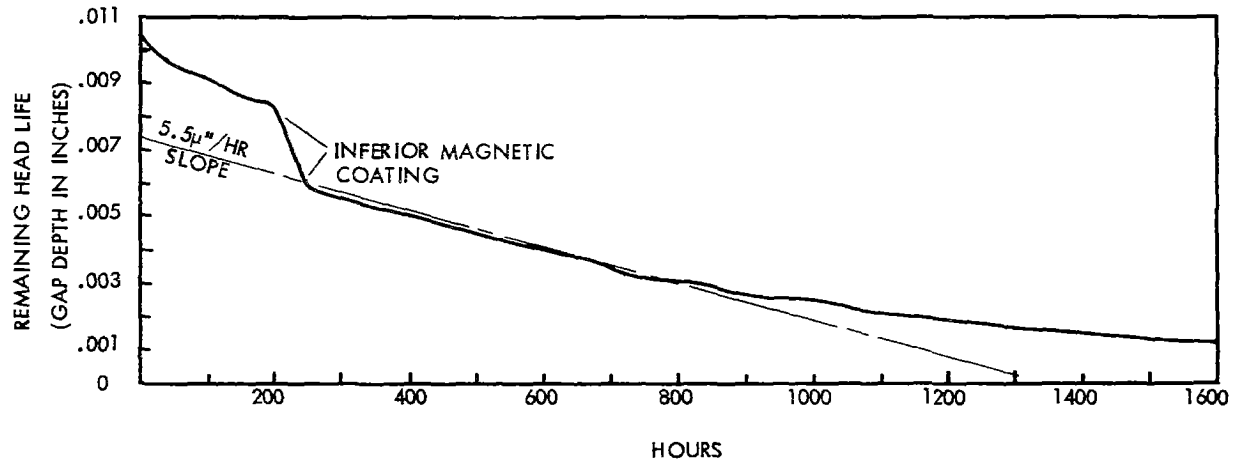
EQUALIZATION

Because of the varying absolute speed of the magnetic medium, some form of "diameter equalization" is necessary. For reasons of simplicity, this is performed in the recording mode only.

Due to the excessive wear occurring when two metals rub against each other with very low relative speed, a standard type of rotary switch is not used to change the equalization. A stack switch with crossbar palladium contacts and excellent wiping action are used instead. The playback equalization is fixed at 80 microseconds; this is the maximum time constant that can be used at the highest medium speed for the particular oxide material, with the use of simple equalization circuitry. Since the

coating is not lubricated, an intimate head-to-oxide contact is insured and simple 6 db/oct slopes are sufficient for recording equalization. This modest recording equalization results in a good overload margin even at the shortest wavelengths.

The equalization is changed in four steps which are practically inaudible when listening to program material due to the negligible change at frequencies of maximum ear sensitivity.



HEAD WEAR VS. USE

FIGURE 1. Showing that after approximately 200 hours of wear, reduced contact pressure and increased wear area of the head result in a fairly uniform slope of 5.5μ wear per hour. Also shown is the radical wear caused by inferior magnetic coating.

