960201

Determining the True Azimuth in Compact Cassette Drives

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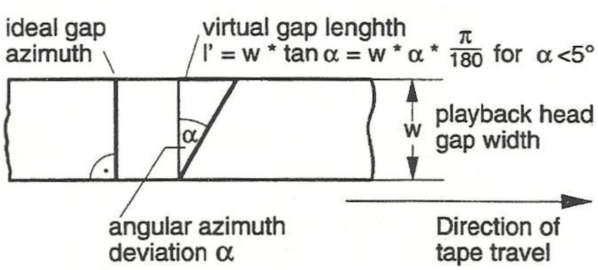
ABSTRACT

In the compact cassette and duplicating business for prerecorded cassettes, the importance of accurate azimuth alignment has grown over the years. Improvements in tape technology at the one hand and in recorder electronics and magnetic heads on the other extended the frequency response of the compact cassette system far beyond 10 kHz, resulting in continuously growing demands in azimuth accuracy. Three major effects will be discussed, which influence the audibility of insufficient azimuth alignment.

1. Losses due to Virtual Gap Length by Incorrect Azimuth

High frequency level losses originate from the elongation of the replay head gap by the deviation from the perpendicularity of the gap from the direction of the tape travel or the recording. Figure 1 demonstrates the effect and shows the mathematical dependencies.



$$l'_{[\mu m]} = \alpha_{[min]} * w_{[mm]} * \frac{\pi}{180}$$

Figure 1: Virtual gap length l' as a function of azimuth displacement and trackwidth

For the further observations it is useful to normalize the equation for the azimuth losses A_L to the recorded wavelength, given by tape speed v divided by recorded signal frequency f (Figure 2):

$$\frac{l'}{\lambda} = w * \alpha * \frac{\pi}{180} * \frac{f}{v}$$

$$\frac{l'}{\lambda} = \frac{\pi}{108} * w_{[mm]} * \alpha_{[min]} * \frac{f_{[kHz]}}{v_{[cm/s]}}$$

$$A_L = -20 * \log * \frac{\sin \pi * \frac{l}{\lambda}}{\pi * \frac{l}{\lambda}}$$ or, in tape related dimensions:

$$A_{L\,[dB]} = -20 * \log * \frac{\sin\left[180° \left(\frac{\pi}{108} * w_{[mm]} * \alpha_{[min]} * \frac{f_{[kHz]}}{v_{[cm/s]}}\right)\right]}{\pi * \left(\frac{\pi}{108} * w_{[mm]} * \alpha_{[min]} * \frac{f_{[kHz]}}{v_{[cm/s]}}\right)}$$

Fig. 2: Azimuth losses caused by angular deviation from perpendicularity

The results will be visualized in the following figures 3, 4 and 5 for 1, 3 and 5 minutes of azimuth deviation.

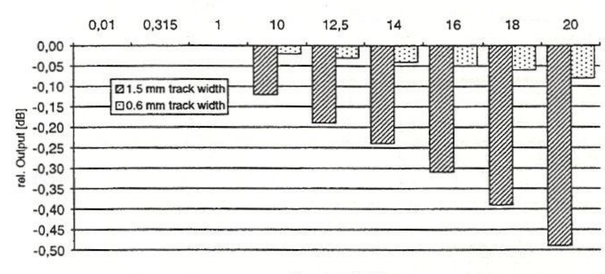


Figure 3: Output variation by azimuth displacement versus frequency at tape speed 4.76 cm/s and 1 minute deviation

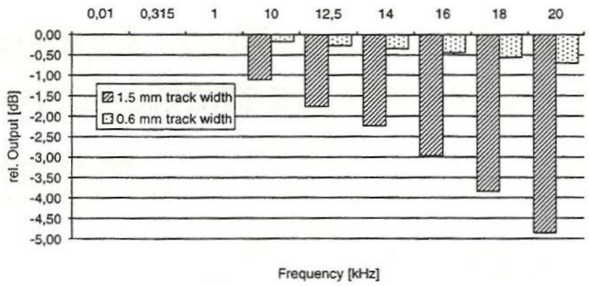


Figure 4: Output variation by azimuth displacement versus frequency at tape speed 4.76 cm/s and 3 minutes deviation

