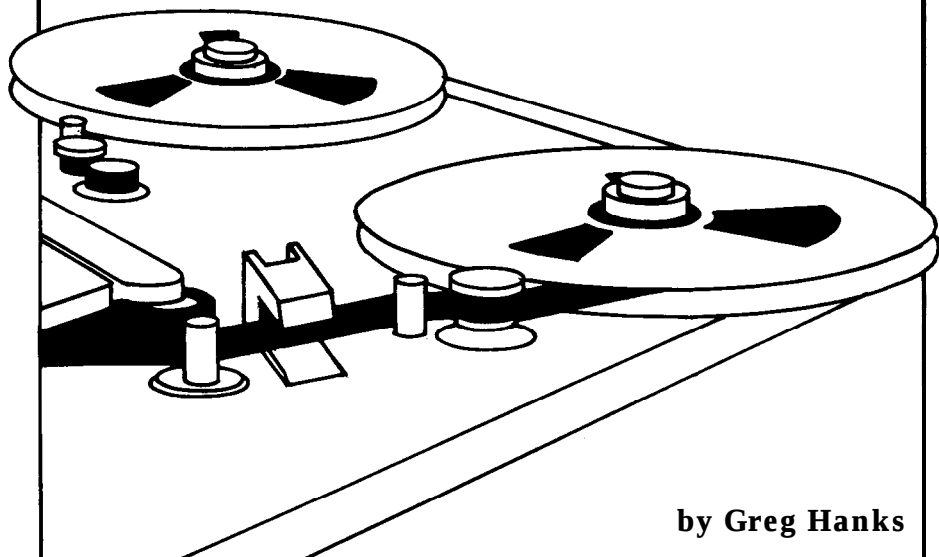


TAPE MACHINE CARE AND REPAIR

With a Special Emphasis on
Transport
Preventative Maintenance



by Greg Hanks

For those of you who were unable to attend the October 1983 AES Convention Workshop on tape machine care and repair, we are presenting here an overview on the philosophy of preventative maintenance, and the theory of tape machine operation. Although the basic concepts involved in putting sound on magnetic tape and getting it back off have been covered in extreme depth many times before in this magazine, we find that most of these treatises assume that the physical transport of tape is being handled, of course, in a theoretically proper manner! Most of us in the recording industry have been faced many times with multitrack machines that, because of mechanical malfeasance, are performing less than ideally. Some of the problems that I refer to are:

- Meter bounce at high frequencies;
- High-frequency instability that often times shows up as excessive noise;
- "Dirty" sound on sustained instruments;
- Incomplete erasure (no matter how many passes you make!);
- Speed instabilities, even though servo machines are in use;
- Etc. etc. etc.

The majority of tape machines will exhibit at least one or two of the above symptoms of mechanical distress at some point during their operating life. This article is intended to de-bunk a number of commonly held beliefs about tape-recorder maintenance, and provide

the reader with a sensible way to approach optimization of the tape path. Let's start with some idea as to what the transport of a tape machine is *supposed* to do, and then we will discuss some methods that enable us to make the machine conform to our desires.

Optimal Transport Behavior

A tape transport is supposed to provide the following functions:

In the Play Mode —

1. Move the tape across the heads,
 - A. At a constant velocity
 - a) That conforms to industry standards, and
 - b) With minimum short and/or long term speed deviations;
 - B. At a uniform height
 - a) That allows tape-to-head contact positioning which conforms to industry standards, and
 - b) That imposes no undue pressures on the tape as to cause deformity of the medium, (for example, stretching, or scalloping of an edge or edges);
 - C. At a uniform tension
 - a) That allows for consistent tape-to-head contact, and
 - b) That does not deform the tape, as above;
2. Transport the tape from the supply reel, and to the take-up reel,
 - A. At a uniform height, and
 - B. At a relatively consistent tension.

In the Wind Modes —

Provide a high speed transfer of the tape

from one reel to another,

- A. At a consistent tension
 - a) As to provide a tight pack on the reel, and
 - b) At a tension low enough to prevent damage occurring to the tape through deformation;
- B. At a consistent height
 - a) So as to be at a correct height on the reel for pay-out during the play mode, and
 - b) So as not to damage the edges of the tape through scalloping or "long edge" deformation.

