Magnetic sound recording

The first complete magnetic recorder (wire on a drum) was constructed in 1898 by Poulsen (Denmark). In 1938 the first recorders using plastic tape with an iron oxide layer were used. Since then, magnetic sound recording has become the most popular way of storing broadcast programmes for transmission at any time. Early attempts with temporary disc recording and photographic recording proved unsuitable for broadcast applications.

Although digital recording systems have gained increasing importance, the analogue magnetic recording is still in wide use and will probably remain so for several more years.

Mechanical, magnetic and electronic principles are involved in tape recording. All of them have to be studied to fully understand the entire system.

During maintenance, the mechanical alignments are always done first. Therefore also this course will start with the consideration of tape recorders' mechanics.

Table of contents

1. The Capstan Drive

Traditionally, synchronous ac motors were used. They were "locked" to the mains frequency. The motor windings can be switched to provide two tape speeds. The motor may have the armature outside or be of standard design with an additional flywheel on the shaft below the motor body. The shaft of the motor extends upwards as capstan.

Disadvantages:

a) The motor speed cannot be varied
(e.g. for special effects or for pilot systems)

b) The tape will run at the wrong speed if the mains frequency is not correct.

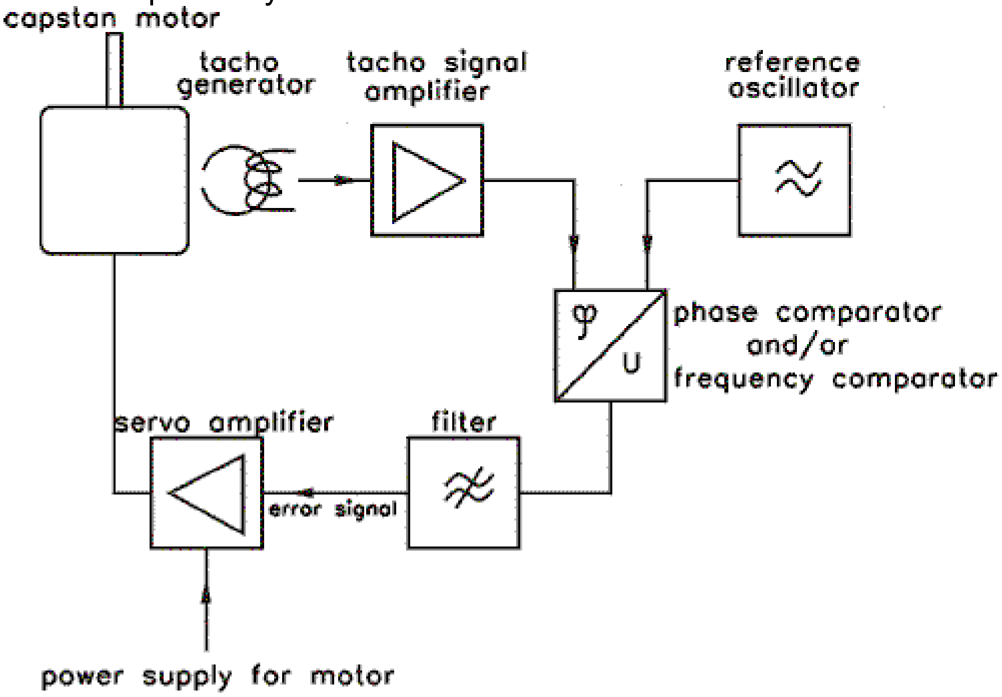
Other makes (e.g. Studer) use an asynchronous ac motor, which is then speed controlled. In all such systems, a generator (or 'tachometer') is attached to the capstan. The frequency from this generator is proportional to the capstan speed. This frequency is checked against a standard (reference frequency). If the two frequencies are not equal, the capstan speed is re-adjusted. In such a closed loop system (servo system) the speed is checked and adjusted all the time, so maintaining it correct and constant.

Such systems make the speed externally adjustable if required and independent of the mains frequency.

The capstan drive may be direct, e.g. as a ac motor (as in Studer models), or as a DC motor (as in Nagra); or indirect via belt drive with a DC motor (as in Telefunken M15 and M15A).

1.1. THE CAPSTAN SERVO CONTROL PRINCIPLE

Capstan speed control circuits are always based on the same principle: A FREQUENCY is derived from the capstan speed. This frequency (f_{tacho}) is COMPARED with a fixed, precisely known REFERENCE FREQUENCY (f_{ref}). The circuit, which compares these two frequencies, produces a signal, which indicates the difference between the capstan frequency and the reference frequency. This is called the ERROR SIGNAL. The error signal controls the SERVO AMPLIFIER for the capstan motor. The whole system represents a SERVO SYSTEM, which is actually a closed loop NFB system.



The principle of the capstan servo system.

To compare the capstan and the reference frequency, two different principles must be distinguished:
- the phase comparator and
- the frequency comparator.

1.2. TACHOMETER SYSTEMS

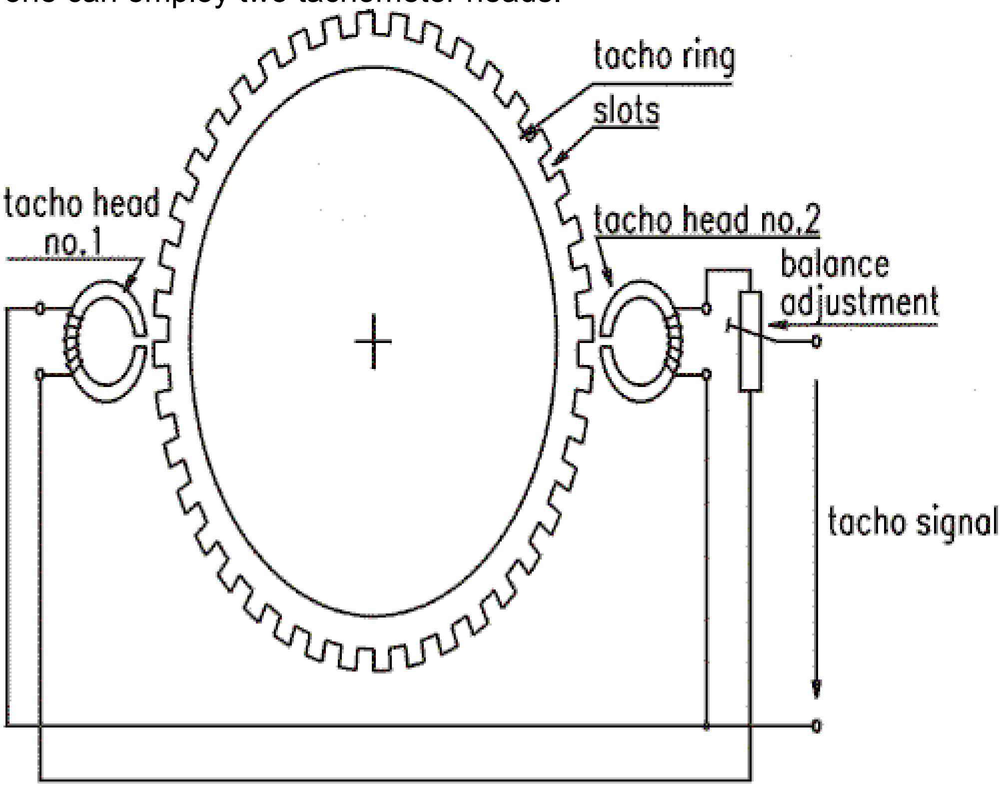
The tachometer system has to provide the information of the actual capstan speed to the servo system. In all cases the system generates a signal, of which the FREQUENCY carries the information.

Different ways are used to generate this tachometer frequency. In most cases the signal is produced by induction, so a coil is involved. The "armature" has a number of poles, which defines, together with the capstan speed, the frequency of the generated signal. The poles may consist of slots or teeth on a disc mounted on the capstan shaft (e.g. Nagra), or on the outside of the motor (e.g. Studer).

