AZIMUTH CALIBRATION MECHANISM

MECHANICAL CALIBRATION MECHANISM

Grundlagen und Praktische Arbeit

Principles and Practical Application

PROFESSIONAL AUDIO VIDEO

BASF

Summary for Experienced Users

In order to ascertain the azimuth angle of audio Compact Cassettes (CC), an azimuth measurement recorder is required. This recorder must meet the following criteria:

1. Conform with agreed construction characteristics
2. Replay head gap set precisely perpendicular to the support plane of the CC
3. Adjustment of all tape guidance components to conform with the Standard

(1) Conform with agreed construction characteristics

Azimuth measurements made on any particular cassette may differ, depending on the construction of the azimuth measurement recorder being used. The characteristics relevant to azimuth include:

- Number and layout of components guiding the tape
- Number of capstans
- Number and layout of tape heads
- Tape stop sensors in contact with the tape
- Layout of CC support points
- Tape take-up and feed torque

Number and layout of components guiding the tape:

This affects the extent to which the recorder influences the tape path and reduces the effect of components within the cassette.

Number of capstans:

With twin capstan (double capstan) machines, the tape tension is increased between the capstans; among other things this increases the effect of the roller guide which is on the take-up side of the cassette.

Number and layout of tape heads:

This can affect the angle at which the tape winds over the pin and stay guides in the CC, which can affect how much the tape path is deflected.

Tape stop sensors in contact with the tape:

Mechanical tape-stop sensors will increase the angle over which the tape is in contact with the pin and stay guides, which may influence the deflection of the tape from its correct path.

Layout of CC support points:

Warping of the cassette shell may change the azimuth angle, depending on the layout of the cassette support points.

Tape take-up and feed torque:

Variation in the take-up and feed torque may increase or decrease any deflection of the tape path which is caused by rollers in the CC, whose axles are not precisely perpendicular to the support plane.

The construction of the azimuth measurement recorder can be seen to have a substantial influence on the azimuth measurement. It is therefore not surprising that testing cassettes on different recorders gives results which differ considerably. Happily, the European and American duplicating industries have already taken an initiative in this respect, in recommending a modified version of the Nakamichi Dragon cassette recorder as the reference machine for azimuth measurement.

Experience has shown that recorders with twin capstans are more sensitive to mechanical imperfections in the cassette housing (C-0) than machines with only one capstan. The former are therefore recommended for precision measurement of azimuth.

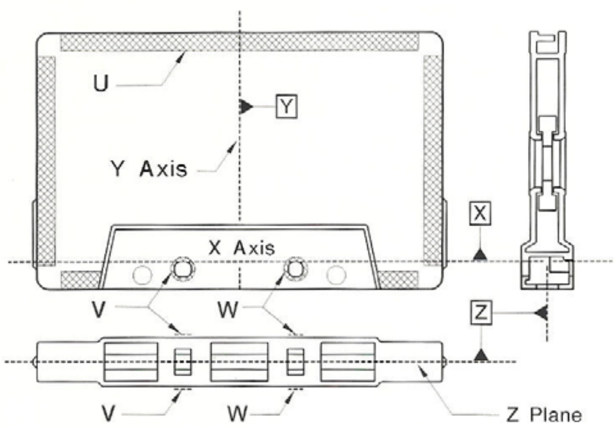
(2) Replay head gap set precisely perpendicular to the support plane of the CC

In theory, the alignment of the head gap with respect to the support plane of the Compact Cassette could be measured optically, using a calibrated microscope. In practice, this method is too complicated to use for azimuth alignment.

Instead, an Azimuth Alignment Cassette is employed; setting the gap at right angles to the plane is achieved conventionally by adjusting for maximum output at high frequencies or for minimum phase difference between adjacent tracks.

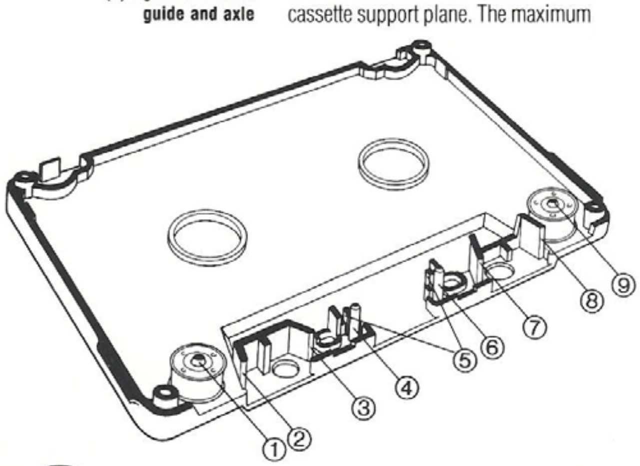
The requirements for an Azimuth Alignment Cassette are specified in IEC Recommendation 94-7, Section 12.4, which deals with azimuth accuracy and the cassette shell. It states: "All guides shall be perpendicular to the Z reference plane." Unfortunately, it is not as easy as it sounds to meet this requirement in practice. Fig. I shows the Z plane and fig. II the tape guidance system.

Figure I



Since the Z plane is parallel to the support plane of the cassette, the requirement is met by mounting the tape guidance elements perpendicular to the support plane of the cassette. This requirement must also be met exactly by an azimuth alignment cassette. The familiar BASF Azimuth Precision Cassette is constructed in such a way that all the tape guidance components in fig. II are precisely perpendicular to the cassette support plane. The maximum tolerance is 5 µm across the tape width of 3.81 mm. Only in this way is it possible to ensure a standardised tape path and, with it, a standardised head adjustment.

Figure II
(1) left-hand roller guide and axle, (2), (3) left-hand stays, (4) left-hand main pin guide, (5) support points for the pressure-pad spring, (6) right-hand main pin guide, (7), (8) right-hand stays, (9) right-hand roller guide and axle



(3) Adjustment of all tape guidance components to conform with the Standard

As an example, fig. III shows the tape path in a twin-capstan CC tape transport, in which the various guidance components in contact with the tape can be seen. To conform with IEC 94-7, we should also be able to say: "All tape guidance components must be perpendicular to the support plane of the cassette." Suitable measuring devices are needed to ensure that this requirement is met. These are availablefrom various manufacturers. They allow the inclination of the heads and capstan with respect to the support plane to be checked, as well as the height adjustment of the tape guide.

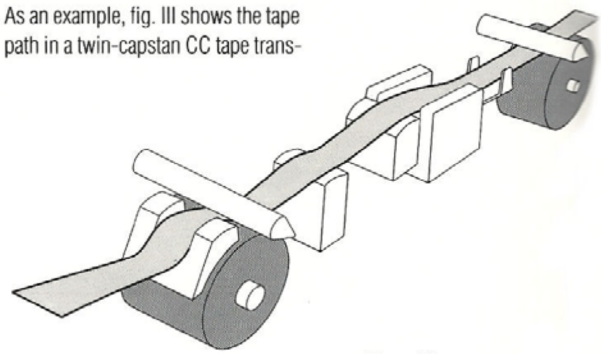
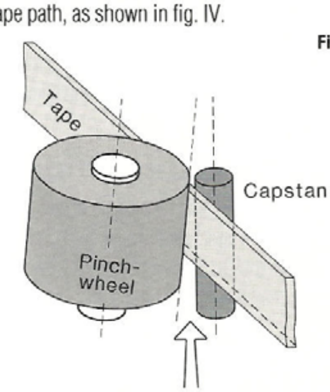


Figure III

However, it is still difficult to verify that the pinchwheels (pressure rollers) are exactly perpendicular to the support plane and, even more important, that they are precisely parallel to the capstans. This is particularly difficult to confirm because of the elastic material from which pinchwheels are made. Even a slight deviation from parallel can affect the tape path, as shown in fig. IV.