In the Stop Mode —

1. Provide sufficient tension to take up any slack in the tape path, and provide for tape-to-head contact;
2. No creep; and
3. Be sufficiently "soft" in tension to allow for manual manipulation of the reels for editing purposes.

Modern day recording adds some of the following demands to the above list:

1. Provide some means of measuring and timing the transported tape; and
2. Detect the end of tape and disengage the transport mechanism.

The above list of operating criteria sounds like it should be a fairly simple task to accomplish. Fat chance! There are a number of physical laws working against us, such as the little known law-of-gravity; we are trying to fight the gravitational force while transporting an elastic medium over fairly large, unsupported distances.

Theoretically, the ideal tape transport would operate with the tape path oriented vertically with respect to the earth. Not only would such an arrangement remove gravity from the guiding system, height of the tape path would also then be easily established by the use of edge guides. However, editing is not very easy when the tape traverses a path that is not perpendicular to the operator's line of sight.

In reality, what all current tape recorder manufacturers are producing is a machine that must provide all of the above mentioned functions, with the least compromise and for the minimum capital expense. There are a number of difficulties in making tape recorders that satisfy all of the above criteria, not the least of which is economy of scale. When you consider that there are less than 15,000 24-track machines around the world, and you compare these numbers to say the manufacture of automobiles — roughly 15,000 a week per manufacturer — then you realize that the economy of scale simply is not there! This fact makes taperecorders, of the two-inch variety at least, very expensive. (The preceding discourse was for the benefit of those makers that we all denigrate for not doing their job as well as we think they should!)

On any orthogonally designed tape transport — in other words, one in which the tape path is at right angles to the deck plate — the primary tape-guiding element is the supply-reel height. The objective of the transport's

guiding elements is to move the tape past the heads, with a tension that is uniform across the surface of the tape. Without the supply reel being at the reference height, either the bottom or the top of the tape will have a longer distance to traverse and, therefore, have a greater tension than the opposite edge.

All transport systems have a designated tape path height above a given reference surface: this height must be the same throughout the tape path (unless, that is, you consider something like the videotape machines, where the tape must travel up or down a given path. In these circumstances, however, the supply and take up reels are angled so that the bottom of the tape, as it moves through the tape path, is a straight line). There have been some instrumentation machines constructed with the reels situated directly above one another, and the elasticity of the tape was utilized to accommodate a tape path that was not a straight and linear path. However, the short wavelength performance of these machines depends upon the consistency of the given elasticity constant of the tape; as a result, they perform poorly with high-frequency analog signals, using different varieties of tape.

All currently manufactured tape recorders intended for studio use are designed to move tape in one plane of travel only. It is a known phenomenon that when a differential tension exists across a moving elastic surface, there is a shift in the plane of travel, so as to equalize the tension across the elastic surface — an effect that accounts for the “hill and dale” action of tape in a transport. The tension can be made dissimilar between the top and bottom of the tape by any number of different aspects of the transport assembly. The most common variant is the supply-reel height. Any non-parallel guiding surface will also cause a top to bottom tension differential in the tape path, which implies that not only must all the motor spindles (capstan, supply, and take-up) be perpendicular to the line of tape travel, but also that all perpendicular guides (contact surfaces) be parallel to one another. (You can imagine what kind of havoc occurs when the supply reel motor shaft has taken a shot, and has 20 to 50 thousandths of an inch run-out at the top!) The edge guides must also be the same height above the reference surface, so as to form a straight line that is positively parallel to the bottom edge of the tape.

There are, however, some misnomers in the above statements. In order to transport the tape off of the supply reel to the first incoming guide, and fulfill the requirements outlined in our introduction, the supply reel flange must be a minute distance from the bottom of the tape. Gravity pulls the

A diagram of a full track tape. It shows a horizontal black bar representing the tape. Above the bar, the text "FULL TRACK" is written. To the left of the bar, there is a vertical dimension line with arrows at both ends, labeled "1/4\" TAPE". To the right of the bar, there is a vertical dimension line with arrows at both ends, labeled "240 TRACK". A small rectangular loop is drawn above the center of the tape bar, representing a tape reel or connector.