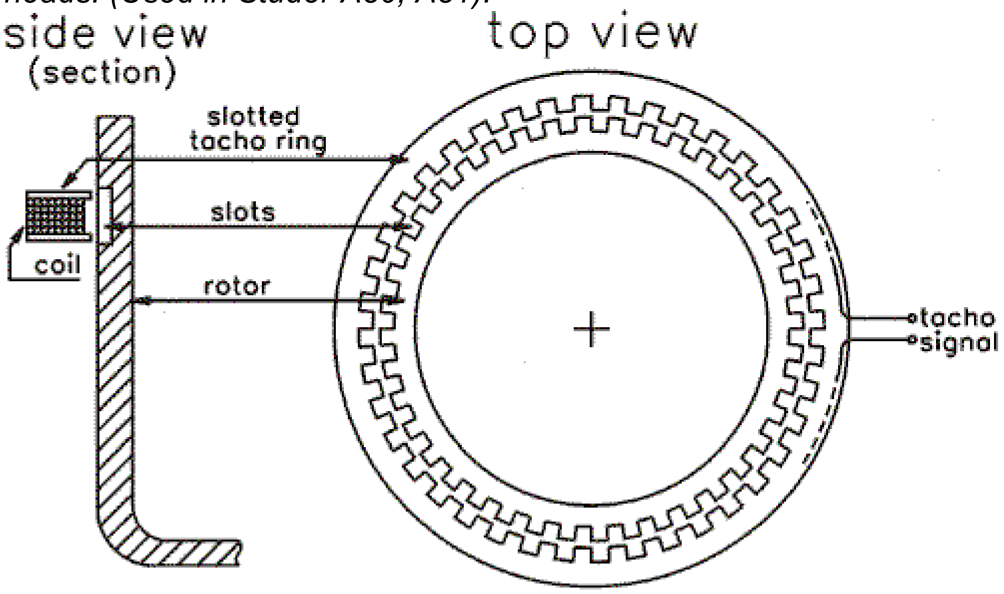
The teeth or slots on the rim are cut to close tolerances. Also, the wheel must run without any eccentricity, otherwise frequency variations will be produced. The tachometer-head is DC-magnetized. The teeth passing produce field changes, the field changes induce a voltage of a frequency, representing the capstan speed (f_{tacho}).

Nagra recorders use a toothed flywheel with a single tachometer head.

To make the frequency of the tachometer output less dependent on the eccentricity, one can employ two tachometer heads.



A system using two tachometer heads 180° apart. Head no.I can be displaced a bit for optimum performance. The potentiometer is set for equal voltages from the heads. (Used in Studer A80, A81).

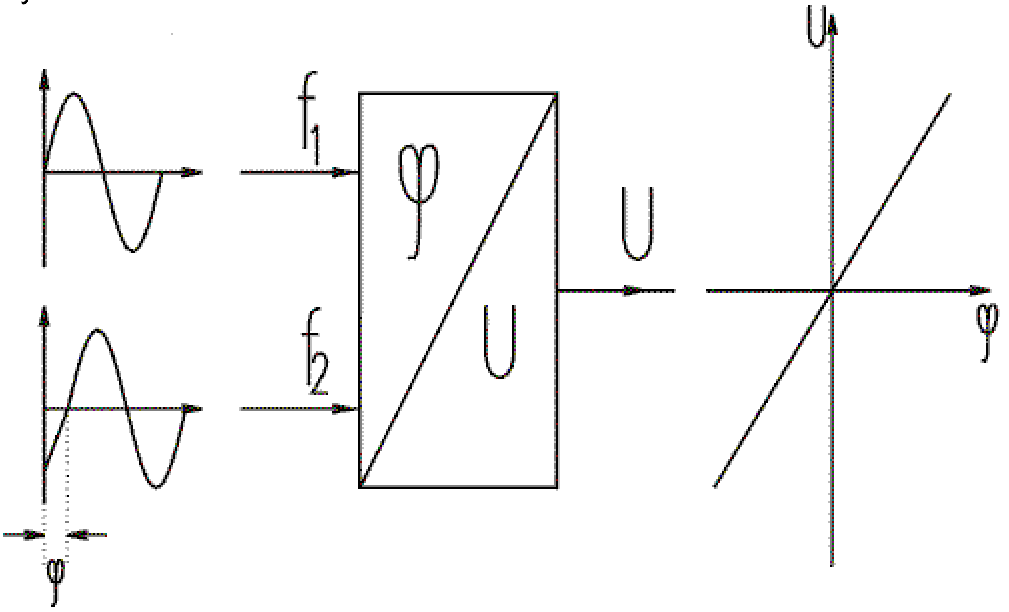


An alternative method for the tacho generator:
the capstan (motor) turns the inner ring against an outer fixed ring, both with equal number of teeth. The outer ring includes a coil, which is DC current magnetized and acts as pick-up (tachometer ring). (Used in Studer A7000, B67 and Telefunken M15, M15A.)

1.3. PHASE COMPARATORS

Phase comparators produce an output signal which depends on the PHASE RELATIONSHIP between the input frequency and a reference frequency. This means in fact, that the two frequencies must be on average absolutely equal. A servo system, using phase comparators normally maintains a phase difference of approximately 90°.

If such a system is used in oscillators, it is called a PHASE LOCKED LOOP (PLL) system.

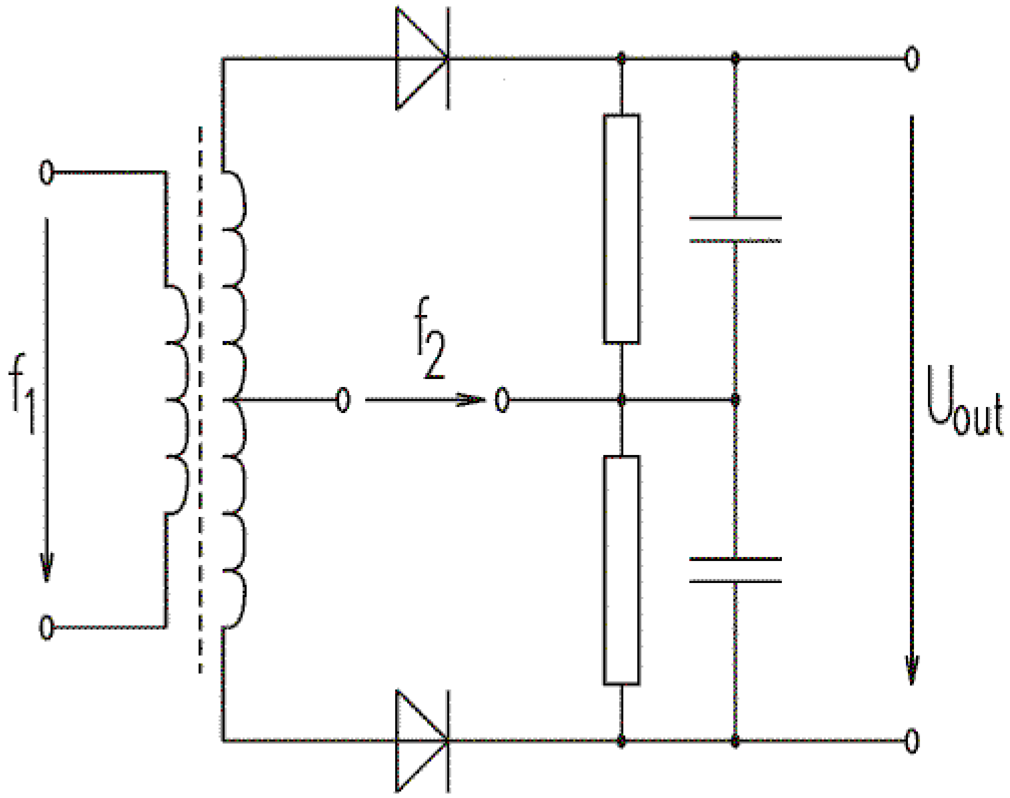


The principle of the phase comparator.

Different circuits can be used as a phase comparator. We mainly distinguish analog and digital principles.

1.3.1. ANALOG PHASE COMPARATORS

The circuit used as the phase comparator is the same as for the modulator, demodulator or mixer.



