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Azimuth in a Magnetic Tape Recorder

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Introduction

Maintaining consistent azimuth angle is perhaps our most difficult job. It is an important problem for the user, but there aren't many good papers on the subject, so this paper attempts to tell you what we do know.

MRL's Azimuth Tolerance

Our azimuth tolerance is an absolute mechanical angle of ±300 microradians (µrad), as given in §5.2.3 of the MRL Publication "Choosing and Using MRL Calibration Tapes..." that is available free from MRL http://home.flash.net/~mrltapes/choo&u.pdf which says:

> ***Mechanical Azimuth Angle***
>
> All signals are recorded with the tape flux parallel to the longitudinal axis of the tape.
>
> Tolerance on mechanical azimuth angle.. . . . . ±300 µrad (±1 min)
>
> *Conversion of Mechanical Angle to Electrical Angle*
>
> The more common measure of azimuth error is the *electrical* phase angle between edge channels on a multi-track reproducer. This electrical phase angle depends not only on the mechanical azimuth error, but also on the tape width, tape speed, and test frequency used for the measurement. With the specified mechanical azimuth angle error (±300 microradians, equivalent to ±1 minute of angle), and a 10 kHz test signal, the electrical phase angle between 2-mm wide edge tracks will be as shown in the Table below. ***If a different test frequency is used, the electrical phase angle will be directly proportional to the ratio of the actual test frequency to 10 kHz.***

Electrical Phase Angle at 10 kHz for a
Mechanical Azimuth Angle of ±300 µrad (±1 min of angle)

Tape Speed	For 2 mm Edge Tracks on a Tape Width of:			
	6.3 mm **¼ in**	12.5 mm **½ in**	25 mm **1 in**	50 mm **2 in**
95 mm/s **3.75 in/s**	±45°	±110°	±260°	NA
190 mm/s **7.5 in/s**	±22°	±55°	±130°	±280°
380 mm/s **15 in/s**	±11°	±27°	±65°	±140°
760 mm/s **30 in/s**	±5°	±14°	±32°	±70°

Our specification is for any MRL Calibration Tape, relative to "absolute mechanical angle of flux to tape direction"; this *mechanical* angle does not depend on the tape speed, and the tolerance is not with respect to any particular sample of recording.

But note that you will usually measure an *electrical* phase angle, and in this case you must know the tape width, tape speed, and test frequency in addition to the electrical phase angle, in order to know whether that phase angle is within our specifications or not. When dealing with an inconsistency between two tapes at different speeds, consider the following apparent paradox: suppose you have two 50-mm (2 inch) wide tapes, one at 380 mm/s (15 in/s) and the other at 760 mm/s (30 in/s). Suppose you set azimuth to 0° at 380 mm/s, and measure the error at 1 kHz, 760 mm/s; the tolerance would be ±7°. But if you set to 0° at 760 mm/s, and measured at 1 kHz, 380 mm/s, the tolerance would be ±14°. If, on the other hand, you use 500 Hz at 380 mm/s, and 1000 Hz at 760 mm/s, the tolerance would be ±7° in both cases.

A major difficulty of interpretation of the specification is that you don't have a reference to measure from—the two MRL recordings in the previous paragraph could be consistent and completely wrong, or (for 1 kHz and 760 mm/s) 14°

different and ok because they were of opposite directions (that is, one at +7°, and the other at -7°). In this case the best thing that I can recommend is for you to make a direct fundamental azimuth measurement yourself.

Absolute Azimuth Measurement Methods

Many schemes have been proposed for the absolute measurement of the mechanical azimuth angle. Unfortunately I do not know of any that does not introduce its own sources of error. As so often happens in tape recording, there is not “another” (that is, non tape-recorder) mechanical system that is inherently more sensitive and more accurate than the tape recorder itself. In most cases, the alternate systems have even lower sensitivity and more uncertainties than the tape recorder!