Diagram of a tape assembly. The assembly consists of a central tape section flanked by two end sections. The left end section is labeled "1/4 TAPE" with a vertical arrow pointing to its bottom edge. The right end section is labeled "156" with a vertical arrow pointing to its top edge, and "ε TO" with a vertical arrow pointing to its bottom edge. The central tape section is labeled "ORO" at its bottom edge. A bracket above the central section indicates its length.

Figure 1 is a schematic diagram of the test specimen. It shows a cross-section of a specimen with a central rectangular hole. The specimen is composed of three horizontal layers. The top and bottom layers are labeled 'TAPE' with a thickness of 1/4 inch. The middle layer is labeled '0.037' with a thickness of 0.037 inch. The total thickness of the specimen is labeled '0.71 ± 0.06'.

(Values slightly different from Ampex chart below.)

tape to the bottom flange of the supply reel on larger tape sizes. The flange must, of necessity, be below the reference tape height so that rubbing does not occur as the tape leaves the rotating flange. The distance that the reel is below the reference surface must be minimized.

There are a number of different types of guides. The most common types are:

- 4 CHANNEL-4 TRACK

A diagram of a 130-gauge tape. It shows a series of horizontal lines representing the tape's structure. A label '070' is at the top right, and '130 G TO 130' is at the bottom right. The word 'TAPE' is written vertically on the left side.

- Fixed guides posts incorporating edge guides as a top and bottom flange
- Rotating surface guides
- Roller guides (with edge guiding)
- Roller edge guides (rare)
- Capstan(s)
- Pinch Roller(s)

The way that these various guides function is both similar and obvious upon inspection. The least obvious guide is the rolling surface guide. When the tape contacts the roller, it travels in such a way as to minimize any drag coefficients that may exist across the surface of the tape. This means that the

Diagram illustrating the dimensions of a four-track half-inch tape. The tape width is 0.070. The track width is 0.060. The center-to-center distance between tracks is 0.460.

FOUR-TRACK/HALF-INCH
10.070TRACKSON 0.130 CENTERS1

Diagram illustrating the dimensions of an eight-track tape. The tape width is 0.980 inches. The track spacing is 0.070 inches. The track width is 0.060 inches. The diagram shows eight tracks, with the center-to-center distance between tracks labeled as 0.130 inches.

EIGHT-TRACK ONE INCH
[0.070 TRACK SPACING
0.130 CENTERS]

16. TRACK/TWO~INCH
[0.070TRACKSON
0.127CENTERS]

**24-TRACK/TWO-INCH
(0.043 TRACKS ON
0.084 CENTERS)**

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tape will try and travel in the same direction as the surface of the roller which, under ideal circumstances, will be perpendicular to the axis of the roller. The dimensions of the various guides under discussion are determined by the manufacturer, and also by the dimensions of the tape being used. The manufacturing tolerances of the tape used mandate the minimum distance between the top and bottom of the guide. There must always be sufficient clearance in the guide to allow for the maximum width tape that may be used on the particular transport.

There are a number of ways to determine whether or not the supply reel is at the correct height. All the various methods that I know of require some measurement tools not normally found in your common "Jensen"-type tool kit. Some of the more common tools required to perform transport maintenance are:

- Dial calipers that can read to 0.001-inch resolution without difficulty,
- Machinist's square, and
- Surface blocks; the ones that we use are of the following dimensions:

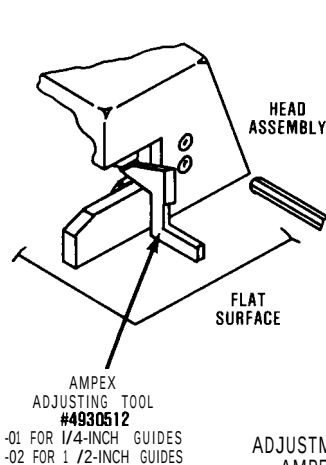
1.996 x 0.375 x 3.000, ± 0.001 inch
 0.996 x 0.375 x 3.000, ± 0.001 inch
 0.496 x 0.247 x 3.000, ± 0.001 inch
 0.780 x 0.750 x 0.625, ± 0.001 inch

All of the above blocks are machined to be "Four Square," meaning that all edges form 90-degree angles so that they can be used as right angles, building blocks, extensions to create a measurement stage, and so on.