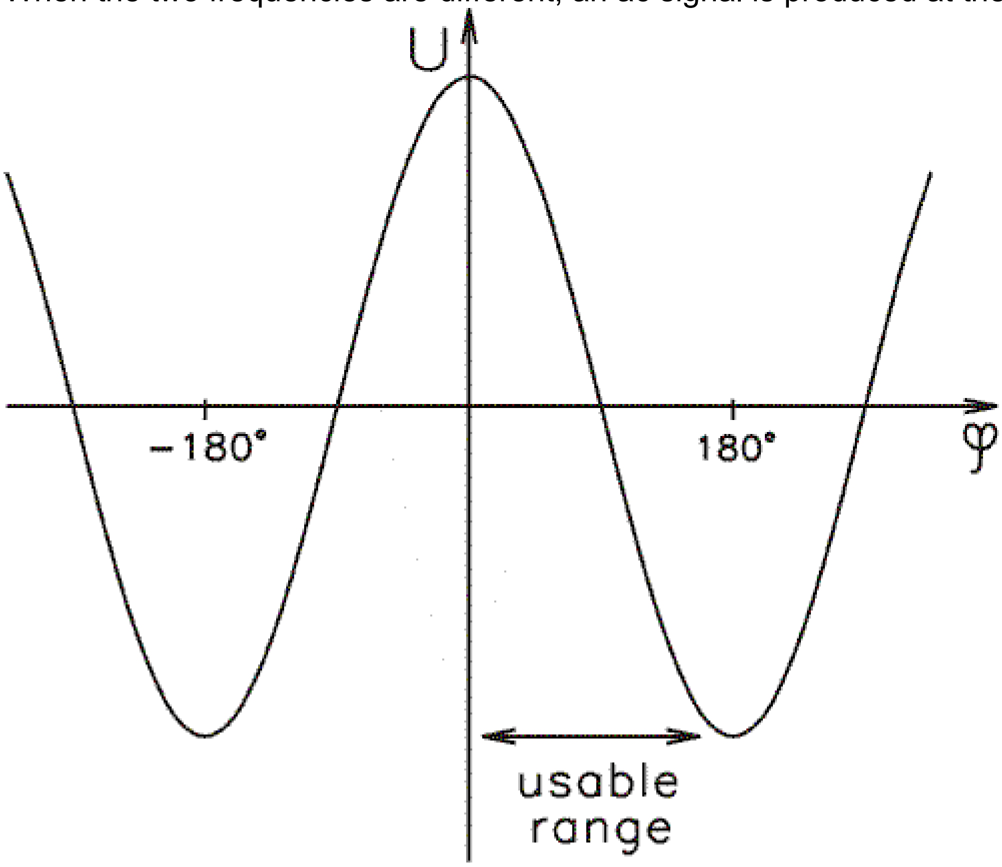
The analog phase comparator using a circuit known as phase discriminator.

This circuit produces an output signal, which is known from the modulation:

$$f_{out} = (f_1 + f_2) \quad and \quad (f_1 - f_2)$$

In the phase comparator the second term (f_1-f_2) is used. The first term (f_1+f_2) is a relatively high frequency, which can be eliminated by filtering. When both frequencies are equal, the term (f_1-f_2) will become 0. Thus the output signal is a DC voltage. The magnitude of this voltage depends on the phase relationship between f_1 and f_2.

When the two frequencies are different, an ac signal is produced at the output.



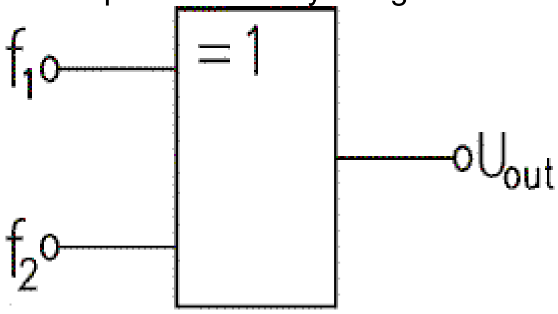
The typical output signal of a phase comparator as function of the phase difference between f_1 and f_2.

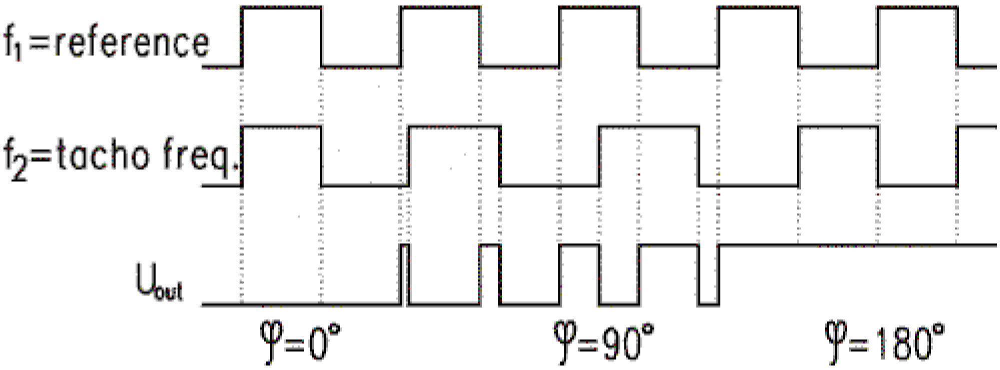
The phase discriminator produces an ac signal as long as the two frequencies are not yet synchronized. This represents no useful error signal. Therefore, in practice additional means are required to produce a useful signal during the speeding up of the capstan motor.

1.3.2. DIGITAL PHASE COMPARATORS

Different principles are used here. There are also ICs specially available for servo systems.

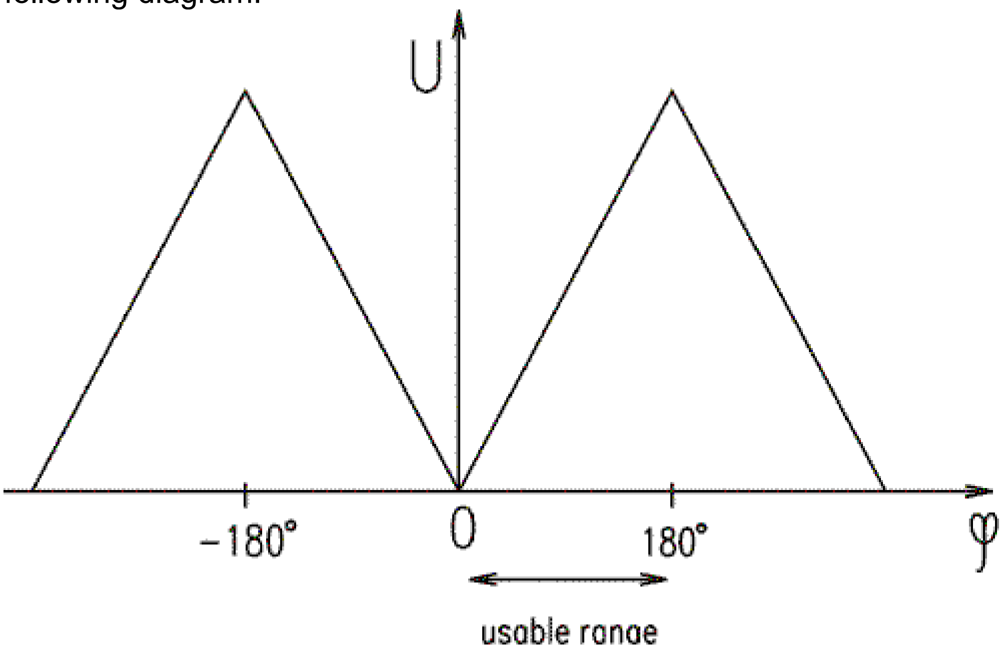
The principle will be explained here by using an ordinary EXOR gate:





The simplest form of a digital phase comparator can be an EXOR-gate.