Figure IV



As a practical solution to this measurement problem, BASF offers 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.

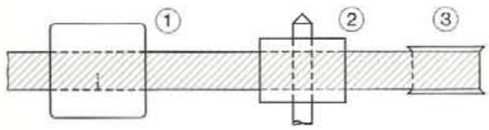


Figure V
(1) Replay head
(2) capstan and pinch-wheel,
(3) roller guide

Fig. V 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.

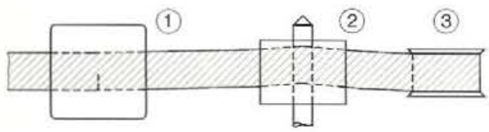


Figure VI
(1) Replay head
(2) capstan and pinch-wheel,
(3) roller guide

Fig. VI is the same as fig. V, 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.

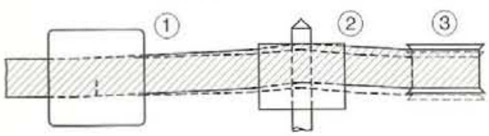


Figure VI
(1) Replay head
(2) capstan and pinch-wheel,
(3) roller guide

In fig. VII, the capstan and pinchwheel are mounted exactly as in fig. VI, 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. VI.

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 nside 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]
— [azimut with axial play]

For practical purposes, the design requirements of the two cassettes can be met as described below: The existing BASF 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 BASF AZIMUTH CALIBRATION MECHANISM.

Six conventional cassettes were then checked for azimuth angle. The results are shown in the upper part of fig. VIII. 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".

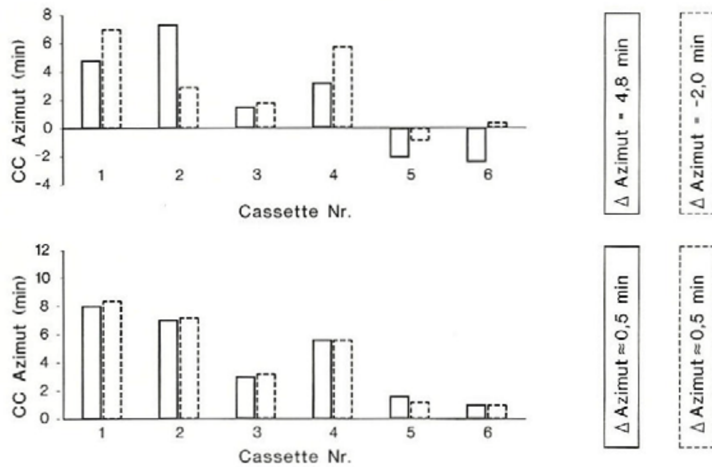
Checking the two decks using the "Δ Azimuth method" gave a difference of +4.8 min for deck 1 and -2.0 min for deck 2, in other words >1 min for both decks. Since the heads and capstans of both decks, as well as the tape height guide, had been optimally aligned using the usual mechanical calibration devices, the significant values of Δ Azimuth must have been due to incorrect alignment between the capstans and pinchwheels. The pinchwheels of both decks were then adjusted to give Δ azimuth 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. VIII.

The two BASF 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.

The same principles described here may also be applied to the DCC (Digital Compact Cassette) system.

Figure VIII

CC azimuth angle, measured on two identical devices



WHY A CALIBRATION MECHANISM?

The AZIMUTH CALIBRATION MECHANISM and the MECHANICAL CALIBRATION MECHANISM are high-precision Compact Cassettes, which can be used for azimuth alignment of the head gap and mechanical calibration of the recorder in both (analogue) Compact Cassette and DCC (Digital Compact Cassette) systems.

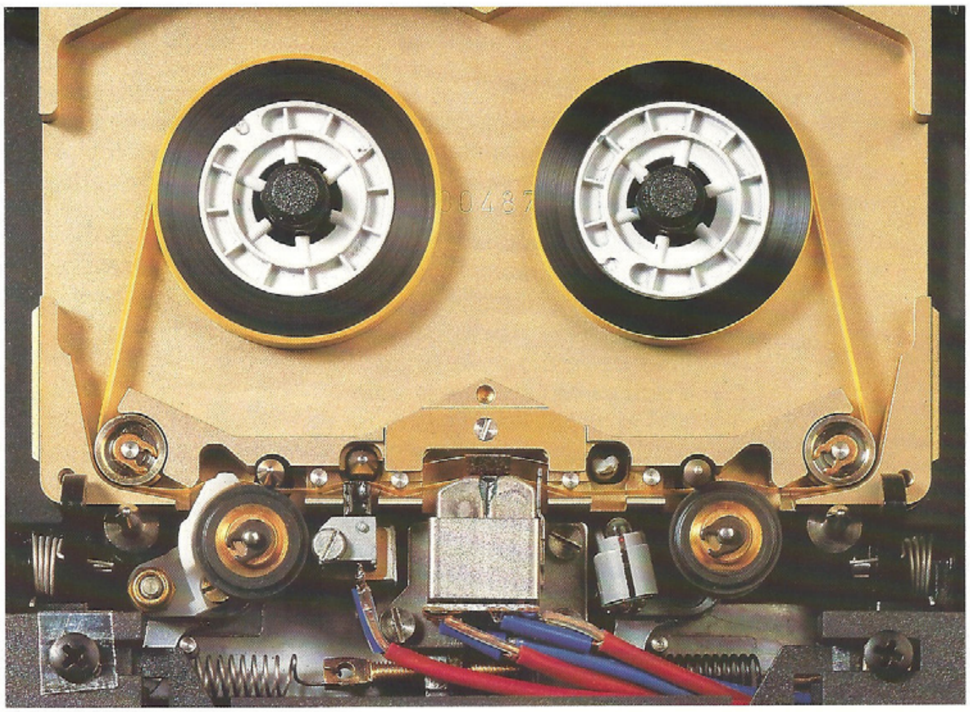


Figure 1:
The CALIBRATION MECHANISM in a cassette recorder

Today's cassette systems are the result of several decades of development. This has allowed ever lower tape speeds to be used, which also means shorter wavelengths and narrower gaps in the tape heads. Recording with wavelengths in the micrometer range requires, among other things, a tape transport system with a very high degree of mechanical precision. 'Precision' in this context means not only a constant and accurate tape speed, but above all an accurately aligned guidance system for the tape as it moves across the head-gap.

Interchangeability and Standardisation

Magnetic tape cassettes are the most commonly used and most important media for the distribution of both pictures and sound. It is very important, therefore, that the media concerned, whether pre-recorded or blank, should be freely interchangeable.

The further the Compact Cassette has been developed, the more demands have been placed on it for higher quality. As cassette recorders and Compact Cassettes have been manufactured with greater and greater precision, improved measuring techniques and - even more important - overall standardisation of the system have been required. After a great deal of work on this, a general standard was specified in IEC Recommendation 94, Magnetic tape sound recording and reproducing systems[1]. For Compact Cassette systems, it is the cassette - or rather the recording on the cassette tape - which is the primary item for interchange and thus for standardisation.

The Compact Cassette as a medium for interchange

IEC 94 defines two calibration tools as of prime importance for standardisation of the electro-acoustical properties of any magnetic tape storage system:

- Calibration tapes, to standardise the alignment of the replay channel;

[1] particularly IEC 94 Part 7, entitled: Cassette for commercial tape records and domestic use

- Reference tapes, to standardise alignment of the recording channel.