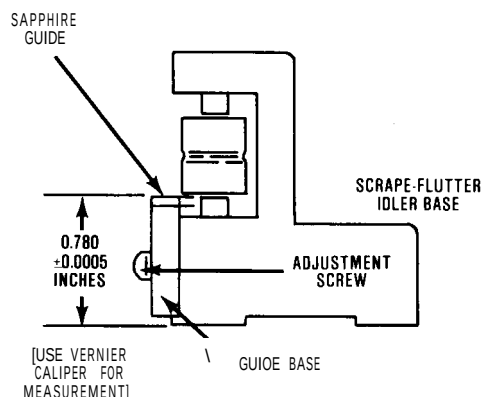
- Dial Indicator, with complete holder accessory package.
- Reference surface; we use a 5/8-by-10-by 10-inch sheet of plate glass.
- Set of brass shim stock material.
- Miscellaneous mechanics/machinist's tools.

As can be seen from the preceding list, there are a lot of tools you don't normally find in your shop that we feel are necessary if you plan to seriously undertake tape machine service.

Returning to my earlier statement, that there are a number of ways to determine correct reel height, the first of



ADJUSTMENT OF SAPPHIRE TAPE GUIDES ON AMPEX HEAD ASSEMBLY AND SCRAPE-FLUTTER IDLER.



which is to measure from the top surface of the bottom-reel flange to the deck reference surface! Such a measurement is not as easy as it sounds most of the time, although it can be done. We prefer to measure with a gauge block from the reference surface to the top of the bottom reel flange. The correct height of the flange will be the reference height minus approximately 0.003 inches. Another way is to see if the tape is being paid out from the reel to the correct height without causing deformation of the tape surface. In other words, the line formed by the tape exiting from the pack is perpendicular to the eye, without any ripples in it. This phenomenon can be only observed upon pay out, however, and not during take up; surface attraction of the wound pack is what causes this line to show up, and it disappears upon take up. We prefer the measurement method. For a list of pertinent heights, see the accompanying Table 1.

Once the correct supply reel height has been established, the in-coming dancer arm and roller guide height and perpendicularity must be observed. Following this is the examination (and correction, if necessary) of the head stack incoming guide(s). The use of a surface block and height gauge is the most expeditious method we have found for accomplishing the above tasks in the field.

The head stack must be examined

next. On most machines, there are some means of adjusting the various parameters of head operation. When the obvious means of adjustment are nonexistent, it is suggested that the head stack be sent to a lapping facility for mechanical alignment. The tools necessary for the proper set up of fixed heads are not portable, nor is it practical to carry a lapping table, micro flat, optical comparator, and such to the studio where the machine is residing!

Head Heights

In order to establish the correct position of the heads in relation to the tape path, there are a number of criteria that must be met. The top gap of a multitrack head should be at the **same** distance from the edge of the tape as the bottom gap. As can be seen from various tape widths shown in Table 1, this is a difficult assessment to make when using tapes from many different manufacturers. It seems to us that the best practice for the operating studio is to set the heights to be correct on the tape that is used **most often**.

In order to work out the correct position of the heads, the record head must be used as the height reference for the other heads. In order to properly center the record head, record a portion of 10 kHz tone, play it back, and note the levels reproduced in sync playback. Turn the tape over, rewind the tape and play the inverted tone, again noting the

TABLE 1: TAPE WIDTHS AND TAPE MACHINE REFERENCE HEIGHTS

By way of an example, Ampex audio tape is manufactured to the following width specifications:

Quarter-inch — 0.246 $\pm$ 0.001 inches.
Half-inch — 0.496 $\pm$ 0.002 inches.
One-inch — 0.996 $\pm$ 0.002 inches.
Two-inch — 1.996 $\pm$ 0.002 inches.

The National Association of Broadcasters only specifies tolerances of quarter-inch tape: 0.248 $\pm$ 0.002 inches.

