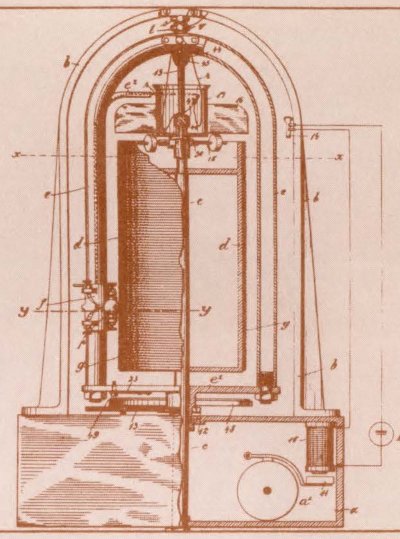
INSTRUMENTATION TECHNICAL INFORMATION NUMBER 4



SIGNAL TIME COINCIDENCE IN AN INSTRUMENTATION TAPE RECORDER

AMPEX

A multichannel instrumentation tape recorder exhibits some predictable time differences between its various data channels. These may or may not cause a problem in a given application depending upon how accurately you need to correlate time between events recorded on different channels. Interchannel timing errors can be attributed to three main factors: 1) Static delays (skew) caused by head manufacturing tolerances and any guiding misalignment of the tape path relative to the heads; 2) Dynamic delays (also commonly called skew) caused by the tape transport and the flexibility of the tape; 3) Static and dynamic delays caused by the electronics.

STATIC TIME ERRORS

The major cause of static timing errors in a multichannel recorder is the manufacturing tolerances of the heads. To illustrate, take as an example the specifications of the Inter Range Instrumentation Group (IRIG) for head design which furnish the standards adhered to by most tape recorder manufacturers (IRIG 106-66, Section 6).

Gap Scatter................	100 microinches
Stack Spacing..............	1.500 ±0.001 inch
Head Tilt..................	±1 minute of arc

Gap Scatter. A multiple track instrumentation head stack has a number of individual heads (typically 7 for a 1-inch staggered head stack), incorporated in the stack. It is mechanically impossible to exactly align these gaps, so the term gap scatter refers to the actual tolerance of alignment of each of these tracks in relation to a line through the mean position of all gaps in the stack. The positional tolerance of these head gaps within a given stack is a band 100 microinches in width. The worst case condition of timing between two tracks would be when the gaps in question on the record head stack were at one limit of the tolerance while those at the reproduce stack were at the opposite end of the tolerance band. This gives a worst case error of 200 microinches between two tracks allowing 100 microinches in the record and 100 microinches in the opposite direction on the reproduce head. As a final note it should be stated that this error is somewhat random in occurence within a stack, and heads with the widest spacing or error may occur adjacent to each other or at the opposite ends of the stack.

Head Stack Spacing. In order to achieve the normal recording density of 14 tracks for 1-inch tape (or 7 tracks for ½-inch tape), it is necessary to place half the heads, the odd numbered tracks, in one stack and the even numbered tracks in a second stack. This allows sufficient shielding to be provided between tracks in the head stack to minimize undesirable signal coupling and crosstalk. The normal spacing difference between the odd and even head stacks is 1.500 inches with a tolerance of ±0.001 inch. This means that under worst case conditions (record stacks spaced at one limit of this tolerance and reproduce stacks at the other limit), adjacent odd and even tape tracks could be displaced from each other by a possible 0.002 inch (2000 microinches).

Head Tilt. This measurement and specification refers to the difference between the mean gap azimuth of a given head stack and a line perpendicular to the edge of the tape. In practice this may be caused either by lack of perpendicularity between the head stack and base plate, or the misalignment of the tape path of the transport relative to the head. These effects are difficult to separate and are usually tested as one measuurement. No attempt will be made here to separate them. The value permissible under IRIG specifications is ±1 minute of arc or a distance approximately 280 microinches across a 1-inch tape width. Again this is an additive specification. Thus in a worst case condition this figure could be doubled between record and reproduce head stacks.

Time Dimensional Changes. Additional effects are caused by the inherent characteristics of the magnetic tape which are not a function of head manufacturing tolerances. The backing of tape is an elastic material. As such, the distance between any two points on the tape depends on the tape tension to some extent. This shows up primarily as a change in the 1.5-inch gap-to-gap dimension. Large temperature changes between the time of recording and reproducing and uncontrolled long term tape storage conditions can have the same effect. This tape tension effect is not as significant as other head spacing tolerances as its value is approximately 240 microinches change across the 1.5-inch head spacing with a 1-ounce tension change between the record and reproduce process on ½-inch tape (1 mil backing thickness). A more significant change is observed if the temperature is varied between the record and reproduce process. For a 50°F difference, the 1.5-inch spacing will change 750 microinches.

An even more interesting change is observed if the relative humidity of the air around the tape is varied over its full range between record and reproduce. In this case, a relative humidity change from zero to 100% would vary the 1.5-inch head spacing by 1650 microinches, more than all other effects put together. These phenomena, although seldom considered, result from the physical properties of polyester base materials of magnetic tape.