The relationship between the input signals and the output signal is shown in the following diagram:



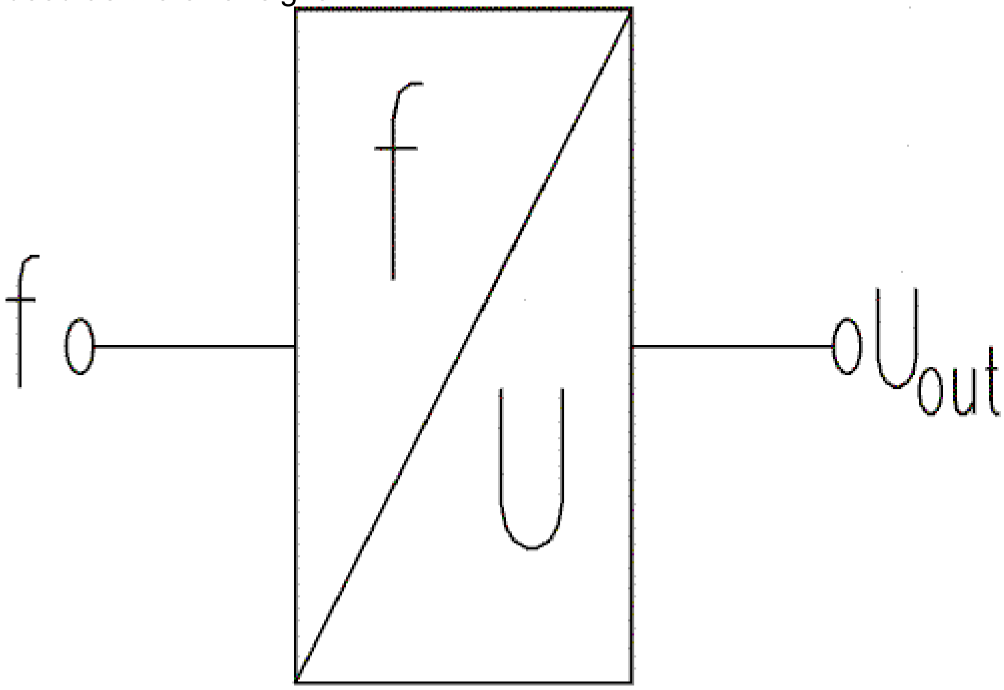
The output signal of an EXOR-gate fed with two signals of different phase.

Only the part between 0° and 180° can be used. Also, this phase comparator is normally operated near 90°.

The disadvantage of this simple circuit is that it does not provide a useful signal, while the capstan motor does not yet run at synchronized speed. Therefore, in practice, more complex integrated circuits or special ICs for servo controls are used.

1.4. FREQUENCY-VOLTAGE CONVERTER

These circuits produce a signal which depends on the frequency of the input signal. The input signal will therefore be the tacho-frequency, while the output voltage will be used as the error signal.



Block diagram of the frequency voltage converter.

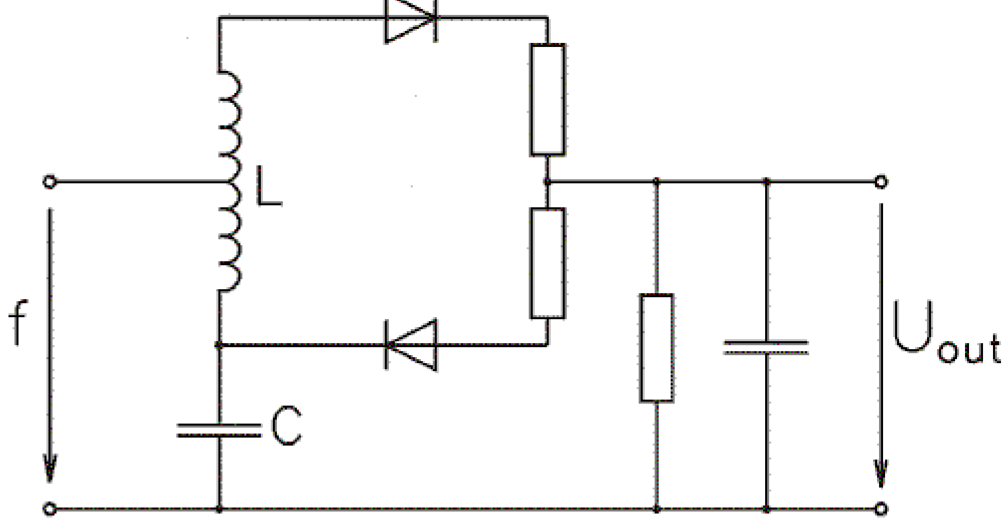
The frequency voltage converter therefore receives only one input frequency. The reference frequency is represented by some circuit elements of the converter. The reference frequency does not physically appear in the circuit.

The frequency voltage converter will only produce some variation of its output voltage if there is a variation of the input frequency. Therefore, a servo system, using a frequency voltage converter, will allow small variations of the capstan speed, while a system using a phase comparator is able to maintain the capstan speed absolutely constant.

Again, analog and digital solutions are possible for the frequency comparator.

1.4.1. ANALOG FREQUENCY VOLTAGE CONVERTER

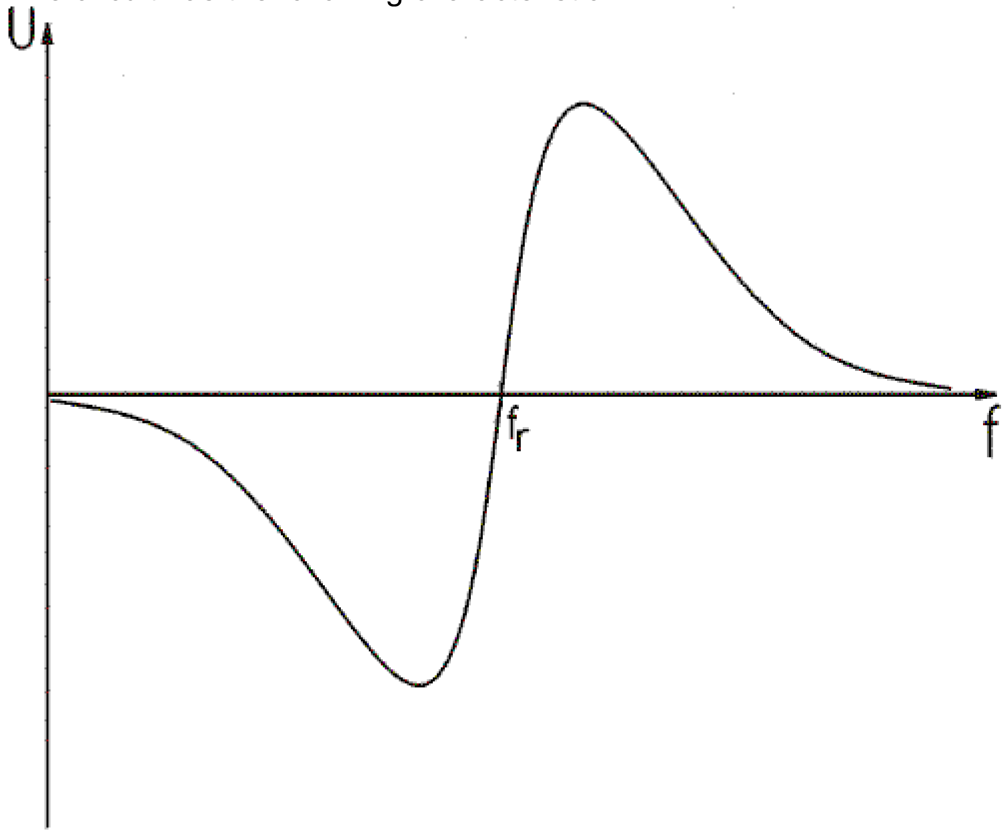
The circuit can be understood as a phase comparator with a tuned circuit, which can be considered as the reference frequency source.



Principle circuit of an analog frequency voltage converter.

In this circuit L and C represent the reference frequency.

The circuit has the following characteristic:



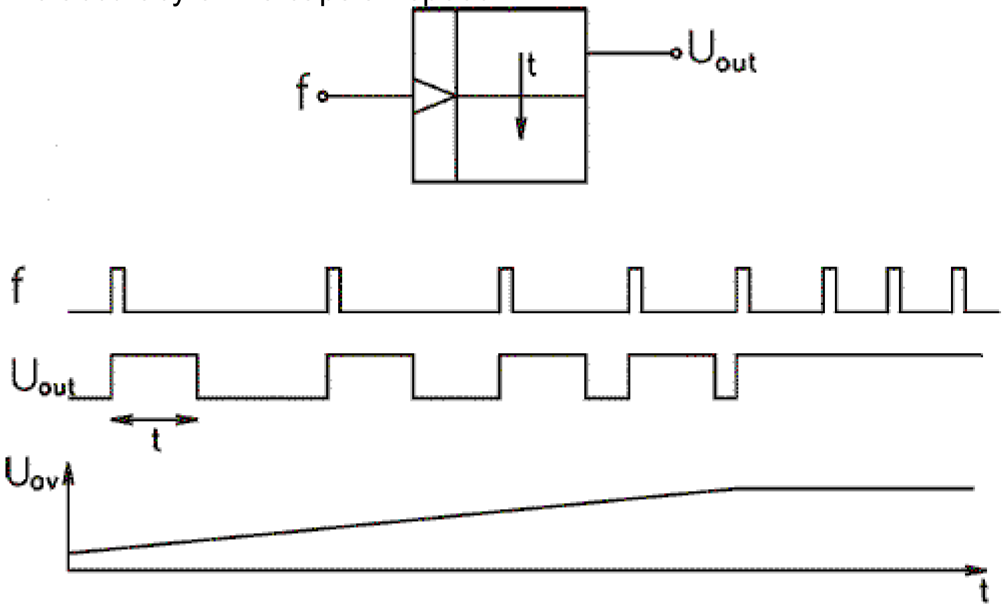
Relationship between input frequency and output voltage for the frequency voltage converter.