Applying these "yardsticks" appropriately is essential for general interchangeability.

The key dimensions, tolerances and general operating conditions necessary for interchangeability are specified in IEC 94-7. Because the cassette is the medium of interchange, the recorder itself is standardised as well, in terms of 'good engineering practice'.

Tape guidance and the effects of errors

Azimuth error theory

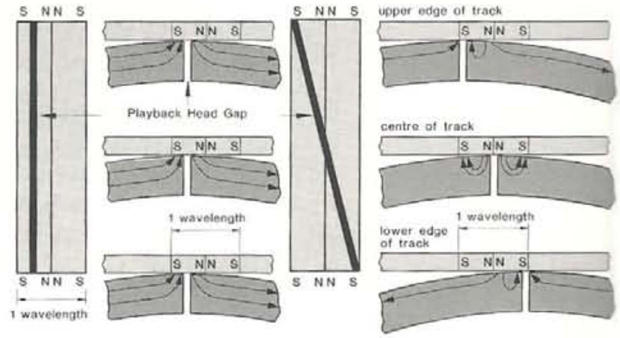
It is fundamental to tape guidance in the Compact Cassette system that any component in contact with the tape will also influence the tape path. It is very significant that the Compact Cassette has been so designed that it contains the main tape guidance components, which have the major influence on the tape path. These components must guide the tape in such a way that the head system scans the tracks correctly, without any errors.

What this means for the quality of reproduction is that, under ideal conditions, the sound of the recording is optimally reproduced, in particular as regards frequency response and dynamic range.

To achieve this, the first step is to ensure correct tracking, i.e. the head pole-pieces must be correctly positioned relative to the tape. Track position errors only cause a loss of output or dynamic range, without affecting the frequency response; but severe errors increase the crosstalk between adjacent tracks. The second requirement for tape guidance is even more critical: the tape edge and head gap must be perpendicular to one another, with no angular error. Azimuth, in the parlance of magnetic tape technology, is understood to be the alignment of head gaps exactly at right angles to the tape edge[2].

Deviations in the azimuth (in short, azimuth errors[3]), are the mechanical causes of electro-acoustic shortcomings (fig. 2) They result in unwanted changes in the sound quality: level errors (linear distortion, loss of high frequencies), fluctuations in high-frequency output (modulation of the output, causing a 'rough' sound), and phase errors, which cause the sound image to shift in stereo recordings. Any audible effect is an error.

Figure 2: Results of Azimuth errors



Azimuth errors mainly affect the high-frequency end of the audio range, that is they are most severe with the shorter recorded wavelengths (fig. 3). Lower frequencies (long wavelengths) are largely unaffected, with the result that they become predominant in the overall sound.

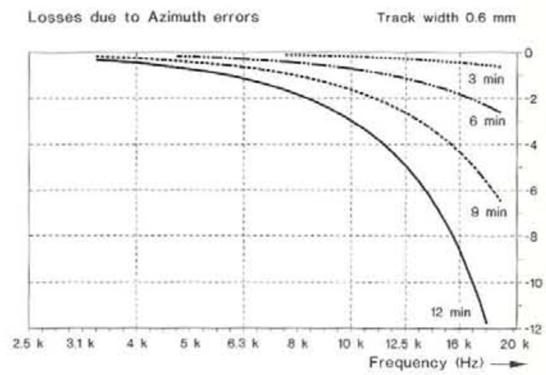
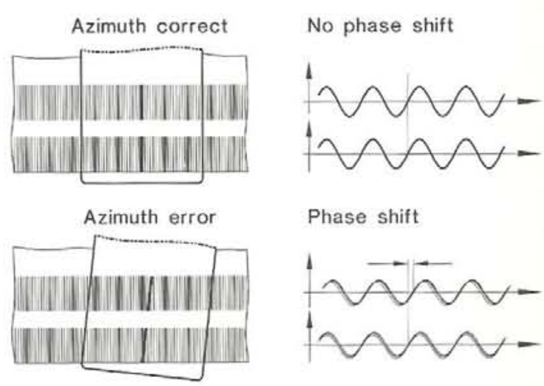


Figure 3: Effect of Azimuth errors on frequency response

The most important requirement for all tape guidance components is 'azimuth accuracy'. Fig. 2, left, shows the relationship under ideal conditions, that is, with the head gap at right angles to the direction of recording.

Figure 4: The origin of phase errors



[2] More accurately, to the vector of the direction of recording

[3] Because it makes no difference whether the tape runs at an angle across a correctly aligned head or whether the tape moves correctly across a misaligned head, the resulting errors are treated as azimuth errors (otherwise known as gap deviation errors or tape deviation errors). If the recording itself is accurate and the loss of high frequencies is caused simply by misaligned tape guidance components, it helps to remove the tape from the old, faulty cassette housing and place it in a new, precision-made housing.

If the recording does not move exactly at right angles to the head-gap during replay, the effect becomes particularly noticeable when the gap spans the length of one recorded cycle diagonally, as shown in the diagram (fig. 2, right). The 'upper' and 'lower' halves of the head induce voltages which are 180° out of phase with one another, resulting in no output overall. This condition is only true at a particular frequency. The longer the wavelength, the less the error in azimuth angle affects the output.

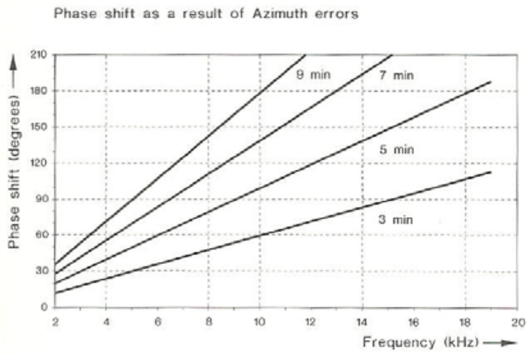


Figure 5: Phase shift as a result of Azimuth errors (mean track separation of 0.9 mm)

Azimuth errors can also introduce phase errors in stereo recordings (figs. 4 and 5). It can be seen how the misaligned head 'reads' the recording at different parts of the waveform, which shows up as a phase shift[4].

Accurate tape guidance is fundamental to a linear frequency response and constant output level, as well as in making full use of the tape's capacity at high frequencies and ensuring phase stability for stereo reproduction. The quality of sound reproduction in a Compact Cassette system depends not only on the electro-acoustic capabilities of the tape and recorder, but also on the 'mechanics' of the Compact Cassette housing and the tape transport.

Clearly, for wavelengths in the micrometer range (approx. 2.5 µm at 20 kHz and 4.76 cm/s) and with track widths of 0.6 mm or 1.5 mm, a high degree of precision must be maintained for good quality sound reproduction. For the loss in output not to exceed 1 dB at 18 kHz, for example, the azimuth error must be ≤ 4 minutes of arc; or for a 3 dB loss, the error must be ≤ 7 min (track width 0.6 mm; see figs. 6 and 7).