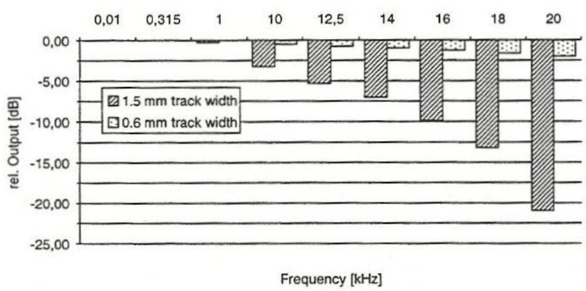


Figure 5: Output variation by azimuth displacement versus frequency at tape speed 4.76 cm/s and 5 minutes deviation

Conclusion:
The acuracy of azimuth alignment for the stereo track layout (2 x 0.6 mm, 0.92 mm centerline distance of the tracks or track pitch as given in IEC Publication 94 Part 7) can be derived from the demand on the permissible frequency response. Figure 6 lists some deviations from frequency response linearity and the corresponding azimuth values.

Permissible Frequency Response	in dB	Maximum Permissible Azimuth Deviation in minutes
10 kHz	2	10
	1	7.2
12.5 kHz	2	8.0
	1	5.8
14 kHz	2	7.2
	1	5.2
16 kHz	2	6.3
	1	4.5
18 kHz	2	5.6
	1	4.0

Fig. 6: Necessary Azimuth Acuracy
@ stereo track layout IEC Publication 94 Part 7
2x 0.6 mm track width ; 0.92 mm track centerline distance

2. Influence of Phase Shift

Phase shift between the two stereo channels results out of three major reasons:

2.1 Electrical Phase Shift

The equalization networks are not operating phase compensated. If the equalization in the two channels is set differently by any reason (unbalanced head systems), a not at all neglectable phase shift will be generated. So if phase shift occures despite of utmost care in azimuth alignment, it is advisable to induce by a coil in front of both playback head systems a sinusoïdal signal of suitable level and hereby to test the phase response versus frequency of the electronics inclusive the heads.

2.2 Gap Scatter

If the two heads of the stereo system are displaced from each other in the tape travel direction, this distance is known as gap scatter (Figure 7). It causes a time deviation between the corresponding signals and introduces a phase shift which has to be differentiated from azimuth errors.

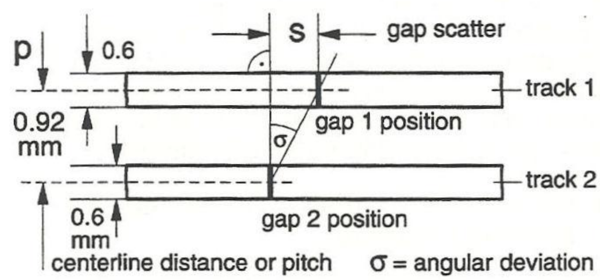


Fig. 7: Influence of gap scatter on azimuth

Azimuth Error caused by Gap Scatter

s (µm)	(min)
0.13	0.5
0.27	1.0
0.4	1.5
0.54	2.0
0.67	2.5
0.81	3.0

$$\tan \sigma = \frac{s}{p}; \quad \sigma_{[min]} = 60 * \arctan \frac{s_{[min]}}{1000 * p_{[mm]}}$$

Figure 7a contains the respective graph showing the introduced azimuth error by gap scatter.