The "Older Industry Standard" is:

Quarter-inch — 0.246 $\pm$ 0.002 inches.
Half-inch — 0.498 $\pm$ 0.002 inches.
One-inch — 0.998 $\pm$ 0.002 inches.
Two-inch — 1.998 $\pm$ 0.002 inches.

And the "Newer Industry Standard":

Quarter-inch — 0.246 $\pm$ 0.001 inches.
Half-inch — 0.498 $\pm$ 0.002 inches.
One-inch — 0.998 $\pm$ 0.002 inches.
Two-inch — 1.998 $\pm$ 0.002 inches.

Reference Heights for various representative tape machines include:

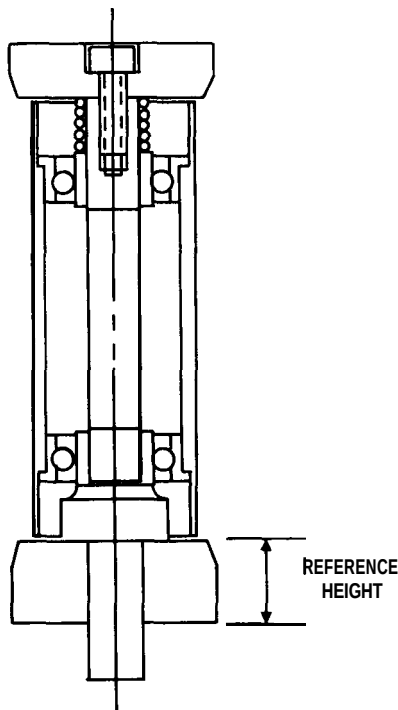
Ampex 300, 350 and 351 0.750 inches, Ampex AG440 0.780 inches, ATR100 0.830, MM-100 two-inch tape 1.000, one-inch tape 1.500 inches, and Auto Tek 0.750; MCI JH-100 0.750, JH-110 0.625, and JH-114 0.750; 3M/Mincom M69 0.812, and M74 0.812; Scully 280 0.689, and 288 0.689; **Stephens** (old style) 0.812; **Studer B-67** 1.572 A-80 1.6025, and A-800 1.6025 inches.

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playback level in sync. Any difference in the perceived levels indicates that the head is not centered on the tape. By deflecting the tape up and down with your finger you can easily determine in which direction the head must be displaced. The corrective action should be such that the level difference first noted should be reduced by one half. When the head has been repositioned (of course, resetting the zenith and azimuth to be correct) the test must be performed again. When the greatest number of tracks reproduce the same level with the tape in either orientation, then the record head is set at its proper height. There will always be some differences in level due to vertical gap scatter or, more succinctly stated, minor track-to-track height differences that are unavoidable in head manufacture.

Once the correct record-head height is established, the playback head can be set by adjusting its height for maximum output when reproducing a tone recorded by the properly adjusted record head.

The erase head is set in a similar manner as the play head, except that it is properly positioned when it is achieving maximum erasure of a tone that was recorded with a proper record-height adjustment. There may be a little



**AMPEX MM-1200 TWO-INCH
INCOMING ROLLER GUIDE**

difficulty with making this measurement, since most erase tracks are wider than the recorded track. Erasure of tracks adjacent to the one being erased is indicative of a height misalignment.

For example, if track #2 is in record, and a 10 kHz tone on track #3 seems to be disappearing, then the erase head is too low, and visa versa for track #1. While on the topic of erase heads, we have found that it is easiest to adjust erase head azimuth by plugging the output into the record-head jacks and in sync mode, using a test tape to adjust in the same manner as a playback head.

Whenever a set of metal heads is to be sent out for relapping, it is also advisable to request that the heads be under-cut, if they are not already. If there is no under-cut, then later height adjustment cannot be performed, since with any wear on the head, a guiding slot has been established that prevents change. If change is attempted, then the surface difference between the worn and unworn portions of the head creates not only guiding problems, but also an area that has large spacing-loss problems. It is not necessary to undercut ferrite or ceramic heads, however, in that there is oftentimes no wear groove, and the only reason for relapping is to remove the surface of the head that has experienced gap erosion. Where adjustments can be made, the face of the head must be set up parallel to the tape path (zenith), the head gaps must be centered on the tape (height), and the gaps must be perpendicular to the tape travel (azimuth). The out-going guide height and perpendicularity must be assured, usually with the aid of shims.