The scheme that we use is to measure the electrical phase angle change when you reverse the tape front-side-to-back-side, so it is oxide-out, and you play the signal *thru the backing*. This reverses the azimuth angle error. I shall call this “reversing” the tape, as opposed to swapping the reels and playing the tape from the other end.

> How you actually physically reverse the tape depends on the tape width and the particular tape transport that you are using. For 6.3 mm (quarter inch) tape, you can just put a “twist” in the tape as you play or fast wind it. For 50 mm (two inch) tape this is not usually possible. How to do it will take some figuring out. Whatever scheme you use, try it first on a piece of “scrap” tape, because your transport may convert the tape into scrap.

Transport Consistency Check

Swapping the reels and playing a tape in the reverse direction does NOT reverse the azimuth error, but it does provide a good way to check the consistency of the mechanical system: a tape transport should be completely symmetrical when the reels are swapped, and the tape is played in the reverse direction. Thus the azimuth angle measured when a recording is played “head to tail” should be identical to that measured when the reels are swapped and the tape is played “tail to head”. Any difference in azimuth that you measure in practice in end-for-end playing gives some feel for the limits of repeatability of the transport system.

How MRL Determines Azimuth

We measure electrical phase angle using a recorded signal of sufficiently long wavelength (low frequency—say 1 kHz for a 50-mm wide tape running at 760 mm/s) that we get good azimuth-test signal level even with the “thru the backing” spacing loss when playing the tape reversed. In other words, when measuring a given time delay, it is easier to get a more sensitive phase meter (±18° full scale) which allows using a low frequency (1 kHz) which in turn gives a clean, high-level signal (only 6 dB of attenuation); than to use a low-sensitivity phase meter (±180° full scale) which requires a high frequency test signal (10 kHz) which will be low level (60 dB of attenuation) and therefore very noisy. Thus our measurement is made with a 1 kHz signal for the edge-tracks on a 50-mm tape width and 760 mm/s tape speed. Under this condition, the ±300 µrad mechanical angle corresponds to an electrical phase angle of ±7°. Because mechanical reversing of the tape doubles the error of the recording, if you set the azimuth for zero phase error on one of our Calibration Tapes, then reverse the tape (oxide-out) and measure the phase angle, the angle you measure is twice the actual azimuth error of the recording.

Such a measurement should enable you to determine which of the several recordings that you have are within our azimuth angle tolerances, and which are outside of our tolerances.

Measuring the Electrical Phase Angle

Analog electrical phase angle meters that work well in this application include the Wiltron Model 351, and the Wavetek Model 740. These meters have been discontinued by their manufacturers, but you may be able to find used ones.

In general, the phase angle on a tape recorder is continually varying, at a rate depending an the tape slitting and the tape speed. The galvanometer meter on an analog phase meter gives a certain low-pass effect; additionally, the phase meter may include an “output smoothing” (low-pass) filter. Therefore the electrical phase angle changes may appear to be larger at low speeds, because the phase meter filters them out at higher speeds.

Digital electrical phase angle meters may be unusable if they do not have sufficient “output smoothing” — you would see wildly “dancing” numbers that are unreadably. So try any digital-display meter before you buy it.

The other electrical phase angle measurement method is an x-y display on an oscilloscope. The method is explained in the Appendix.

Why Can’t Azimuth be Controlled More Closely?

We are often asked about the ±0.3 µrad specification – recording engineers would like smaller time delay values, but they simply cannot be realized in practice by the simple “brute force” mechanical systems used in analog audio transports. We find that the uncertainties of our mechanical tape transport systems (Studer A80s) are something like ±0.15 µrad “on a good day”. Thus even if we allowed no manufacturing error at all, we could not better ±0.15 µrad. We need to allow an equal practical manufacturing tolerance of ±0.15 µrad, and this gives the published ±0.3 mrad.