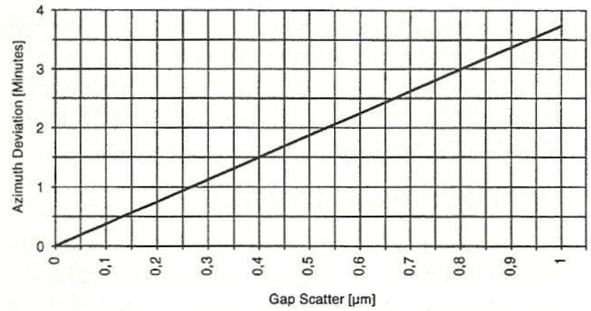
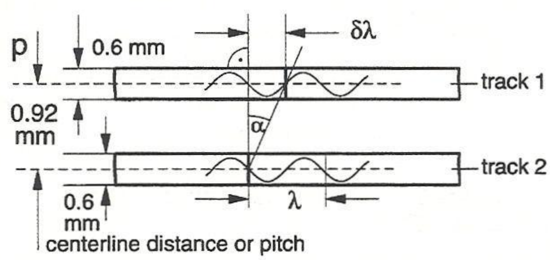


Figure 7a: Azimuth deviation versus gap scatter @ 0.92 mm centerline distance of track according IEC Publ. 94 Part 7

2.3 Phase shift by Azimuth Displacement

Whereas gap scatter by time difference in replay simulates an azimuth displacement, an azimuth deviation is causing time delays in playback so introducing a phase deviation between the two stereo signals. Figure 8 explains the effect and figure 9 shows the respective graph.



$$\delta\lambda = p * \tan\alpha \, ; \qquad \frac{\Delta\lambda}{\lambda} = \frac{\varphi}{360}$$

$$\varphi = \frac{360°}{\lambda} * \tan\alpha \quad \text{with } \alpha << 5° \Rightarrow \tan\alpha = \alpha * \frac{\pi}{180}$$

$$\varphi_{[\text{degrees}]} = \frac{f_{[\text{kHz}]} * 10\pi * p_{[\text{mm}]} * \alpha_{[\text{min}]}}{3 * v_{[\text{cm/s}]}}$$

Fig. 8: Phase shift by azimuth displacement

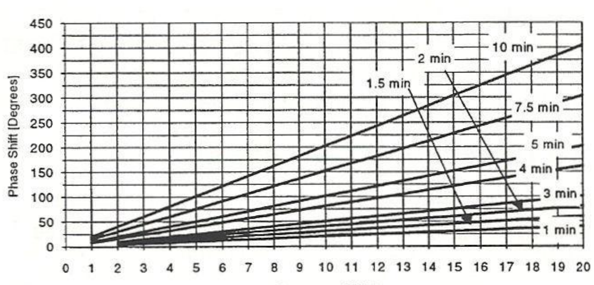
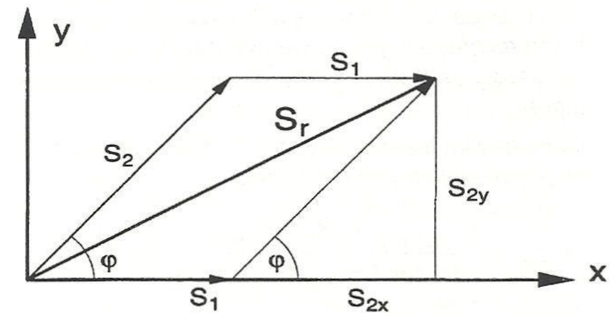


Figure 9: Phase shift vs. frequency @ 4.76 cm/s, 0.92 mm centerline distance of tracks according IEC Publ. 94 Part 7

3. Level Reduction by Phase Shift

If by any reason the stereo signal recorded onto the tape is played back in mono mode (mono portable recorder or mono position on the amplifier) the combined phase shifted signals will be reduced in their amplitude compared to those being in phase and consequently adding. Figure 10 shows how to derive the losses and figure 11 shows the graph.