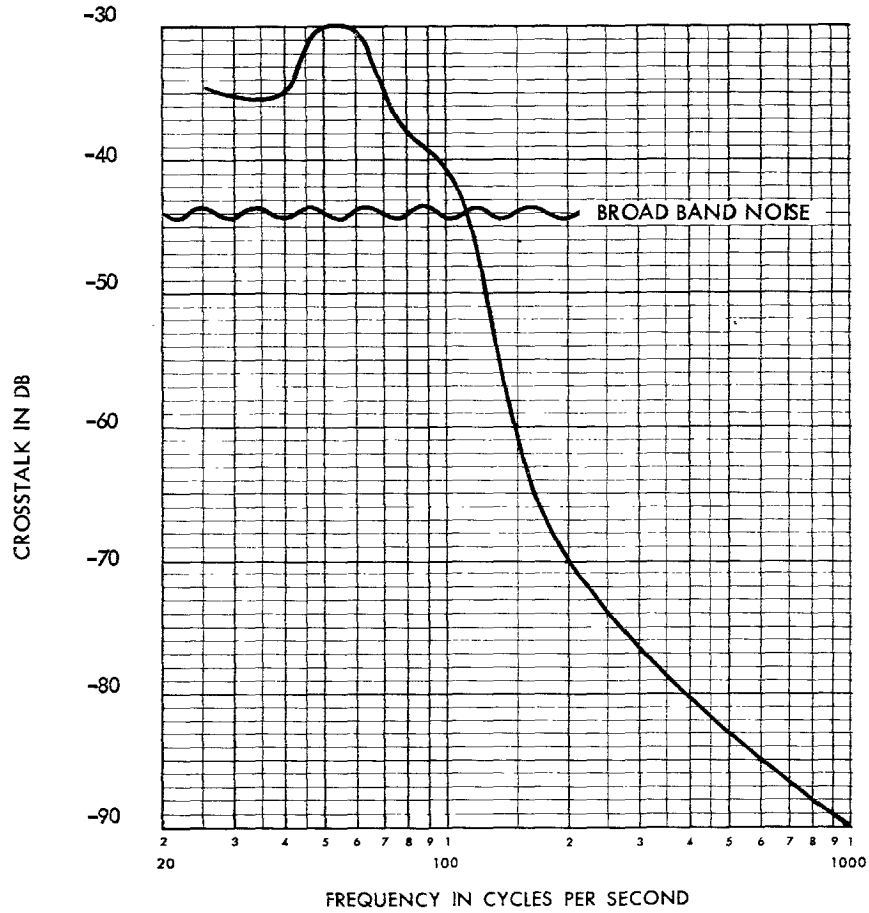


FIGURE 2 TRACK TO TRACK CROSSTALK VS. FREQUENCY

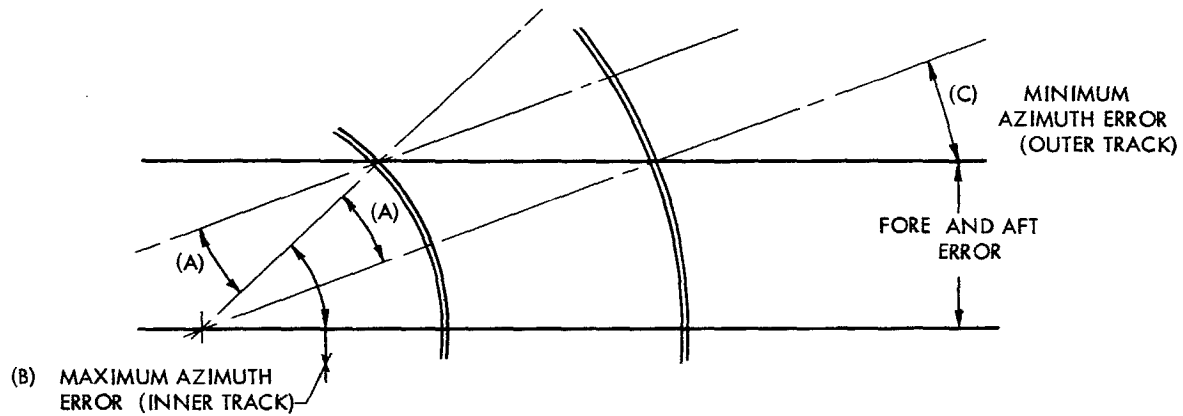
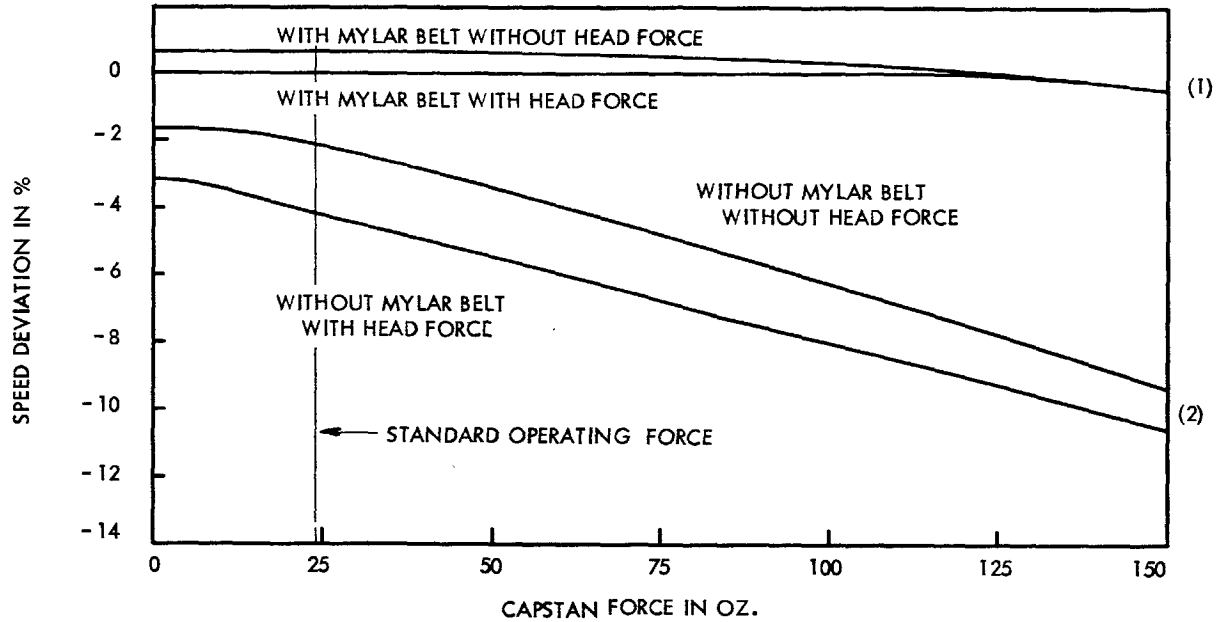


FIGURE 3 Showing effect of head fore and aft error on azimuth. If azimuth is adjusted to maximum output at outer track, the minimum error (C) will be eliminated and the maximum error (B) will be reduced to $A = B - C$.



TURNTABLE SPEED VS. CAPSTAN FORCE

FIGURE 4 Showing the turntable speed losses with increasing capstan force on compliant rubber rim alone (1), and with addition of peripheral mylar band (2). Comparison may also be made in the degree of loss in each case under conditions of identical external loading.