The uncertainties mentioned above reflect the limitations of the design and construction of the mechanical systems – including the tape itself – used in all commercial tape recording transports, and the fact that very small mechanical angles cause appreciable time delays between – phase shift – in the recorded signals on the two edge tracks. These are quantified by way of an example for a 6.3-mm recorder in AES Preprint 1666 on “Azimuth and Interchannel Time Displacement Error...” available from MRL at no charge http://home.flash.net./~mrltapes/mcknight_azimuth-and-interchannel.pdf . I believe that you will find the situation on 50-mm tape not too different -- you can calculate the angle that the tape can move between the guides, and it will probably be comparable to that for the 6.3-mm system.

We learned it 1994 that in a space instrumentation application, where they are *very* serious about tape guiding, they use an active tape guiding system: The tape edge position is sensed optically, and the tape is guided by changing the zenith angle of a roller in the tape path. This is what one would have to do to better control the azimuth and time delay between tracks in a multitrack audio tape recorder.

Other Manufacturers’ Azimuth Tolerances

M IEC Publication 60094-2 (nee 94-2) (1975), Sec. 3, General requirements, specifies “Each section shall be recorded at a recording angle of 90° + 2', relative to the edge of the tape.” (the + is a typo: should be ±.)

M Agfa literature for 6.3 mm tape width: “Azimuth Position 90° ±2'.”

M BASF literature for 25 mm tape width: “The magnetization is in right angle to the tape run direction with a tolerance less than ±3 min. (deviations are lower than the measuring accuracy of ±1 min.). “

M STL (Standard Tape Lab, which went out of business in 1999-04) literature does not contain any azimuth accuracy specification that I can find.

Sources of Error

This paper assumes that the azimuth is measured by measuring the phase or time-delay between two channels (usually the edge channels) of the tape recorder. With this technique it is necessary that the electrical phase response of the heads and amplifiers be identical. This is usually the case, but it should be verified: Use an induction loop to make a flux input to the reproducing head, and see that the channels stay in phase over the entire frequency range of interest. Since this system is usually a minimum-phase system, any difference in the channels’ frequency response (even above the audio bandwidth) will make some difference in their in-band phase response. Even a difference in the head resonating capacitor and damping resistor may make a measurable phase error, tho it will usually be small compared to the mechanical errors.

There are a number of mechanical errors in the tape and the tape transport that produce tape tracking errors or inconsistencies, and these produce inconsistent azimuth readings. These include:

M blank tape that was slit, not in a straight line, but sinuously (“country laneing”), which produces azimuth that varies back and forth, often with a period corresponding to a tape length of 1- to 3-feet. Ampex/Quantegy tape sometimes had this slitting problem – try to find a roll of BASF/Emtec tape, historically, it had very good slitting)

M tape wear grooves in the heads and/or guides, that act a additional guides that can act intermittently and cause more than one apparently stable guiding position; guide the tape with your thumb to see if the tape can take more than one stable position;

M differences in the height of the tape pack on the reels, and/or differences of the reel turntable heights and/or differences in the tape flange thickness, all of which can cause the tape to be fed into the head assembly at different heights, and therefore at different angles relative to the head gaps;

M the “zenith” error of the heads and guides, which causes a deflection of the tape path that depends on the tape tension and compliance, and therefore an azimuth error that changes with the tape tension at the heads;

M the “azimuth” error of the *capstan shaft* which pulls the tape up or down on the head face, changing the angle between the tape and the head;

M a polished capstan shaft, which allows the rubber capstan idler roller to guide the tape, especially if the roller shaft is not self-adjusting, and is not exactly parallel to the capstan shaft; and if the roller is wider than the tape, in which the capstan drives the roller which in turn drives the *back* of the tape; this effect is similar to the one just above, where the capstan shaft has an “azimuth” error;

M the two errors above (capstan shaft and capstan idler roller “azimuth” errors) may be in opposite directions, so that the tape will pull upward out of the capstan at one tape tension, but downward out of the capstan at another tape tension;

M when the tape is reversed (run with the oxide out), the difference in coefficients of friction of the oxide-side and the backing-side may cause differences in the tape guiding.