$$s^2 = [s_1 + s_2 * \cos\varphi]^2 + [s_2 * \sin\varphi]^2 \quad \text{with } s_1 = s_2 = s_0$$

$$s^2 = s_0^2\,[2 + 2\cos\varphi]^2$$

$$\Rightarrow \quad s = s_0 * \sqrt{2 * (1 + \cos\varphi)^2}$$

$$\text{with } \varphi = 0 \quad \Rightarrow \quad s = 2 * s_0$$

$$P_L = -20 * \log\frac{s}{2s_0}$$

$$= -20 \log\frac{1}{2} * \sqrt{2 * (1 + \cos\varphi)^2}$$

$$= -10 \log\frac{1}{2}\,(1 + \cos\ \varphi)$$

Fig. 10: Superimposition of phase shifted sinusoïdal signals

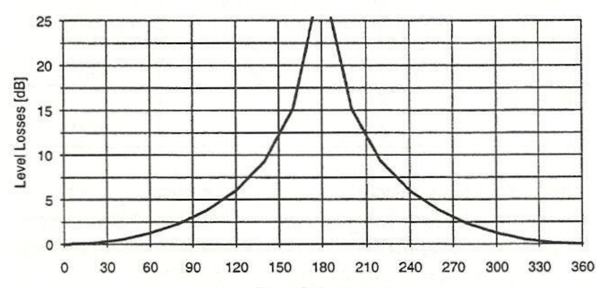


Figure 11: Level losses of superimposed sinusoïdal signals by phase shift

3.1 Overall Phase Incoherence

In practical voice and music signals all degrees of phase shifts are occuring. By integration of the aplitude reductions over the range from 0 to 360 degrees the average losses are 3 dB.

3.2 Additional Phase Losses

When measuring however with sinusoïdal signals being recorded in phase we are able to derive the necessary azimuth acuracy for permissible signal losses.

Derived from the final equation in figure 9 the azimuth displacement can be calculated.

$$\alpha_{[min]} = \frac{\varphi_{[degrees]} * 3 * v_{[cm/s]}}{10 * \pi * p_{[mm]} * f_{[kHz]}}$$

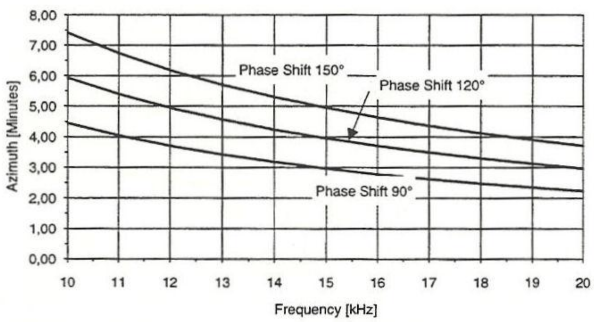


Figure 12: Necessary azimuth accuracy for given phase shifts @ 4.76 cm/s - IEC Publ. 94 Part 7

①	in dB	②	③
10 kHz	2	10	
	1	7.2	5.9
12.5 kHz	2	8	
	1	5.8	4.7
14 kHz	2	7.2	
	1	5.2	4.2
16 kHz	2	6.3	
	1	4.5	3,7
18 kHz	2	5.6	
	1	4	3.2

Legend: ① permissible frequency response;
② maximum permissible azimuth deviation in minutes;
③ accuracy of azimuth for 120° phase shift (level reduction 6 dB for sinusoïdal signals given in minutes)

Fig. 13: Necessary azimuth acuracy @ stereo track layout IEC Publication 94 Part 7 - 2 x 0.6 mm track width; 0.92 mm track centerline distance.

Figure 13 repeats figure 6 supplemented by accuracy demands for level reductions allowed to a maximum of 6 dB caused by phase shifted signals. The level reductions are a major part in the demands for stereo/mono compatibility.

4. Practical Measurements

The electrical measurement of phase differences between to signals is much easier than mechanical deviations in the order of a few or even fractions of a minute. Therefore figure 14 shows the dependences between azimuth on one hand and phase for different frequencies on the other. Care has to be taken that phase shifts over 360° do not occur. It is advisable therefore to start the measurements at lower frequencies.