[4] *The same error occurs if the two head-systems of a stereo head are displaced relative to one another*

For practical purposes, the relationship between azimuth error and loss of high frequencies can be expressed in the following equation:

$$\frac{E}{E_\circ} = \frac{\sin\left(\frac{\pi \cdot b \cdot tg\alpha}{\lambda}\right)}{\frac{\pi \cdot b \cdot tg\alpha}{\lambda}}$$

in which E, $E_\circ$ = output voltages with and without azimuth error, respectively; b is the track width [m]; α the azimuth error [deg]; λ the wavelength [m]. The

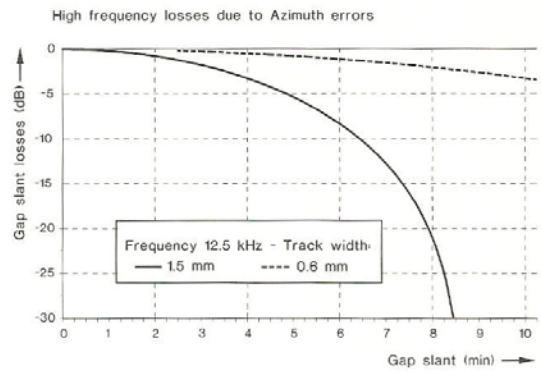


Figure 6: High-frequency losses due to Azimuth errors (azimuth angle errors in the range 0-10 min)

high-frequency loss can be calculated as an attenuation ratio, in dB:

$p = 20 \lg (E/E_\circ)$ [dB]

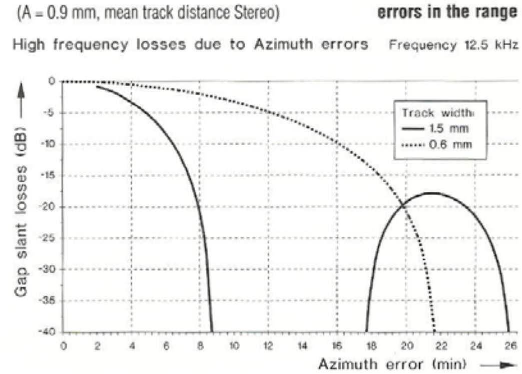
The formula shows the predominant influence of wavelength λ on high-frequency loss, as well as the inverse effect of the track width b: the narrower the track, the less critical the azimuth errors, as shown indirectly in fig. 2, for example. The magnitude of the high-frequency loss provides no direct information on the contribution of individual tape guidance components to the overall azimuth error.

The amount of phase shift is calculated as follows:

$$\phi = tg\alpha \cdot \frac{360 \cdot A}{\lambda}$$

(A = 0.9 mm, mean track distance Stereo)

Figure 7: High-frequency losses due to azimuth errors (Azimuth angle errors in the range 0-25 min)



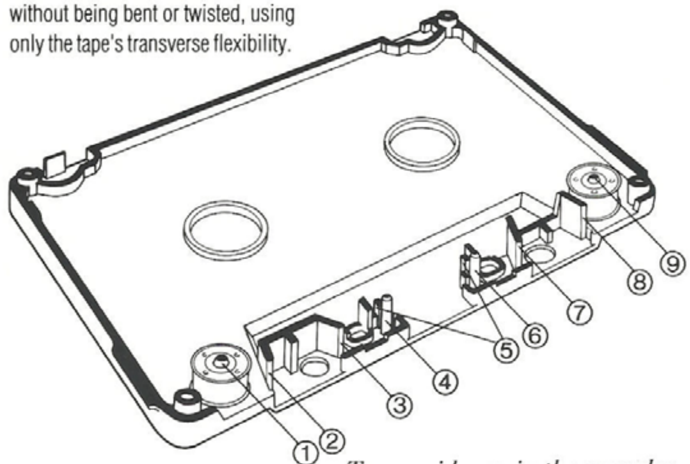
Tape Guidance in the Compact Cassette

According to IEC 94, the Compact Cassette must guide the tape in such a way that:

- the tape edge remains in the same plane, from the feed side to the take-up side;
- the tape-path plane of the Compact Cassette is parallel to the cassette support plane of the transport;
- the tape surface is maintained exactly perpendicular to this support plane, without being bent or twisted, using only the tape's transverse flexibility.

(conical) or barrel-shaped running surfaces, and inclination of the axle. The main faults in the pin and stay guides are deviations from correct zenith with reference to the Z plane. These 'twist' the tape along its complex path. Similar errors may also be caused by a warped cassette housing: the Z plane is then no longer the plane of symmetry for the Compact Cassette. All these faults will deflect the tape in its path across the head, even though the head gap itself remains perpendicular to the Z reference plane.

Figure 8: Pins and stays, the tape guidance elements of the compact cassette (1) left-hand roller guide and axle, (2), (3) left-hand stays, (4) left-hand main pin guide, (5) support points for the pressure-pad spring, (6) right-hand main pin guide, (7), (8) right-hand stays, (9) right-hand roller guide and axle



Definition of the Z plane in IEC 94

The Z plane is defined[5] by IEC 94-7 as the reference plane, to which the plane of the tape surface and therefore all tape guidance elements must be perpendicular (see figs. 8 and 9). It is positioned exactly half way between the U, V and W surfaces of one side of the cassette and the corresponding surfaces of the other side. In other words, the Z plane is the plane of symmetry which has the greatest area of all the planes of symmetry in the Compact Cassette.

Tape guidance components in the cassette

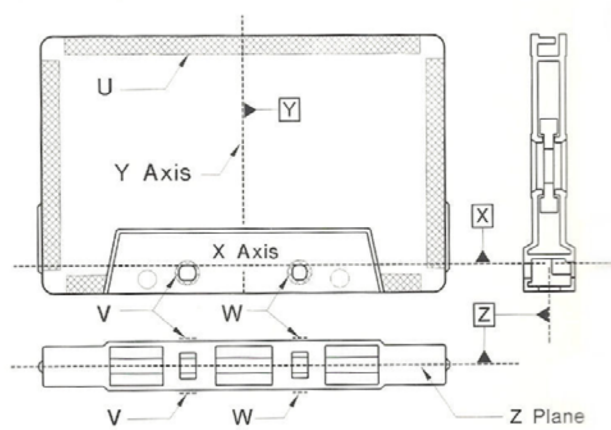
The important tape guidance elements in the Compact Cassette are the rollers, the stay and pin guides, and the pressure pad spring together with its felt pad (fig. 8).

Although relatively remote from the tapehead, imperfections in the rollers are still disturbingly significant. Such imperfections include eccentricity, tapering

Tape guidance in the recorder

With standardisation of the Compact Cassette as a medium for interchange, the most important requirements for the recorder (cassette support and tape transport) already exist from the point of view of 'good engineering practice'[6]. In the recorder, the cassette support surface parallel to the Z reference plane is as important as the Z plane in the cassette itself. Consequently, all the tape guidance elements of a recorder must be exactly perpendicular to the cassette support plane.

Figure 9: Position of the U, V, W, X, Y surfaces and the Z reference plane (reference plane Z as defined by IEC 94, part 7)

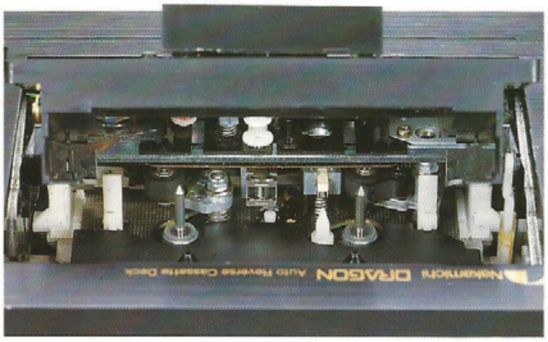


[5] *p.11, clause 12.4, Tape path and guides: All guides shall be perpendicular to the Z reference plane.*

[6] *IEC 94-7 says nothing about dimensions, etc, in the recorder.*

Any component in the recorder which touches the tape affects the tape guidance. The most important elements affecting tape guidance are the pinch-wheel and capstan, all the magnetic heads, the U-shaped guides (on the tape-heads), as well as mechanical tape-stop sensors in contact with the tape. All these components must be exactly perpendicular to the cassette support plane.