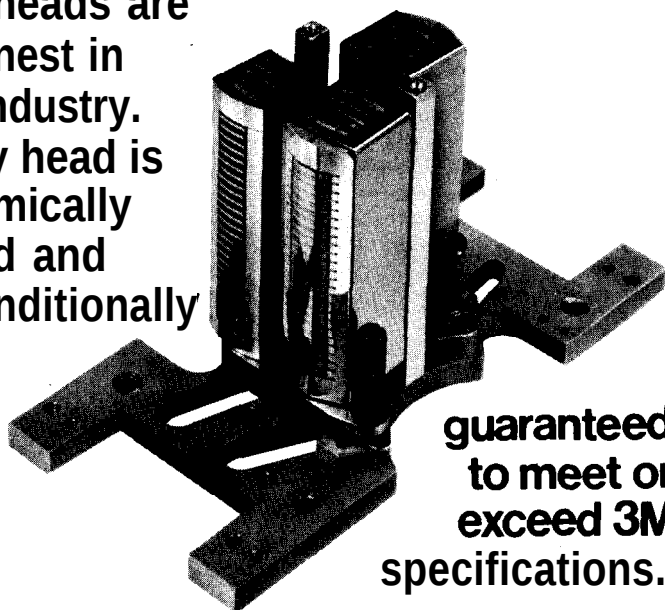
Capstan and Pinch Roller Alignment

The next important guiding element of the tape is the capstan/pinch roller system. Any azimuth error in the capstan shaft will drive the tape in the direction of the tilt of the shaft. The easiest method of determining accurate capstan azimuth is to observe the tape as it is exiting the outgoing head-stack guides. If the capstan alignment is correct, the tape will neither ride up nor down when initiating play, but will assume and maintain a given height. If the capstan azimuth is incorrect by set up, then the tape will ride to one edge of the outgoing guide and will be bound there. In extreme instances, the tape will be observed to ride out of the guide, especially when encountering leader, or a splice. The tape path should encourage the tape to ride in the proper place on the guides, and assume to correct height, even when physically pushed out of its correct path. However, the correct hold-back tension for the system should exist for the above statements to be true.

The very basic capstan drive is a rotating shaft driving the tape at a constant speed, the tape being pulled by friction. In order to maintain a reasonable tension over the heads, the most method is to clamp the tape against the capstan with a compliant pinch roller. The tape speed is now determined by the pinch roller, since the area on the pinch roller and the