DYNAMIC CHANGES

Dynamic skew and dynamic registry changes between channels are caused by runout of the tape transport, which is always present to some degree, as well as tape guiding eccentricities, tape slitting errors, and tape damage. While static skew can be allowed for and ignored to some extent in the data, dynamic skew is a time variable phenomenon and thus is much more difficult to eliminate. The only known method for minimization of this is control of the record and reproduce transport guiding. Typical values of dynamic skew on a state of the art basis are 250 microinches from record to reproduce across the full width of a 1-inch tape. Typical tape transports of the instrumentation variety have a normal value of 500 microinches. (The zero loop design of the Ampex FR-1800 and FR-1900 capstan reduces the dynamic skew to 225 microinches.)

ELECTRONIC DELAYS

The delay variation between channels caused by the signal record and reproduce electronics are normally inconsequential compared to the mechanical delays shown above. For instance, the time delay from a FM system would be primarily a function of the reproduce filter. The typical delay of such a filter for a 10-kHz bandpass (60 ips) would be 62 microseconds with a delay variation of only 1 to 2 microseconds between filters. This would correspond to only 120 microinches at 60 ips, well below the values for mechanical errors.

MEASUREMENT CONVERSION

In the previous discussion, dimensional changes caused by heads and tape are expressed in two different units: linear measurement in microinches and time measurement in microseconds. The conversion between units can be easily made if you remember that a tape recorder running at 120 inches per second moves tape 120 microinches per microsecond. This would mean a linear error of 240 microinches would occupy 2 microseconds of time at 120 ips, 4 microseconds at 60 ips, etc.

WORST CASE CONDITIONS

Figure 1 is a compilation of the various skew contributions in an absolute worst case condition. It is divided into 1) errors caused by the tape dimensional change, 2) errors caused by transport and head static errors, and 3) errors caused by transport dynamics. It should be noted that the contribution of the tape back material (polyester) due to extreme environmental changes is approximately as great as all other manufacturing tolerances on the head assembly. The majority of these contributions are of largest effect on the stack-to-stack spacing of 1.5 inches, and this is the real cause of misregistry problems.

In-Line Heads. The minimization of these errors by the use of an in-line head assembly can be illustrated by Figure 2. This is the same data as Figure 1 with the exception that the errors caused by the 1.5-inch spacing, the tolerances on it and changes to it, are eliminated by the expedient of manufacturing a head with all tracks in a single stack. However, manufacturing a single in-line head stack with the same number of tracks as two staggered head stacks creates two main problems. First, it requires that the amount of intertrack shielding be reduced. This increases the crosstalk between data channels. Second, the track width must be reduced which cuts the signal-to-noise ratio, since it is impossible to make a full width track because there is only a 20-mil space between them. Little or no room remains for shielding, mounting, or wirewinding. FM recording is desirable when using in-line heads because its inherent signal limiting characteristics help compensate for the increased crosstalk and reduced signal-to-noise ratio. Bandwidth will be reduced with FM as compared to Direct, so the trade off with dynamic range must be weighed against this. An alternative to special in-line heads is to put all data needing precise time correlation in the same head stack.

Significance to User. What does this mean to the user of instrumentation recorders? In real terms if he is recording vibration data on different tracks of a recorder, the correlation available betwe heads on different head stacks may limit the able correlation frequency to below 1 kHz at ips. Two ways to get around this are to use in-line heads (with an FM recording technique, depending on bandwidth and dynamic range requirements) or a method of multiplexing such as constant bandwidth FM which places many data channels on the same tape track. On 1.5-MHz channels, for instance, constant bandwidth recording may allow at least 7 tracks of 20-kHz data with approximately 40-dB signal-to-noise ratio to be put on the same data track, or up to 49 channels in the same 1-inch, 7-track head stack.

While the values presented in the table are worst case values, they do illustrate the extent of the problem. Even if it were possible to significantly reduce all the mechanical contributions of the transport to the time misregistry of the data, the environmental problems related to the tape could still cause large amounts of trouble with a staggered head arrangement. It would appear that the only solution for the user who must have the ultimate in registry between data channels lies in the use of in-line head assemblies with their inherent drawbacks, in-line recording on the same head stack of critical time related data, or a method of multiplexing which preserves the data registry of all channels within the same track. Other methods of electronic registry are possible, but the cost is extremely high.

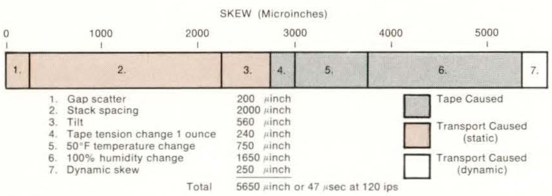


FIGURE 1. Worst case skew for a staggered head assembly. Most errors are caused by the tolerances related to the 1.5-inch stack-to-stack spacing.

FIGURE 2. Worst case skew for an in-line head assembly. Although it eliminates the major source of errors (stack-to-stack tolerances and dynamics) an in-line head has two drawbacks: 1) crosstalk increases beyond an acceptable level, 2) narrow (non-standard) track spacing is required, which reduces the signal-to-noise ratio, and makes the tape non-interchangeable. Recording all time-related data in the same staggered head stack is a commonly used alternative.

Reprinted from READOUT®
Volume 7 Number 4
A magazine of Ampex Corporation

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