Figure 10: View of mechanism of dual-capstan recorder



there are, how many tape guides[7] there are and where they are employed, the tape path can follow one of a number of routes (fig. 12).

Misalignment of tape guidance components in the recorder

The magnitude of the resulting azimuth error depends on the deviation of the tape guidance elements from their nominal position and on the individual angles of wrap: the greater the angle through which the tape turns around a guide, the greater the possible error. The tape path is affected in different ways by the various guides inside the cassette, depending on the layout of the recorder. This means that one and the same cassette can give a variety of azimuth error readings in recorders with differing configurations, even when accurately aligned.

Similar requirements to those for azimuth apply to zenith. In other words, the face of the tape head must be exactly parallel to the tape surface. The face of a head which is not correctly aligned for zenith will, with sufficient angle of wrap, deflect the tape upwards or downwards. This makes azimuth adjustment of the recorder difficult or even impossible, resulting in further azimuth errors. Similar considerations apply to mechanical tape stop sensors and to U-shaped head guides, if fitted.

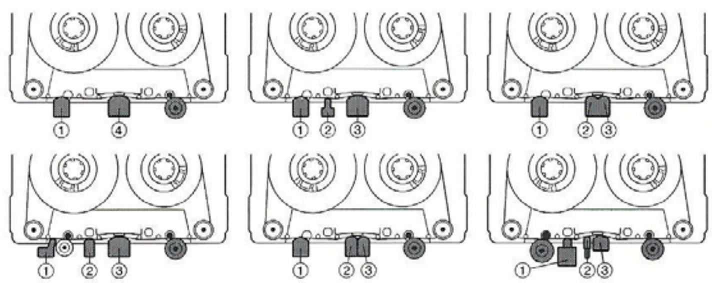
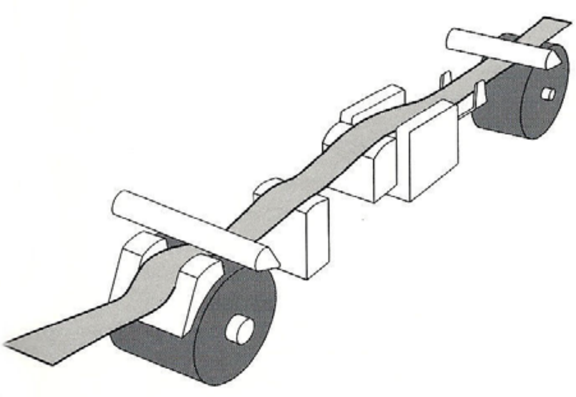


Figure 11: Compact Cassette recorders with various configurations of tape guidance elements: (1) erase head, (2) record head, (3) replay head, (4) combined R/P head

Differences in recorder configuration

Cassette recorders are manufactured with various configurations of the tape transport (fig. 11). Depending on the number and layout of the magnetic heads, how many capstan/pinch-wheel assemblies

Figure 12: Tape guidance components in a compact cassette recorder



The line of contact between the pinch-wheel and capstan is particularly critical in the way it affects the tape path. The shape, elasticity and various mountings make the adjustment of the pinch-wheel relative to the capstan difficult. The capstan, must of course, be mounted exactly perpendicular to the Z reference plane.

As the pinch-wheel is pressed against the capstan, it is elastically deformed.

[7] including some which are hardly noticeable, such as a mechanical tape-stop sensor in contact with the tape.

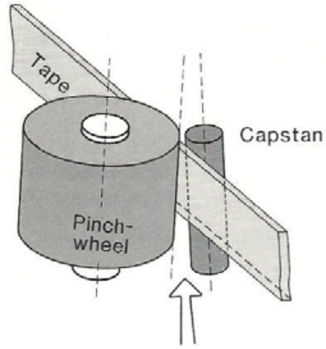
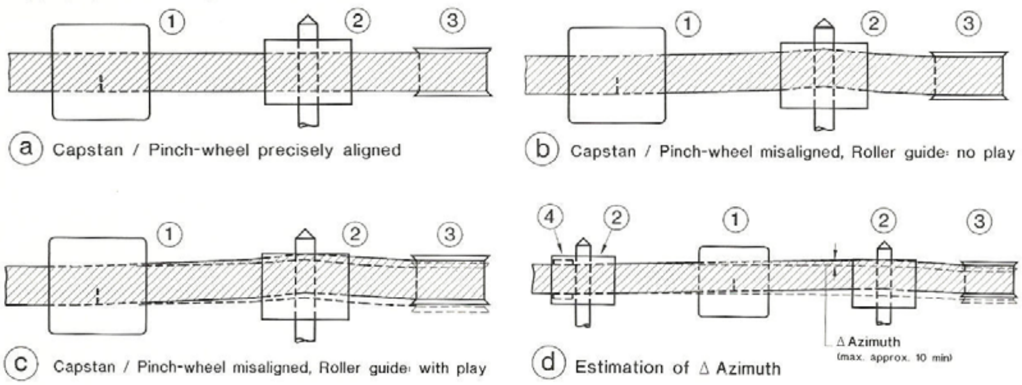


Figure 13: Misaligned pinch-wheel, showing wedge-shaped gap

If it is correctly aligned, the amount of pressure between the pinch-wheel and capstan is constant along the line of contact between them, parallel to the axis of the capstan. Ideally, if all elements in contact with the tape are correctly aligned, the tape is transported along its nominal path across the tape-heads and the azimuth error is zero (fig. 14a). In practice, if the pinch-wheel surface is not exactly parallel to the capstan surface, the pressure from the pinch-wheel is unequal over the width of the tape. A wedge-shaped gap results, the tape is drawn into this gap (fig. 13) and may even become damaged. Basically, pinch-wheel zenith errors result in a deflecting force on the tape; this force is superimposed on the effects of other tape guidance components and can cause further azimuth errors[8].

Figure 14 a-d: Tape paths with correctly and incorrectly aligned pinch-wheels (roller guides with and without axial play); (1) replay head, (2) capstan and pinch-wheel, (3) roller guide, (4) tape guide



Axial play in the roller guides

The special interaction between axial play in the roller guides of a Compact Cassette and a misaligned pinch-wheel is particularly critical. A roller guide with inegligible axial play pulls the tape back to its nominal path (fig. 14b).

It is rather different with a roller which is free to move: with a typical axial play of ±0.15 mm, it follows the deflected tape and only exerts a restoring force when it reaches its limit of travel. The total azimuth error is therefore increased (fig. 14c). It can be calculated that an additional error of up to 10 min can arise due to this. A certain amount of axial play is, however, inevitable in production cassettes.

The Δ-azimuth parameter

Assume a recorder with all tape guidance elements (other than the pinch-wheel/ capstan assembly) correctly aligned. Cassettes without play in the roller guides will show a different angle of azimuth error from ones with play in the guides. The difference in azimuth angles, defined as Δ-azimuth, is a measure of the "quality" of the pinch-wheel alignment.

Δ-azimuth =

azimuth error measured in a cassette without axial play in the roller guides

minus

azimuth error measured in a cassette with axial play in the roller guides

or, in short:

Δ-azimuth =

azimuth error "without play"

minus

azimuth error "with play".

Δ-azimuth thus denotes the difference in azimuth angle caused by the interaction of the misaligned pinch-wheel and the roller guides, with and without axial play.