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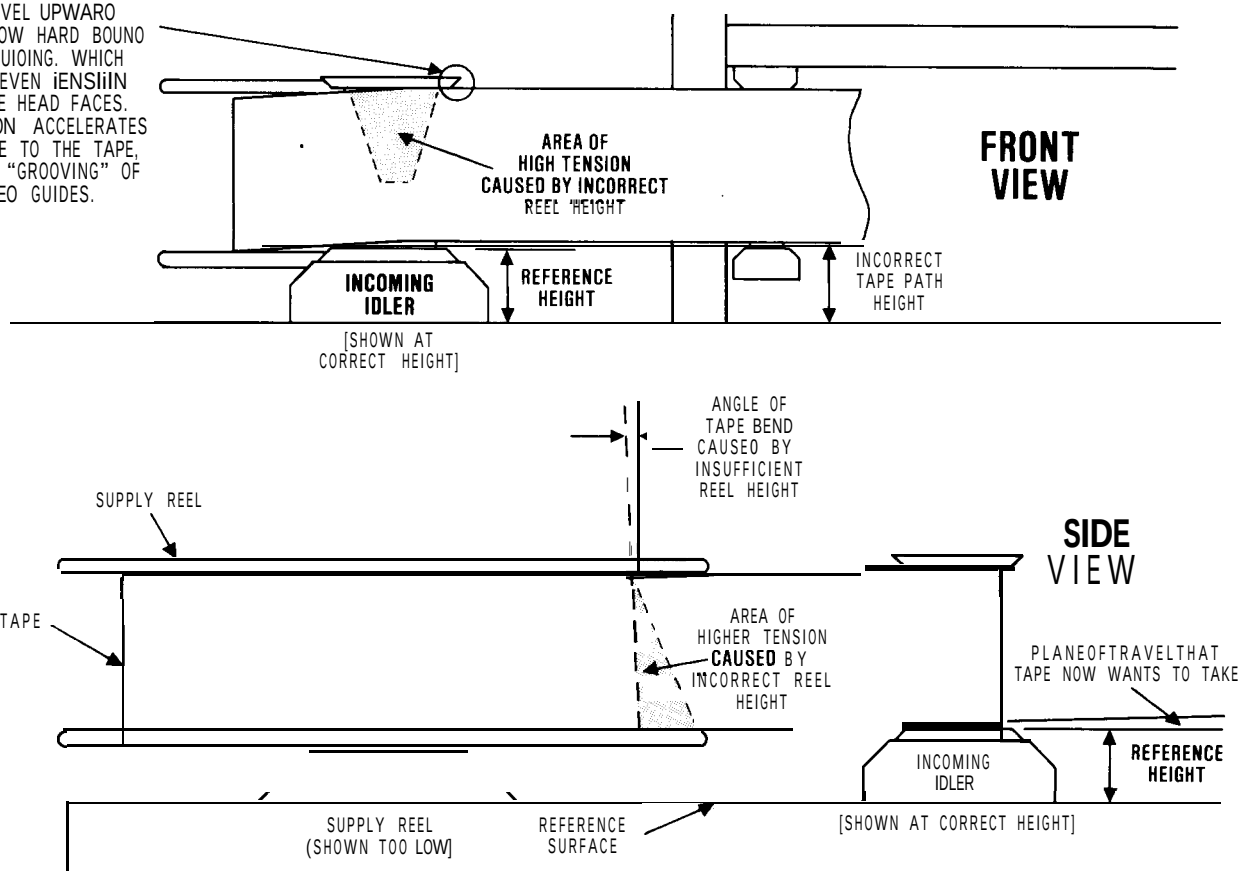
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POTENTIAL TAPE TENSION PROBLEMS CAUSED BY INCORRECT SUPPLY-REEL HEIGHT

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coefficient of friction between the roller and the tape is greater than that of the capstan and the tape. As a result, the true tape speed may no longer be equal to the surface speed of the capstan. Because the pressure causes an indentation of the pinch roller, the effective radius of the roller is reduced from R_2 to R_3 . The tape enters and follows the pinch roller during angle θ_1 with speed of V_1 , and leaves the roller during the angle θ_2 .

The surface speed of the pinch roller in the nip area is somewhere between

$$V_2 = \omega R_2, \text{ and } V_3 \leq \omega R_3,$$

and the tape speed is:

$$V_3 \leq \text{Tape Speed } V \leq V_1 < V_2.$$

The tape leaves during the angle θ_2 and the surface speed V_2 of the pinch roller is greater than the tape speed, V . Therefore the tape will slip and the relative speed difference between V_2 and V will be small, so that large scale stick-slip friction occurs. This would also be true if the tape contacted the pinch roller prior to the capstan, which generates a high degree of scrape flutter that is induced into the head area, and is buffered by the capstan in a well designed transport².

Pinch rollers are a study in themselves! Over the years, many different types of material, densities, diameters,

strike positions, and heights have been tried, in an attempt to minimize the influence of the rotating rubber tyre of the path of the tape. The greatest success has been encountered in cases where the pinch roller is not hard bound to a given zenith, but is allowed to self center on the capstan shaft. It has been noted that the influence of the pinch roller is minimized by grooving the surface of the pinch roller on wider tape widths, to make it seem to the tape that it is being driven by a number of small rollers. On Ampex transports, for example, considerable improvement is made by reducing height of the roller to less than the width of the tape for MM-1000, -1100, and -1200 machines.