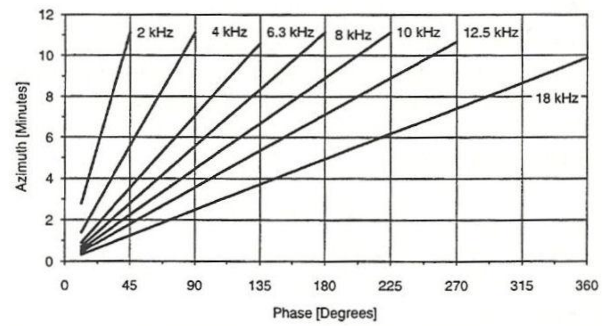


Fig. 14: Azimuth deviation versus phase shift @ 4.76 cm/s (IEC Publication 94 Part 7). Formula as in Fig. 12

Now - having discussed the basic dependencies - we are able to start to discuss the main subject.

5. Determining the true Azimuth of Compact Cassette Drives

We have to observe this from two different directions: For maintaining the system compatibility as well the cassettes (including the prerecorded cassettes) as the mass produced recorders have to be checked respectively set to close tolerances concerning azimuth. These tolerances are in a high degree defining the product performance and therefore have to be considered within the suppliers quality target.

5.1 Prerecorded Cassettes

The adjustment of high speed duplication slaves mostly is done by their manufacturers in a suitable way.

An appropiate way would be when a head change has been done (after the mechanical installation) to run a prerecorded azimuth calibrating tape (open reel) and to connect the heads first to an oscilloscope and a phase meter and use them as playback heads.

Prerecorded tapes can be purchased having an accuracy of better then 0 ±1.5 min. So the duplicator can ensure to supply prerecorded tapes width nearly the same accuracy and consistency of azimuth.

The influence on the prerecorded cassette is mostly given by the precision of the C-Ø. Due to moulding injection parameters like temperature, pressure, cooling time before ejection and plastic used the flatness of the support areas (figure 15) can be influenced in a wide range even when the moulds are ideal. Uneven support areas will introduce azimuth errors by taking the wrong position in the player. Additionally the tape guiding element in the cassette are no longer perpendicular to the tape path (Z-Plane of the cassette shell, see figure 16).

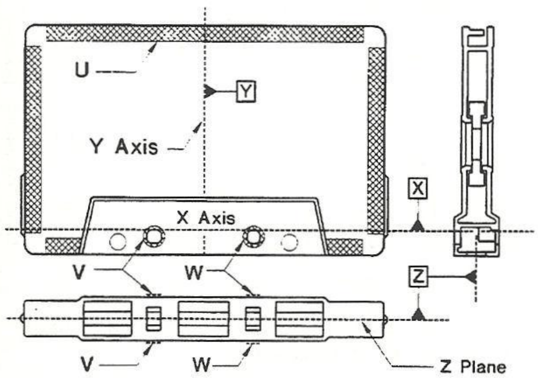


Fig. 15: IEC 94-7: „All guides shall be perpendicular to the Z reference plane."

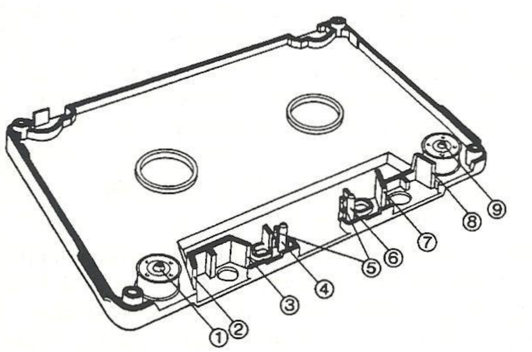


Fig. 16: ① left-hand roller guide and axle; ②, ③left-hand stays, ④ left-hand main pin guide, ⑤support points for the pressure-spring pad, ⑥ right-hand main pin guide, ⑦, ⑧ right-hand stays, ⑨ right-hand roller guide and axle

Deviations force the tape out of its normal path causing azimuth errors. Consequently control of azimuth of the C-Ø is a prerequisite for consistent prerecorded cassette quality. The control is most efficiently done on a Reference Recorder.