This principle is used in the Nagra 3 and Telefunken M15.

1.4.2. DIGITAL FREQUENCY VOLTAGE CONVERTER

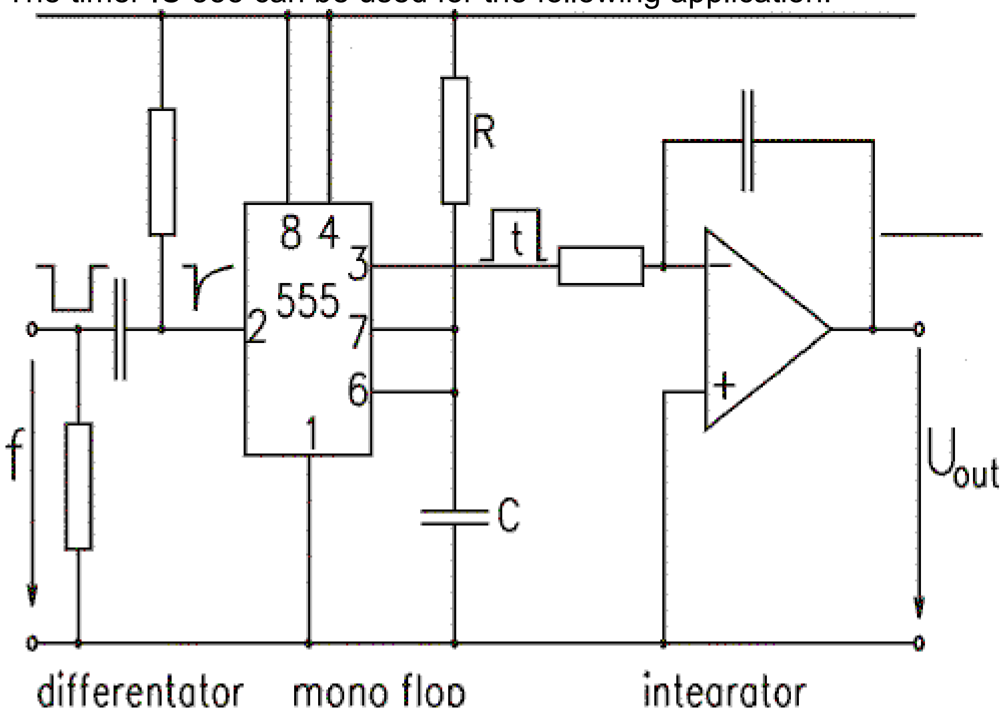
These circuits use a monoflop, producing a pulse of defined length.

The length of the pulse represents the reference to the circuit. Its accuracy will define the accuracy of the capstan speed.



Block diagram of a monoflop and time diagrams for an input signal of increasing frequency.

The timer IC 555 can be used for the following application:



Monoflop with timer-IC 555. The circuit differentiates the input signal to produce short pulses, and integrates the output voltage to produce a pure DC signal.

This method is used in the Studer A77, B77 and Nagra 4.

1.5. CHANGING CAPSTAN SPEEDS

As most tape machines run at different tape speeds, the capstan speed must be controllable. In principle there are two ways to achieve this:

1. The tacho signal is manipulated. E.g. to achieve the double capstan speed, the tacho signal is divided by two.

2. The reference is manipulated. For phase comparators the reference is a frequency. If the reference frequency is doubled, the tacho frequency must also double, so the capstan will run at double speed.

For voltage comparator circuits, manipulations must be done to the circuit elements setting the internal reference of the circuits.

For vari-speed applications these parameters are manipulated continiously. Method 1 is not suitable for this variation. In this case, the vari-speed action uses method 2, while the standard capstan speeds are selected by method 1.

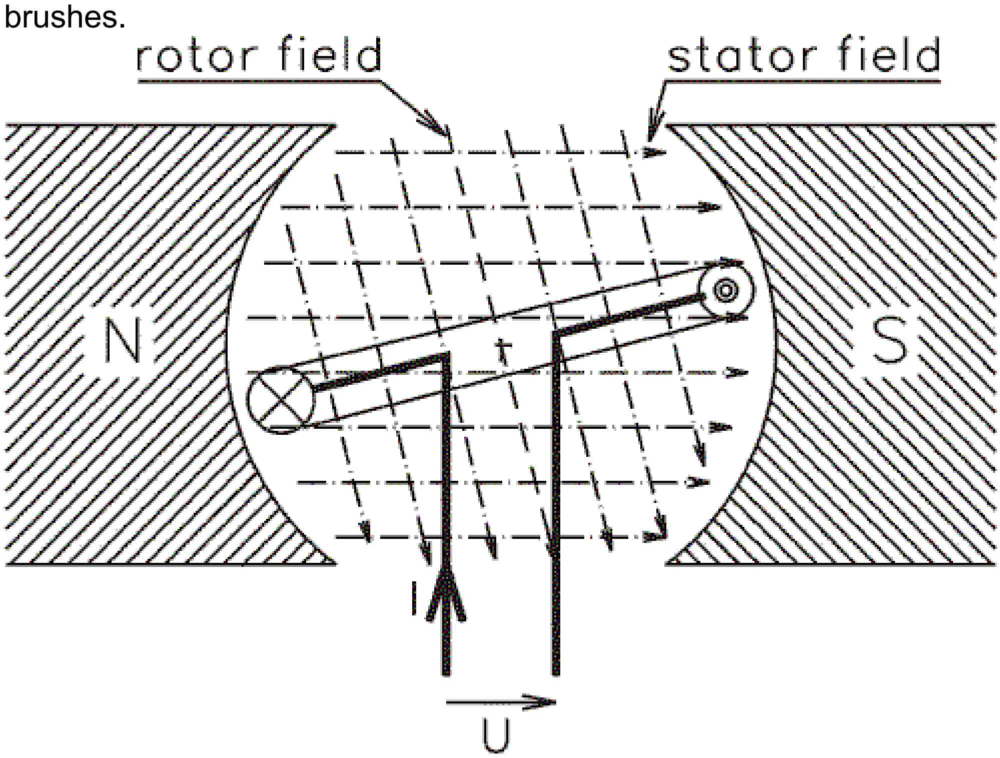
1.6. DC MOTORS

In most modern tape machines DC motors are used.
This gives the following advantages:

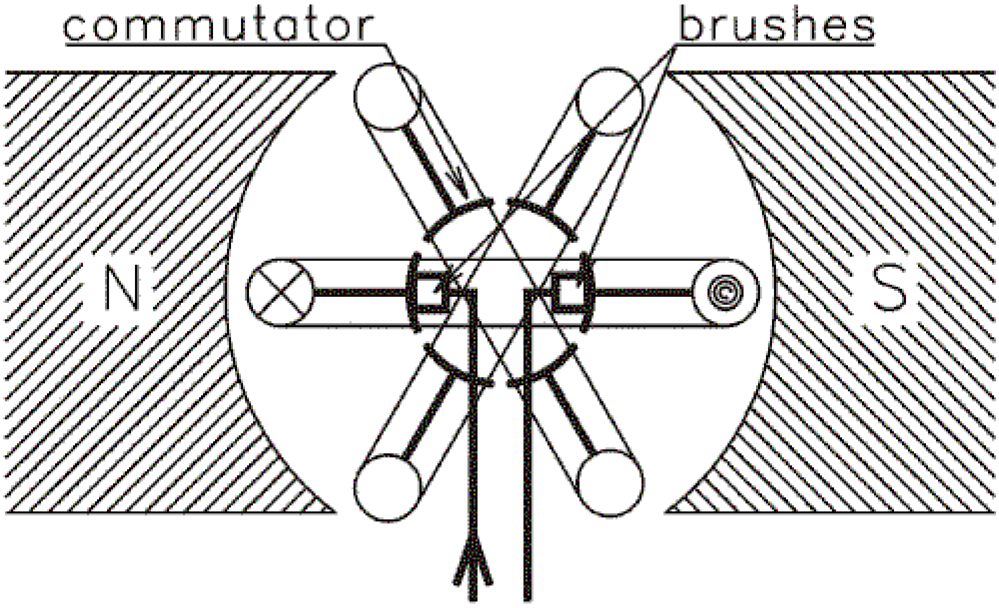
- Tape speed independent of main frequency,
- Battery operation possible,
- High accuracy achievable with servo systems,
- Easy variation of tape speed,
- Good efficiency,
- Low running noise,
- Low magnetic stray fields.