Finally, an effect that we have observed on 6.3 mm width tapes, but have not seen on wider tapes: Suppose that we record a tone on a tape, then cut it into two pieces. The azimuth on both measures the same, as it should. We put one aside, and we use the other about twice a day to set azimuth on our tape transport. After a month or two we compare the azimuth on the used tape and the set-aside tape, and find that the azimuth is considerably different (sorry—don’t have a value at hand).

We do not know in what way the tape has changed to cause this effect, but it happens repeatedly. It does mean, however, that using one “master azimuth” tape apparently does *not* guarantee azimuth consistency! It also means that when you compare the azimuth of a new Calibration Tape with that of a used one, and you observe a difference, it is not certain whether they were differently manufactured to begin with, or whether the used one has simply changed from its original azimuth because of being used repeatedly.

When you include all of these other problems, I think you'll find it surprising that the time delay errors aren't even worse!

Azimuth Differences Between Tapes of Different Speeds

When two tapes of different speeds show different azimuth angles, the source of difficulty could be that the tapes really were recorded at different azimuth angles, or it could be any of the many possibilities listed above. One valuable consistency check is to pick one of the tapes, and play the tone you are using for azimuth measurement at the normal speed of the tape, and set the azimuth to 0 °. Then, using the *same tone on the same tape*, change only the tape speed to the speed of the other tape, and measure the azimuth. It should still be 0 °. Any change of phase angle represents a problem with the *transport* or the *reproducing* electronics, not with the Calibration Tape. Then repeat this test, using the other tape.

If the difference between the tapes is considerably greater than the difference in the same tape, same tone, at the different speed; then the tapes really do have different azimuths.

Appendix: Measuring Phase Angle With an Oscilloscope

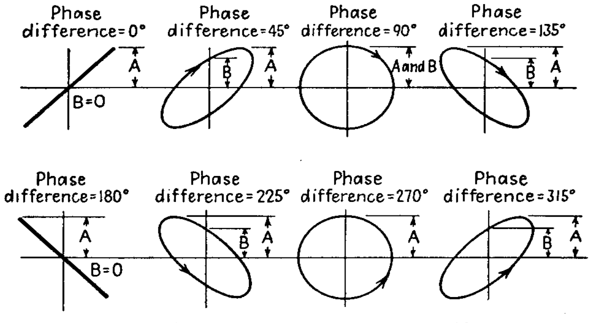
The following is reprinted from Terman and Pettit, "Electronic Measurements", 2nd edition, McGraw-Hill Book Co, New York, 1952, page 267.

6-9. Measurement of Phase Difference. *Cathode-ray-tube Methods.*

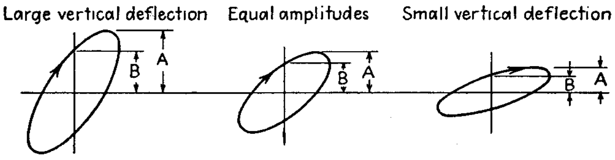
A cathode-ray tube is commonly used to determine the phase difference between two voltages of the same frequency. Thus, if one of these voltages is applied to the horizontal-deflecting electrodes, while the other is applied to the vertical deflectors, an elliptical pattern results, the exact character of which depends upon the relative phase and amplitude of the two voltages concerned. Patterns in typical cases are shown in Fig. 6-24. The phase difference θ between the two waves is given by the formula

$$\sin\theta = \pm (B/A) \qquad (6\text{-}14)$$

where A and B have the significance shown in Fig. 6-24. The quadrant must be worked out from the orientation of the major axis of the ellipse and the direction in which the spot travels.



Equal amplitudes and varying phase differences



Constant phase difference of 45° but varying amplitude on vertical deflection

FIG. 6-24. Typical patterns produced by a cathode-ray tube when sinusoidal voltages of the same frequency, but differing in phase and amplitude, are applied to the horizontal and vertical deflectors.