5.3 The Calibration of the Reference Recorder

Specially for this purpose there has been developed the Azimuth Calibrating Mechanism, the application of which shall be shown in the following. For this purpose the European and the American Duplicating industry has agreed upon the usage of a modified version of the *Nakamichi Dragon* cassette recorder, a dual capstan drive which by higher tension between the capstans on one hand reacts more on non-perpendicular parts touching the tape, which on the other hand allows to be very exact aligned to give results with good reproducability.

There are offered normaly some tools which allow an exact adjustment of the recorder such as head, capstan and heigth of the heads. However there are no tools which allow to ensure the perpendicularity of the pinch roller. This is particularly difficult because of the elastic material the rollers are made from.

As a practical solution to this measurement problem, we offer the Mechanical Calibration Mechanism in addition to the Azimuth Calibration Mechanism, to allow the alignment of the pinchwheel parallel to the capstan to be verified. How this is achieved is explained below.

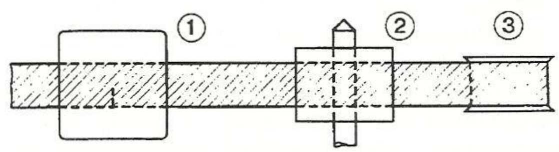


Figure 18: ① Replay head. ② capstan and pinchwheel, ③ roller guide

Fig. 18 shows part of the tape path, with the cassette deck replay head, capstan and pinchwheel, as well as the roller guide on the take-up side of the cassette. All the parts are adjusted very precisely to ensure that the tape path is correct, with no deflection.

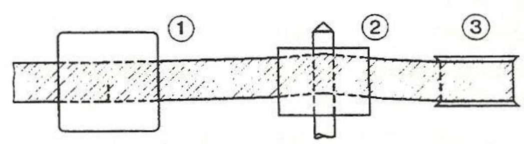


Figure 19: ① Replay head, ② capstan and pinchwheel, ③ roller guide

Fig. 19 is the same as fig. 18, but with misalignment between the capstan and pinchwheel; these are no longer parallel to one another. This causes an upward deflection of the tape. It is assumed that the roller guide inside the cassette has no play along its axis and will pull the tape down again. The deflection of the tape causes an azimuth error at the replay head.

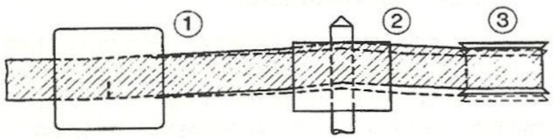


Figure 20: ① Replay head, ② capstan and pinchwheel, ③ roller guide

In fig. 20, the capstan and pinchwheel are mounted exactly as in fig. 19, but now with some play along the axis of the roller guide inside the cassette. Once again, the misalignment between the capstan and pinchwheel deflects the tape upwards, but the roller guide is also deflected, by an amount which depends on the amount of axial play. This increases the overall deflection of the tape observed along the tape path, and causes a change in azimuth at the replay head compared with that in fig. 19.

This gives rise to the following observation: With misalignment between capstan and pinchwheel, the amount by which the tape is deflected (and thus the change in azimuth angle) depends on the amount of axial play in the roller guide inside the cassette.

Making use of this fact, we modified two identical high-precision cassettes so that one had a maximum axial play of only ±0.015 mm, the other ±0.15 mm. For the measurements, we assume that the cassette deck has been mechanically aligned using the procedures mentioned above, so that the only foreseeable misalignment would be between the capstan and pinchwheel. The two cassettes are then placed in the transport in turn and the difference in azimuth readings noted. If the azimuth readings with the two cassettes are virtually identical (any difference <1 min of arc), it can be said that the capstan and pinchwheel are correctly aligned. If there is a noticeable difference in azimuth reading (>1 min), some adjustment is required.