[8] *i.e. an angle of inclination relative to the capstan, whose residual zenith error should be negligible.*

The CALIBRATION MECHANISM alignment tool

To be able to align a recorder correctly and standardise a cassette transport for measurement, one needs above all an "ideal" Compact Cassette or "Mechanical Reference": in other words, the mechanical equivalent of the IEC 94-7 Standard which exists on the electro-acoustical side in respect of calibration and blank reference tapes[9].

The design of such a mechanical measuring standard requires a completely different approach to the housing from that adopted for a mass-produced cassette. The latter are, of course, unsuitable as measuring devices; it is impossible to manufacture such a precision device, with long-term stability, if thermo-plastic materials and injection moulding are used. Recognising this, the precision cassettes known as the AZIMUTH CALIBRATION MECHANISM and MECHANICAL CALIBRATION MECHANISM have been developed (see cover). They are manufactured using computer-controlled machinery to maintain the required degree of precision. Their stable, all-metal construction virtually eliminates distortion and wear.

The alloy 'german silver' (argentan) turns out to be a suitable material for the cassette housing. This combination of copper, nickel and zinc exhibits long-term dimensional stability, is easy to machine and is non-magnetic. The corrosion resistance of the material means that there is no need for special treatment of the surface; this is an advantage, as the required precision would be difficult to maintain with any plating process, due to surface imperfections.

Practical experience has highlighted certain additional requirements:

- long-term stability: in particular, the position of the various tape guidance components must remain unchanged over long periods;
- the identification apertures for IEC Class I, II, III and IV magnetic tapes and erase tabs must be easily changeable.

By removing the transparent cover, the magnetic tape may be changed and pegs inserted to close off the identification (or 'sensing') apertures. Pegs for the "IEC Class I Tapes" aperture are supplied in the box which houses the cassettes. The erase protection tabs are built up from pegs inserted in a similar fashion.

The CALIBRATION MECHANISM is built strictly to the dimensions laid down in IEC 94 Part 7, which states in particular that "All guides shall be perpendicular to the Z reference plane" (12.4). The Z plane is therefore the starting point for the construction of the CALIBRATION MECHANISM.

The CALIBRATION MECHANISM is put together from a large number of individual components, each of which can be finished without difficulty. Thus every complete CALIBRATION MECHANISM is assembled only from parts which exhibit exactly the required dimensions. Each CALIBRATION MECHANISM is individually numbered and all dimensions which affect azimuth are individually measured. Particular care is needed in the design and finishing of all the tape guidance components: selected and specially ground steel rods are inserted exactly perpendicular to the base as pin guides and roller axles; the stay guides are accurately ground to the correct zenith. The roller guides are highly concentric and their contact surfaces are truly cylindrical.

Accuracy of the CALIBRATION MECHANISM

All tape guide pins in the CALIBRATION MECHANISM are so designed that any deviation from the perpendicular, measured over the tape width of 3.81 mm, is less than 0.005 mm and is typically 0.003 mm.

Together, the CALIBRATION MECHANISM and the test recorder (QC machine) form an azimuth measuring system; in other words, for exact measurement of azimuth, the test recorder must meet the same requirements of precision as the CALIBRATION MECHANISM.

To say whether the CALIBRATION MECHANISM deviates from "zero" azimuth

[9] *It is assumed in the following description that the recorder has been correctly aligned with the help of these calibration tools*

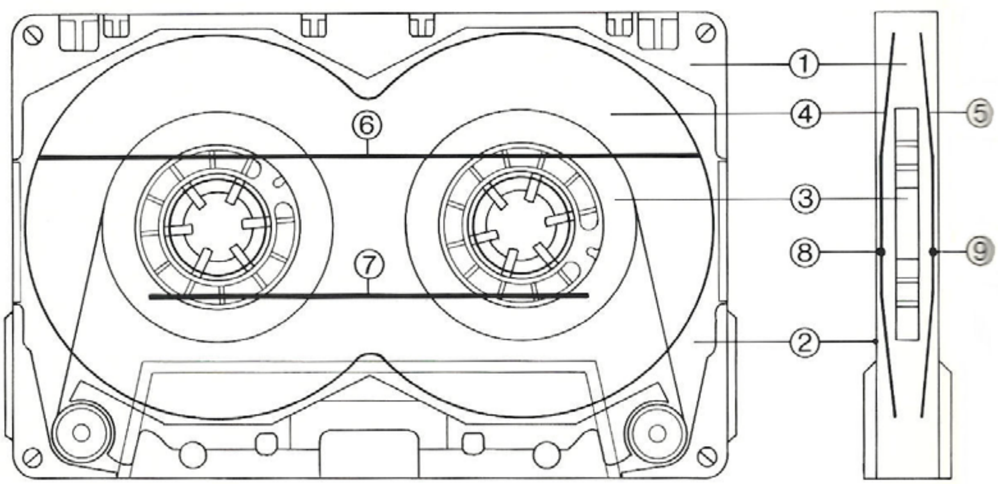
is only possible, strictly speaking, with a cassette recorder whose tape guidance components - including the contact surfaces of the tape-heads, the capstan and the pressure-roller - are all exactly perpendicular to the cassette support plane (deviation ≈ 0.0 µm). At present, however, there is no such recorder in which every tape guidance component can be adjusted for tilt. For this reason, measurements have been carried out on recorders which have been optimally aligned as far as their construction allows.

(and thus exhibiting negligible phase errors between tracks); level approx. - 10 dB with respect to a reference level of 250 nWb/m. Tape length approx. 20 m.

- an IEC Class II blank tape, for adjustment of the azimuth of the record head; length approximately 20 m.

However, it is possible for other tapes to be used in the CALIBRATION MECHANISM, for instance the 3.81 mm IEC 94-1 calibration tapes. The arrangement of the foils (liners) should be noted (fig. 15).

Figure 15:
Position of foils (liners) in the CALIBRATION MECHANISM. Foils must be inserted as shown when assembled.
(1) housing,
(2) cover,
(3) tape,
(4) foil 1,
(5) foil 2,
(6) continuous fold,
(7) limited fold,
(8) this side towards cover,
(9) this side towards housing



Using the CALIBRATION MECHANISMs in recorders adjusted in this way has produced a spread of tolerances between ±0.5 min and ±1.0 min, equivalent to losses of 0.01 dB to 0.03 dB at 12.5 kHz, respectively, or 0.02 dB to 0.06 dB at 18 kHz (measured with a track width of 0.6 mm), or a phase shift of 12° to 25° at 12.5 kHz between two stereo tracks.

There is one limitation on the precision of the CALIBRATION MECHANISM: only the metal side may be used as the support side. That is to say, as a measuring standard the CALIBRATION MECHANISM is only single-sided.

Tapes supplied with the CALIBRATION MECHANISM

The CALIBRATION MECHANISM is supplied complete with two sections of tape, separated by yellow spacer. The two sections are:

- a 12.5 kHz tone for tape-head azimuth adjustment, using the maximum output or phase comparison techniques; recorded across the full width of the tape

Identical tapes should be used in both CALIBRATION MECHANISMs, to avoid tape-related azimuth errors.

Why two CALIBRATION MECHANISMs?

The principles behind the AZIMUTH CALIBRATION MECHANISM have been confirmed in practical use, which has also provided further insight into the problem. The MECHANICAL CALIBRATION MECHANISM has been developed to provide a tool for alignment of the pinch-wheel.