In order to produce a rotating movement, commutation is required to convert the DC into a current, which changes its polarity according to the position of the rotor.

Traditionally, this is done by using a commutator ring on the rotor and stationary brushes.



The principle of the motor: the current through the rotating coil produces a mechanical force in the stationary magnetic field. In order to continue the rotation, the current in the coil has to change the direction if the rotor field is in line with the stator field.



Commutators on the rotor supply the rotor coils with a constantly changing current, which provides a constant force on the rotor. The current is provided to the rotor by brushes.

The mechanical commutation of DC-motors has the following disadvantages:

- Wear on brushes and commutator ring,
- Mechanical noise,
- Arcing and hf-radiation,
- Non-linear angular torque,
- The coil is the rotating part, therefore centrifugal force act on the coil.

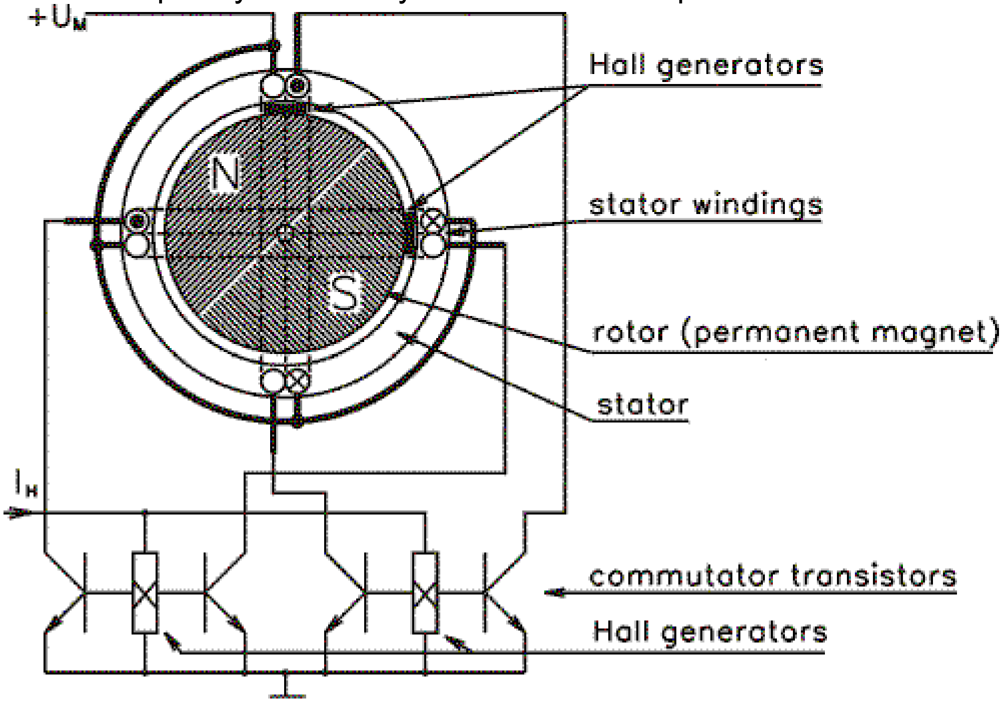
Because DC motors with commutators are cheap, they are, despite there disadvantages, today still widely used in simple cassette recorders.

Electronic commutation avoids all the disadvantages of the mechanical commutation. It is therefore entirely used in all modern professional tape machines and in more sophisticated consumer equipment.

Electronic commutation makes use of the hall generator to detect the position of the rotor. It also controls the stator current via a current amplifier, so that a rotating magnetic field is achieved in the stator windings.

Principle of action:

The rotor is a permanent magnet with one or many pairs of poles. A hall generator is mounted to the stator to detect the position of the rotor. The signal from the hall generator controls a transistor amplifier, which passes current through the stator winding so that a constant torque is achieved to the rotor. If the rotor rotates at constant speed, the current through the stator winding will have a sine shape and will have a frequency which is synchronous to the speed of rotation of the rotor.



The principle of the burshless DC motor and the commutating circuit.

There are many different arrangements for the rotors, stators hall commutators and electronic circuits of such motors. Some of them have the commutation circuit integrated in the motors (Ampex 440), some have it externally (EMT, STUDER, Telefunken). Some use the commutation transistors directly as servo amplifiers (EMT, Studer A807).

All these motors have the same advantages:

- No mechanical wear (except bearings),
- Suitable for very low and very high speeds,
- High efficiency,
- Constant angular speed and torque, even at very low speeds (direct-driven record players),
- No arcing and hf radiation.

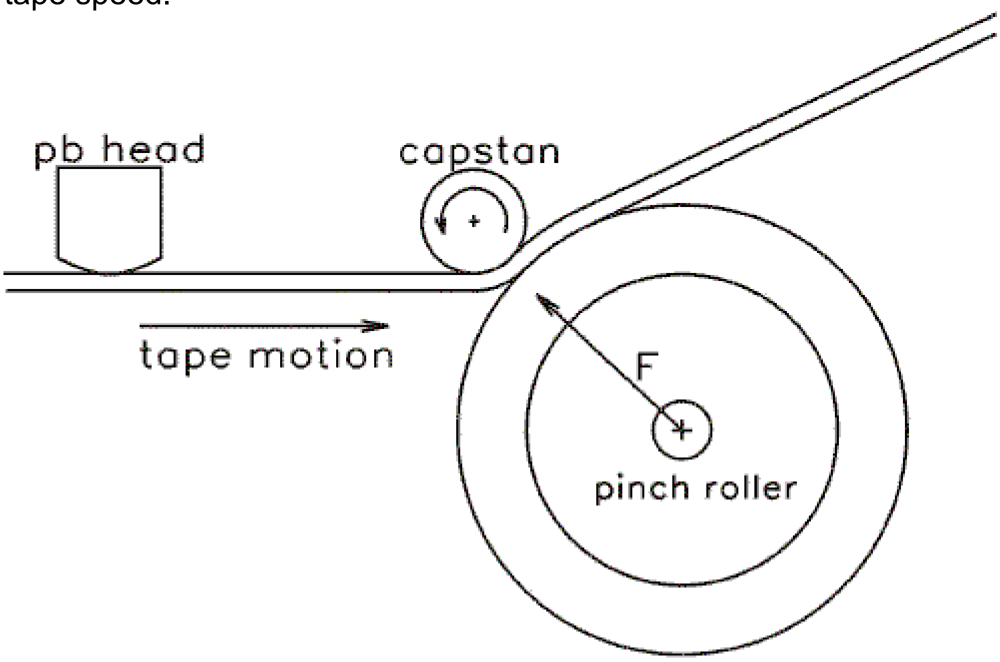
1.7. DRIVING THE TAPE

Very stringent demands are put on the mechanical behaviour of a professional tape machine:

a) The tape must be transported at constant and even speed,

b) it must be guided from the supply reel to the heads via the capstan to the take-up reel. It must lay flat on the heads, not move up or down, not flutter and not vibrate (longitudinally).

The pressure roller is used to press the tape to the capstan to force it to run at the circumferential speed of the capstan. The pressure roller must meet the capstan at such an angle, that the tape will first touch the capstan and later the pressure roller. This is necessary to avoid eccentricity of the pressure roller (rubber) affecting the tape speed.