The difference in azimuth reading between the two cassettes can thus be used as a measure of how parallel the pinchwheel is to the capstan:

Δazimuth = [azimuth without axial play] *minus* [azimuth with axial play]

For practical purposes, the design requirements of the two cassettes can be met as described below: The existing Precision Cassette Azimuth Calibration Mechanism already fulfils the requirements for one of the cassettes, due to the precision of its mechanical construction and the very small axial play in the guide roller (±0.015 mm). The second cassette required, the Mechanical Calibration Mechanism, can be designed using a similar cassette, but increasing the axial play of the roller guide by a factor of 10 (to ±0.15 mm).

The effectiveness of this method of measurement, as described above, has been demonstrated using two identical, high-quality double-capstan decks of the same type. The azimuth of both decks had previously been optimised using the Azimuth Calibration Mechanism. Six conventional cassettes were then checked for azimuth angle. The results are shown in the upper part of fig. 21.

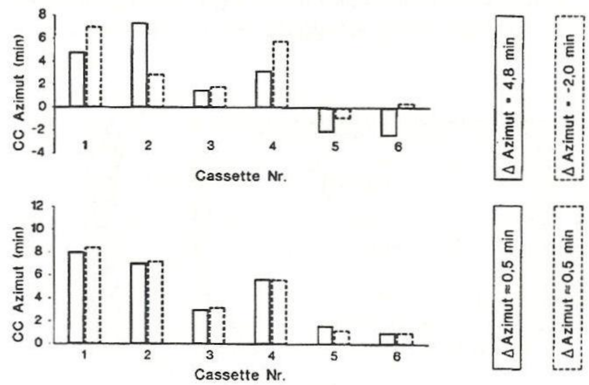


Figure 21: Compact-Cassette Azimuth Angle, measured on two identical recorders.

It can be seen that the six cassettes give quite different results in the two decks, even though both decks were of identical construction and had been aligned for the same azimuth. Both units met two of the three requirements for an azimuth alignment recorder as described above, namely "Conform with agreed construction characteristics" and "Replay head gap set precisely perpendicular to the support plane of the CC". The variation in azimuth readings must therefore be accounted for by failure to meet the third criterion, namely "Adjustment of all tape guidance components to conform with the Standard".

Checking the two decks using the "ΔAzimuth method" gave a difference of +4.8 min for deck 1 and -2.0 min for deck 2, in other words >1 min for both decks. Since the heads and capstans of both decks, as well as the tape height guide, had been optimally aligned using the usual mechanical calibration devices, the significant values of ΔAzimuth must have been due to incorrect alignment between the capstans and pinchwheels. The pinchwheels of both decks were then adjusted to give ΔAzimuth values of <1 min. Finally, all six cassettes were checked again and were now found to give identical results on both decks, as shown in the lower part of fig. 21.

The two Precision Cassettes allow the pinchwheel to be adjusted so as to be parallel to the capstan, as well as enabling the azimuth of the replay head gap to be aligned correctly.

5.4 Evaluation of C-Ø Azimuth Consistency

After the calibrating of the Recorder the cassette shell can be judged. For this purpose a random sample of a lot is loaded with a few meters of prerecorded azimuth calibrating tape and the phase respectively the azimuth is measured on the recorder.

The following three diagrams (Figs. 22, 23, and 24) show the results of an evaluation of different brands of C-Ø according to the described procedure.

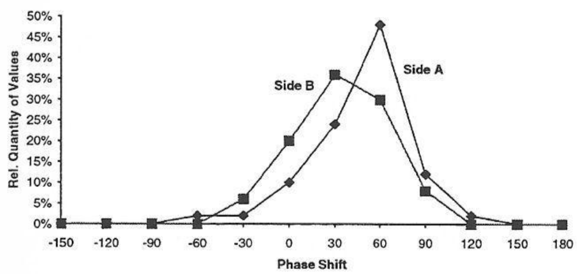


Fig. 22: Distribution of Azimuth Deviation of C-Ø in degrees of Electrical Phase Shift, Manufacturer „X". 67 % limits: Side A: -0.6' < 1.5' < 2.4'; Side B: -0.1' < 1.0' < 2.2'