Role and application of the MECHANICAL CALIBRATION MECHANISM

Δ-azimuth and pinch-wheel alignment
As described above, Δ-azimuth is the difference in azimuth angle reading caused by the combination of a misaligned pinch-wheel and the roller guide, with and without axial play. Looking at the Δ-azimuth question strategically provides a direct answer to the problem of ensuring that the pinch-wheel is aligned

parallel to the capstan under operating conditions: two otherwise identical high-precision cassettes are required, one with minimal axial play in the roller guides, the other with relatively high play. The AZIMUTH CALIBRATION MECHANISM is the first of these cassettes, with minimal axial play (±0.015 mm); the other is the MECHANICAL CALIBRATION MECHANISM, which has a closely defined play of ±0.15 mm; there are no other differences between the two cassettes.

Thus the primary function of the MECHANICAL CALIBRATION MECHANISM is to provide dynamic alignment of the pinch-wheel, when used in conjunction with the AZIMUTH CALIBRATION MECHANISM. If the azimuth reading is virtually the same with both the AZIMUTH CALIBRATION MECHANISM and the MECHANICAL CALIBRATION MECHANISM (difference <1 min), the pressure-roller and capstan can be regarded as being precisely aligned. The optimum adjustment is achieved by using the two precision cassettes alternately. Reliable calibration could not previously have been achieved using any other procedure.

Role and application of the AZIMUTH CALIBRATION MECHANISM

The AZIMUTH CALIBRATION MECHANISM was introduced in 1989; its roller guides have absolutely cylindrical surfaces, run accurately and have minimal axial play (±0.015 mm). The principal application of this cassette is in the overall calibration of the tape-heads (see fig. 17) and in particular accurate azimuth alignment.

As previously mentioned, the capstan and pinch-wheel can only be adjusted by alternating playback between this cassette and the MECHANICAL CALIBRATION MECHANISM. Only after all the tape guidance components of the recorder have been optimally aligned can the most important electro-acoustic parameters be reliably set, including replay equalisation, bias setting and record equalisation. This can be done using standard calibration tapes or reference tapes (as appropriate) in the AZIMUTH CALIBRATION MECHANISM. Care must be taken to ensure that the appropriate tabs have been inserted in the identification apertures.

Practical Aspects: *Using the CALIBRATION MECHANISM*

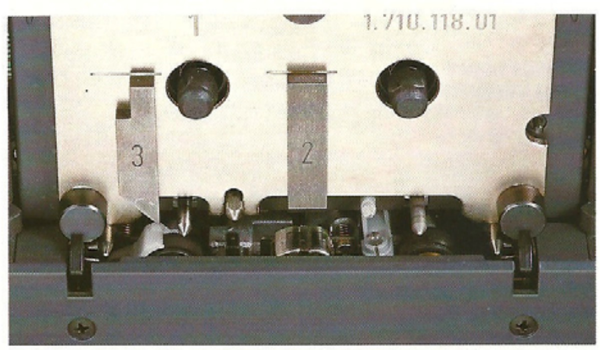
The CALIBRATION MECHANISM is a measuring standard. It should be handled with care, to ensure long life and precision results.

Before using the CALIBRATION MECHANISM, all the tape guides in the recorder must be aligned exactly to the correct height. All tape-heads and components such as tape-stop sensor pins must be set with the correct zenith, exactly perpendicular to the cassette support plane of the recorder. That leaves only the alignment of the pressure-roller in the recorder.

There are two stages to the alignment of the recorder: first, alignment using mechanical aids; then, azimuth alignment of the tape head is alternated with adjustment of the pinch-wheel, until the optimum point is found, namely minimum change in azimuth between the two CALIBRATION MECHANISMs.

The CALIBRATION MECHANISM must be operated vertically, otherwise the tape rollers will be deflected 'downwards' due to their weight and will deflect the tape accordingly. During alignment with the CALIBRATION MECHANISM, recorders in which the cassette is normally horizontal must be operated in an upright position, with the cassette vertical.

Figure 16: The Revox Head Alignment Gauge in a recorder



Mechanical alignment of the recorder

Various tools and devices are available for mechanical alignment of the recorder. In the following description, the Revox alignment set[10] is used to carry out the necessary steps.

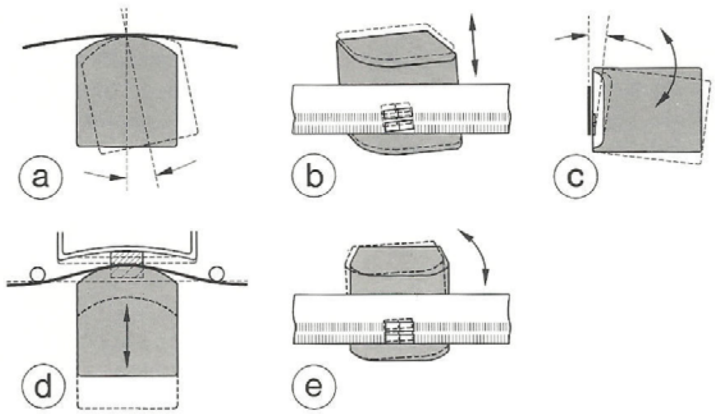
The base-plate (part 1) is inserted into the recorder in place of the Compact Cassette. The machined surface of the baseplate is exactly parallel to the Z reference plane, with an offset of 3.81/2 mm (i.e. 1.905 mm). The knife-edges of gauges 2 and 3 are used to form a high-precision straight-edge, which is used to detect small errors in angular alignment. With suitable illumination, the light shining in the gap between the measuring edge and the surfaces to be aligned (tape guidance components, heads, etc) can be seen clearly and this allows alignment to micrometer accuracy.

Using part 2 of the Revox alignment set, with the edge of the gauge against the base-plate, the exact height of all U-shaped head guides can be set relative to the Z reference plane (fig. 17b). The clearance of precisely 3.81 mm in these components can be verified using part 3 of the alignment set.

Grooves cut into the tape guides and magnetic heads by the tape may, in particular, have the effect of secondary tape guides. Such parts should be replaced if possible, because the effect of these pseudo-guides, especially grooves in the magnetic heads, is uncontrollable.

The angle through which the tape turns as it passes over the head must be symmetrical with respect to the gap (fig. 17a). Correct alignment is generally maintained through the design of the system, but for safety this should always be verified.

Figure 17 a-e: Tape head alignment (see text)



IEC 94-7 lays down[11] that the tape-head should penetrate the central window of the cassette by 3.35 mm (+0.45, -0.25 mm). This ensures an adequate angle of wrap (fig. 17d). However, this should be checked as well.

Tape tension also has some influence on the azimuth alignment. In particular, recorders used for tests on cassette housings should have their tape tension checked. It is recommended that the relevant standards of the ITA (International Tape Association) should be observed. In general, a tape tension of 30 - 50 cNm on the take-up side and approx 8 cNm on the feed side are appropriate.

Tape guides

Part 3 of the Revox alignment set is inserted with the edge of the gauge perpendicular to the base-plate (fig. 17c). This enables the zenith of all tape guidance components (i.e. tape-heads, capstans, mechanical tape-stop sensors) to be checked and adjusted.

Inaccurate, misaligned or worn-out bearings of the head stack are other possible causes of tape guidance errors. Recorders with such faults cannot normally be aligned satisfactorily.

[10] *Revox Part. No. 46 172; available from Revox service agents*

[11] *IEC 94-7, fig. 5, p. 19, clause 12.8*

Tape head alignment using the CALIBRATION MECHANISM

Replay head azimuth alignment

In general, the azimuth of the replay head is aligned first, as it is used for alignment of the record head. Before starting any measurements, the magnetic tape should be wound forwards completely and then back again; this precaution is essential for reliable results. Dual-capstan drives should be allowed to run for one minute before measurements are taken, to ensure that constant tape tension is achieved on the test recorder.