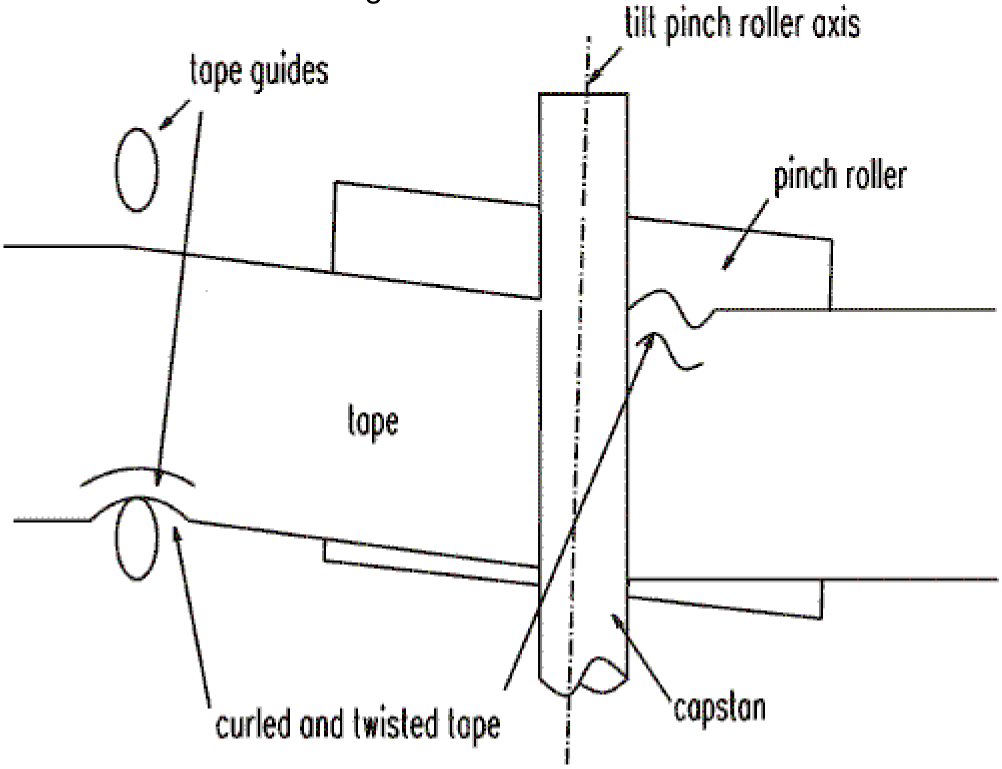


The arrangement of pinch roller and capstan.
The tape, coming from the heads, must first meet the capstan, then the pressure roller.

The pressure roller is pressed against the capstan by a spring- loaded solenoid.The pressure is adjustable, the correct value is quoted in the service manual. Capstan and roller tend to collect tape particles and dirt. Both must be cleaned regularly (e.g. daily) with alcohol.

Special care is essential when lubricating: remove all traces of oil from roller and capstan.

The capstan must be vertical to the tape, the pressure roller must run true parallel with the capstan. In some machines this is adjustable. The pressure roller position can be checked by watching the tape to run off straight from the capstan without any tendency to twist upwards or downwards. Mis-adjustment will cause the tape to become curled and damaged.



If the axis of the capstan and pressure roller are not parallel, the tape will be twisted and pulled out of track.

When pressure and/or alignment are not correct, TAPE SLIP will increase. This will also increase the WOW AND FLUTTER and can be checked with suitable instruments. Note that slip and wow and flutter also depend on other mechanical parameters of the tape machine like dirt, tape tension and the alignment of the brakes.

The capstan (with its motor and/or flywheel) is precision engineered to very close tolerances.

Take care not to knock it. A damaged capstan has to be replaced.

2. THE TAPE TENSION CONTROL

Professional tape machines normally have a sophisticated tape tension control system.
Tape tension is important during all operational modes of tape machines:

1. During play-back
a certain tape tension is required to provide good head contact with the tape.

2. During spooling
a certain tape tension is required to ensure safe running of the tape and to provide a good tape "cake".

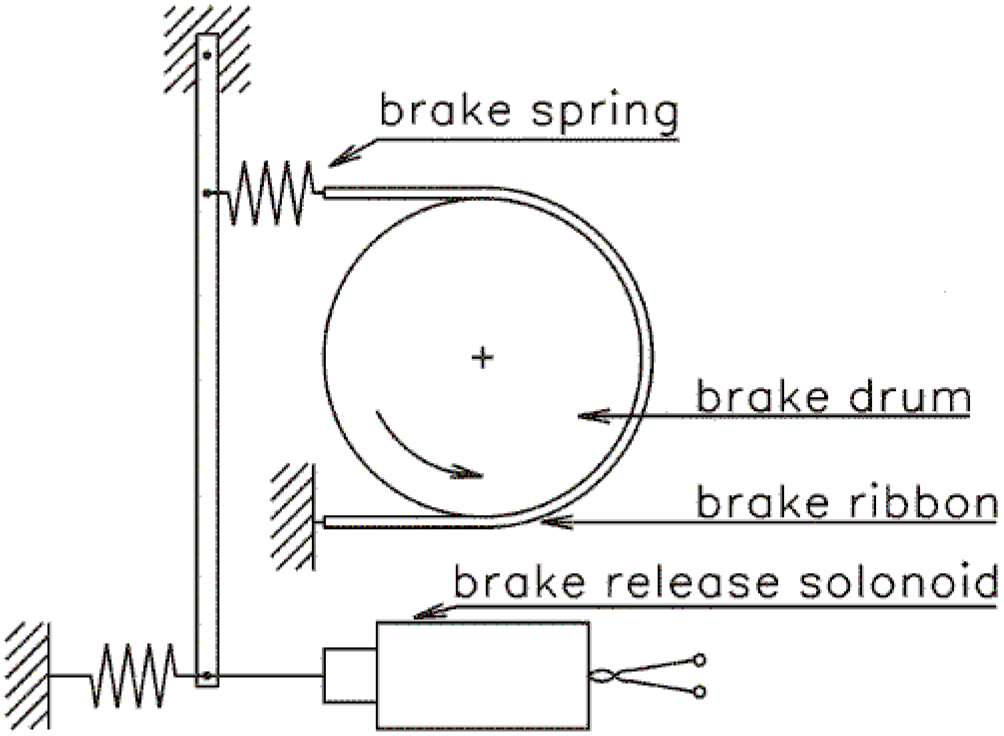
3. During spooling and braking
the tape tension must be kept in safe limits to prevent over-stressing and stretching of the tape.

Numerous methods and technologies were developed in order to solve these requirements. Generally they combine electronic and mechanical aspects.

2.1. BRAKE SYSTEMS

The brakes are always mechanical. They typically consist of a brake drum mounted on the spooling axis, and a spring-loaded brake ribbon which produces friction if the brake is applied. Some machines use brake shoes instead of a ribbon (Nagra).

The brakes are **disengaged (off) during "run**" (play-back and record modes) and during fast wind (fast forward or rewind). This is achieved by solenoids which pull the brake ribbons away from the brake drums. When these solenoids are not powered the brakes come into action, being pulled in by brake springs. This ensures that the tape comes to a smooth **stop in case of power failure**.



Principle of the spool brakes, showing the brake drum, the brake ribbon and the brake release solenoid. The brake will be off if the solenoid is exited.