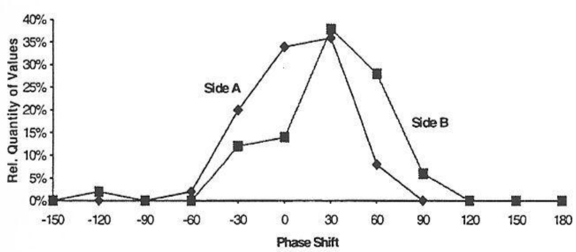


Fig. 23 Distribution of Azimuth Deviation of C-Ø in degrees of Electrical Phase Shift, Manufacturer „Y" 67 % limits: Side A: -1.3' < -0.16' < +1.0; Side B: -0.9 < +0.6 < +2.09

Phase Shift (degree)	-150	-120	-90	-60	-30
Azimuth Deviation (min)	-6	-4.75	-3.6	-2.4	-1.2
Phase Shift (degree)	+150	+120	+90	+60	+30
Azimuth Deviation (min)	+6	+4.75	+3.6	+2.4	+1.2

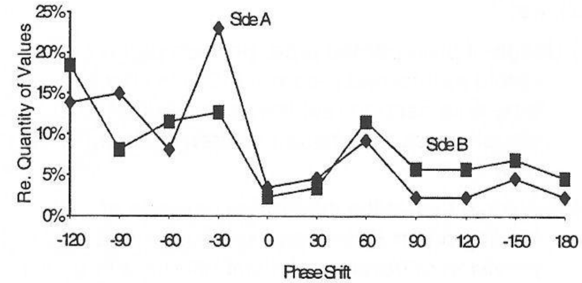


Fig. 23 Distribution of Azimuth Deviation of C-Ø in degrees of Electrical Phase Shift, Manufacturer „Z".

Brand "X" and brand "Y" show a relatively symmetrical distribution:
67 % are within 15°< 38°< 60° for Side A and -3° <26° < 55° for side B or -34°< -4° < 26° for Side A and -23°< 15°< 53° whereas brand "Z" shows a wide distribution obviously containing two different sets with two distribution maxima at -30° and +30°.

Recalculated into the angular azimuth values in minutes we can derive:

	Brand "X"	Brand "Y"
Side A:	-0.6' < 1.5' < 2.4'	-1.3' < -0.2' < 1.0'
Side B:	-0.1' < 1.0' < 2.2'	-0.9' < +0.6' < 2.1'

The mentioned distributionmaxima for brand "Z" are at -1.2' and +1.2' respectively.

Bearing in mind that a phase shift at 12.5 kHz of 60° means an azimuth deviation of around 2.5 minutes the influence of the accuracy of the cassette shells can be derived and is not at all of secondary importance.

6. Mass Produced Compact Cassette Drives

Despite of progress in mechanical alignment in recorder assembling - as in the field of Reference Recorders - a final adjustment has to be carried out using tape. For this purpose the usage of the Calibration Mechanism would be too cost intensive. Therefore test cassettes are available which have been produced from specially selected and maintained tools. Moulding injection and assembling conditions are tightly controlled. Together with the prerecorded azimuth calibration tape an accuracy within ±1.5 minutes can be maintained.

The procedure for maintaining the accuracy is as follows:

a) Usage of prerecorded tape, prerecorded on very stable reel-to-reel recorders. Cross check the tape on a second reel-to-reel recorder and individually ceck the phase between adjacent channels.

b) Individual test of the calibrating cassette after loading on an Reference Recorder and daily supervision of trends and distribution. Casettes exceeding preset limits have to be rejected.

c) Periodically preventing maintainance of the equipment used.

equipment and comparation of the "Ø" azimuth setting with previous findings.

e) Not to produce any tape before reasons of deviations are found and correction measures have been taken.

The characteristic of the manager of the calibration tape production can be described *as Mr. 0.1 dB and 0.1 Minutes.*

The tools for maintaning good azimuth consistency of the complete system are available. Any individual company has to decide ist efforts in improving the quality.