The pinch roller contact pressure should be sufficient to maintain intimate contact between the capstan and the tape. The exact figures are given by the manufacturer for the pinch roller pressure and, as can be seen above, this pressure to a great degree will determine the speed accuracy of the transport! The slippage that occurs in the capstan can be minimized by making the capstan diameter as large as possible, a fact that is evidenced in the design of later machines. It is also advisable to retrofit older, low-speed machines (3% and 7% IPS) with a new capstan that has a larger diameter and a lower RPM. The slippage is also exaggerated when the burnished finish of the capstan shaft is polished off by the slip-stick action of the tape. When this occurs, speed errors

are greatly increased, and the short-term speed is influenced much more by the supply and take-up reel tensions. (Here you find an explanation for the timing errors that occur on most two-track machines!)

All (or most) of the above discussion has centered upon the open-loop type or transport design, but much of it still holds true for closed-loop designs, such as the 3M-Series of stereo and multitrack machines. With a single capstan, and two pinch rollers engaging different diameters of the single capstan, and two pinch rollers engaging different diameters of the single capstan, as in the 3M transport design, tape tension is maintained across the heads. (With the Technics design, however, the pinch-roller pressure is established as the differential between the incoming and outgoing idlers; the incoming pinch roller contacts the tape on the supply reel side of the capstan, so that the capstan shaft can buffer out the scrape flutter created by stick-slip.) On 3M transports, the incoming idler engages slots in the capstan that should be 0.003 inches smaller in diameter than the outgoing idler engagement position. In other words, the outgoing idler is trying to take more tape out of the loop than the incoming idler is bringing in, and it is this principle that creates the loop tension on such transports.

The most sensitive area of closed-loop design transports is the perpendicularity of the reversing idler on the front

of the transport. If the pinch rollers are adjusted to have too great a tension, then this idler will exhibit a small degree of bending that causes perturbations of the tape path. The tape will try and climb up this idler, while being guided out of the loop at a different height, causing the tape to ride up and down around the reversing idler a closed condition that should be avoided! Tape speed of a closed-loop machine is also determined by the existence of the burnished surface of the capstan. When this surface becomes shiny after much use, it should be replaced.

It is equally important that tape runs at the proper reference height for both open- and closed-loop type of transport designs. After the tape exits the capstan, it usually encounters either an outgoing idler (which usually comprises some form of counting system) or on the smaller width transports, an end-of-tape arm; the same rules of height and perpendicularity exist here. From this point, the tape encounters the take-up reel. The reel height should also be about 0.003 inches below the reference height, to allow the tape to evenly pack on the reel without being scalloped by the minor variations in reel height due to bent flanges. It should also be noted that the various tape manufacturers use slightly different flange thicknesses. All of which means that a tape machine should be provided with a good straight supply reel that stays with it in the studio, and that the take-up height should be set for the type of tape that the studio uses most often. (To this author at least, it seems a bit impractical to set the reel heights every time a different brand or type of tape is being used.)

Well, that pretty much takes us through the entire transport! Oftentimes, the effects of various parts being in minor misalignment results in the machine being only a bit peevish about maintaining its calibration. But there are other times when the beastly will try and separate every splice that runs through it or, better yet, runs the tape out of the guides, under a flange, and transform two-inch tape to something under S-inch! Usually in these situations, the star performer died a month earlier, so duplication of the performance is impossible.

When dealing with the mechanical repair of tape machines, it is always best to be careful and methodical and check out the system from the beginning to the end. Changing a factory adjustment should only be done after you have proven to yourself in two or three different ways that it *is* indeed incorrect. It is with horror that we have encountered machines where the customer, in trying to "correct" the initial mechanical alignment of the machine, has tightened every screw, and removed every shim! When properly performed, it is not uncommon for a complete mechanical overhaul to take two or three days to complete, even when all of

the parts needed to complete the job are on hand. The factory is often reticent about providing advice on mechanical alignment because, most of the time, more harm than good comes from unenlightened poking, probing and prodding. Whenever a guide is removed, or a bearing replaced, it is always a good practice to take notes on how many and what size shims were there.

The concept of thinking about *how* and *why* something works the way it does goes a long way whenever service is to be performed. With care and attention, and access to the correct adjustment tools, a tape machine can be kept in perfect tune. This article should prove helpful in showing the way

towards keeping the studio hardware running. ■ WU

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For general reading and reference to various technical bulletins:

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