Azimuth adjustment for maximum output

Whenever possible, the initial position of the azimuth adjustment screw should first be marked, for safety. While playing the 12.5 kHz section, the replay head is aligned for maximum output. This is also the position where the output level changes least. To avoid lining up the head to a secondary peak (see below), it is advisable to check that the output is in the range -10 dB to -20 dB relative to the reference level (depending on the specification of the calibration tape used).

Note that:

- the peak in the curve 'High-frequency losses due to azimuth errors' is comparatively broad. For a track width of 0.6 mm and a recorded frequency of 12.5 kHz, the output level drops by only 1 dB within a range of ±5.7 min (see figs. 6 and 7);
- the curve has a secondary peak, with an output >17 dB below the main peak (see fig. 7);
- if the two pole-piece systems of a stereo head are displaced relative to one another, or are at an angle to one another, they will exhibit peaks at different head angles; in such cases alignment should be for minimum average error;
- any large rotation of the azimuth adjustment screw will result in a change in the height of the tape-head; alignment must then be repeated, step by step, from the beginning.

Azimuth adjustment for minimum phase difference

With any procedure that involves finding the maximum output point, the alignment of the heads has to be disturbed, simply because that is the only way to find or even verify the optimum setting. Precisely aligned heads are therefore disturbed unnecessarily. For critical azimuth adjustments, in particular for stereo, alignment for maximum output can only serve as a preliminary step. However, simply measuring the phase difference between the two channels[12] is sufficient to tell whether any improvement can be expected from re-alignment of the head.

Precise alignment is achieved with minimum phase difference between the output voltages, measured using a dual-beam oscilloscope or a phase meter. Obviously, any phase shift caused by the head system and replay amplifiers must be known. This inherent phase difference can be measured using a test signal, applied directly to the replay head (e.g. with an induction coil). Any perceptible error here must be taken into account when calculating the overall phase difference.

Record head azimuth alignment

Almost all three-head recorders have electrically separate record and replay head electronics, but the heads are mechanically linked (see fig. 11). True alignment is not possible in this instance. With individually adjustable heads, however, the replay head should be aligned first. After that an appropriate high-frequency signal (at 10 - 12 kHz, approx. 10 - 20 dB below reference level) is recorded. The record head is then carefully aligned while checking the result at the replay channel output[14].

Phase shift caused by bias changes

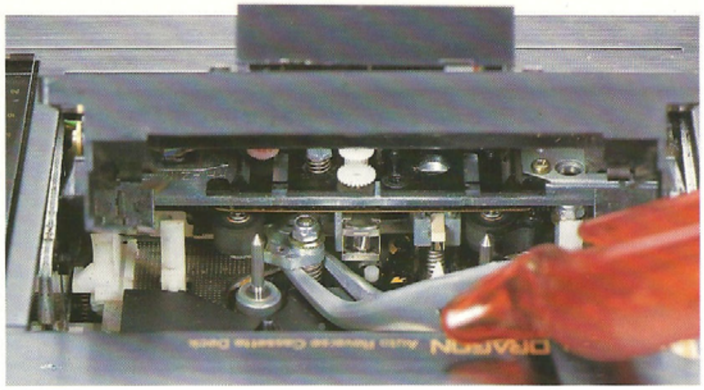
If the bias is individually adjustable on each channel, it must be borne in mind that any change in bias will result in further phase shifts[13]. In practice, a bias difference of 2 dB will produce a phase difference of 20°- 40° at 12.5 kHz.

[12] Apart from special versions, all reference and calibration tapes are full-track recordings, so phase remains constant over the entire tape width.

[13] The head-to-head delay must be taken into account where necessary.

[14] Among other things, the bias level determines the position close to the trailing edge of the record-head gap where the sound is actually 'recorded'.

Figure 18:
Pinch-wheel adjustment using long-nosed pliers



Alignment of the pinch-wheel using the Δ-azimuth method

The adjustment of the recorder using the two CALIBRATION MECHANISMs is achieved by inserting the two cassettes alternately and adjusting the pinch-wheel in relation to the capstan, until the Δ-azimuth is as small as possible. There is no known recorder currently available on which the pinch-wheel axis can be moved using an adjustment screw. The only way to do so is to bend the pinch-wheel arm very carefully. Of course this is only possible with an all-metal construction. Recorders with pinch-wheels mounted on plastic parts are unsuitable; the latter either bend elastically back to their initial position, or break during adjustment.

If there is significant axial play in the pinch-wheel, this must be reduced symmetrically, in order to obtain consistent results from the adjustment. Afterwards the tape head height and the force with which the pinch-wheel presses on the capstan must be checked and adjusted, if necessary, to the manufacturer's specification.

Where necessary, the pinch-wheel should be cleaned with a dry, non-shiny cloth. After cleaning with a liquid[15], it must be run for as long as recommended in the manufacturer's handbook, as the surface properties of the pinch-wheel may have altered temporarily.

Precise alignment of the pinch-wheel is only practical using the phase comparison method for Δ-azimuth.

Requirements for alignment:

- AZIMUTH CALIBRATION MECHANISM (minimal axial play in the roller guides), loaded with 12.5 kHz azimuth calibration tape;
- MECHANICAL CALIBRATION MECHANISM (±0.15mm axial play in the roller guides), loaded with an identical 12.5 kHz azimuth calibration tape;
- phase error meter or a twin-beam oscilloscope with which the phase relationship and order of magnitude of the output level can be read easily;
- a strong pair of long-nosed pliers (see fig. 18)

Useful tools include a small angled mirror and a suitable light source (for instance, a cold light source with a fibre-optic conductor) in order to see the pinch-wheel area better. The following steps are carried out during alignment:

Preparation:

- Insert the MECHANICAL CALIBRATION MECHANISM and observe the take-up side roller guide while the tape is running. It should run centrally, within the limits of axial play; if necessary, adjust by carefully bending the pinch-wheel axle mounting as required.

1. Using the AZIMUTH CALIBRATION MECHANISM, adjust for minimum phase difference (between the channels) by optimum azimuth alignment of the tape-head.
2. Insert the MECHANICAL CALIBRATION MECHANISM and adjust for minimum phase difference, carefully bending the arm on which the pinch-wheel axle is mounted.
3. Repeat steps 1 and 2 until a Δ-azimuth of <1 min is achieved.

[15] *preferably using a product recommended by the manufacturer*

It may happen that a recorder shows no azimuth error when using just the AZIMUTH CALIBRATION MECHANISM. If this is due to pseudo-alignment, the error will show up instantly when the MECHANICAL CALIBRATION MECHANISM is used. Only measurements using both the CALIBRATION MECHANISMs can give valid results!

Azimuth alignment of a test recorder for Quality Control of Cassette Housings

Because the tape guidance is distributed between the Compact Cassette and the tape transport, a test recorder must have the same degree of precision as the CALIBRATION MECHANISM with regard to the perpendicularity of all parts in contact with the tape. In particular, the tape-heads, capstan and pinch-wheel must be exactly perpendicular to the reference plane of the cassette (within an acceptable tolerance, ≤5 µm over 3.81mm).

For test purposes, the 12.5 kHz recording supplied with the CALIBRATION MECHANISM should preferably be used. The angle of deviation of the tape-head from the azimuth position for maximum output serves as a suitable measure.
It is recommended that after alignment with the AZIMUTH CALIBRATION MECHANISM, the position of the adjustment component should be marked as a reference and an azimuth deviation scale mounted, calibrated in minutes of arc.