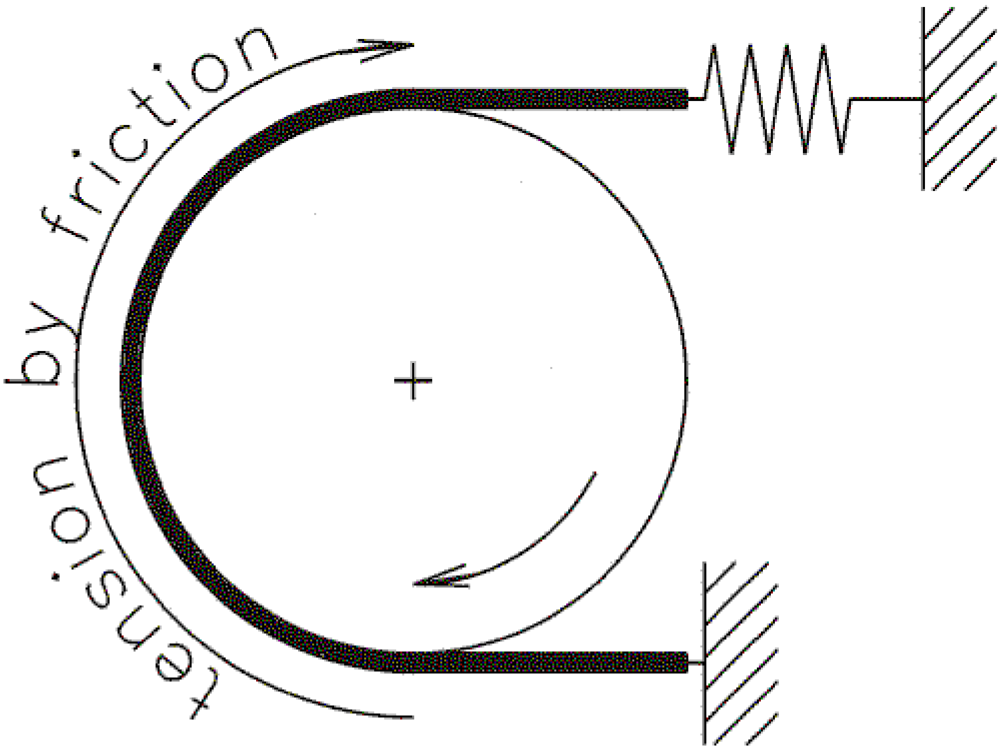
Since the brakes are always applied when the machine is not running, it is difficult to move the tape by hand for editing. Therefore many machines have an EDIT mode. **In EDIT mode the brakes are partly or fully released** to allow the tape to be shifted easily.

2.1.1. THE SERVO-BRAKE PRINCIPLE

The brake for the supply reel (left) and the brake for the take-up reel (right) are always applied simultaneously. The rotating spools and motors have **considerable inertia** (energy), especially during fast wind.

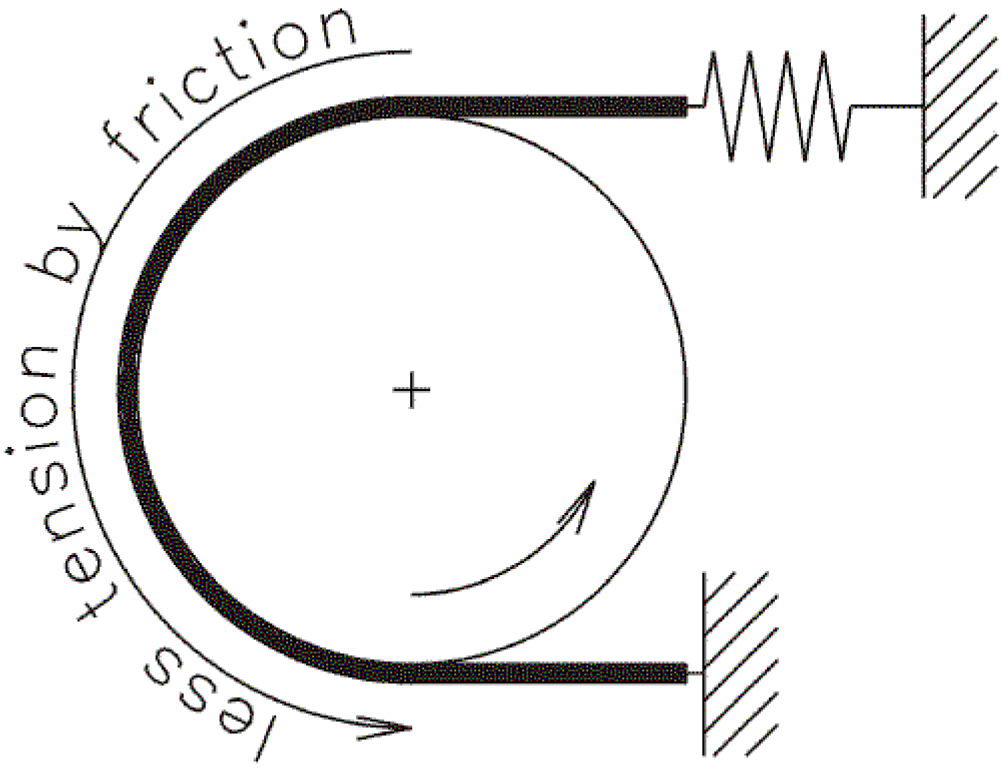
If during fast wind the tape were stopped, it would spill off the reel if the take-up reel stopped faster than the supply reel. It is therefore essential that the supply reel receives stronger braking torque than the take-up reel. In this way the tape is always held under tension until stand-still.

This is achieved through correctly positioned brake ribbons.



The servo brake for the right-hand spool during fast rewind. As the brake drum turns clockwise, the friction tends to increase the ribbon tension, supporting the action of the spring.

When the brakes are applied, the brake spring pulls the ribbon tight. The drum turns clockwise (see arrow). The friction between drum and ribbon pulls the ribbon towards the spring, thus pulling it tight and so increasing the braking force. This does not happen on the left-hand brake. The right-hand brake action is therefore stronger than on the left: the tape is held tight.



The same right-hand brake during fast forward. As the brake drum turns anti-clockwise, the friction tends to reduce the ribbon tension.

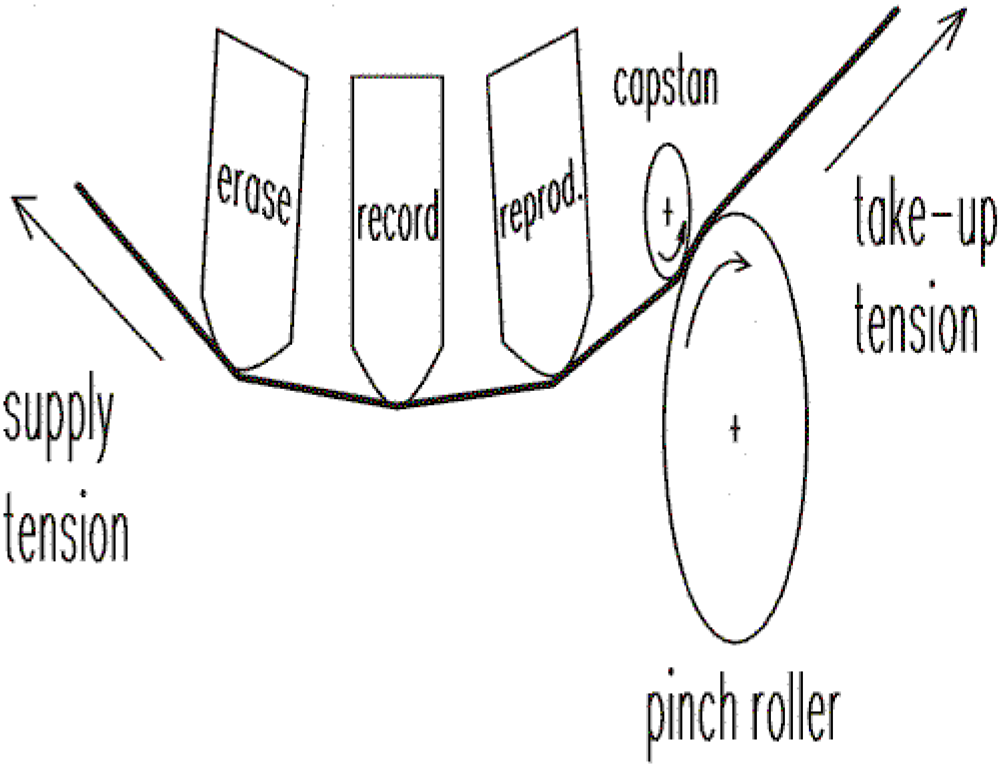
When the brakes are applied, the brake ribbon is pulled tight by the brake spring, but this time the drum turns anti-clockwise. The friction pulls the ribbon away from the spring and so reduces the brake force. The right-hand brakes produce less brake torque than the left-hand spool: again, the tape is kept tight.

2.2. THE PLAY TENSION

Near the heads, the tape should ideally have **constant tension**. This will maintain constant tape-head contact pressure. This is important since only the **tape tension will press the tape onto the head**. Pressure pads are not used in professional recorders. They are likely to cause undue and uneven head-wear and other troubles.

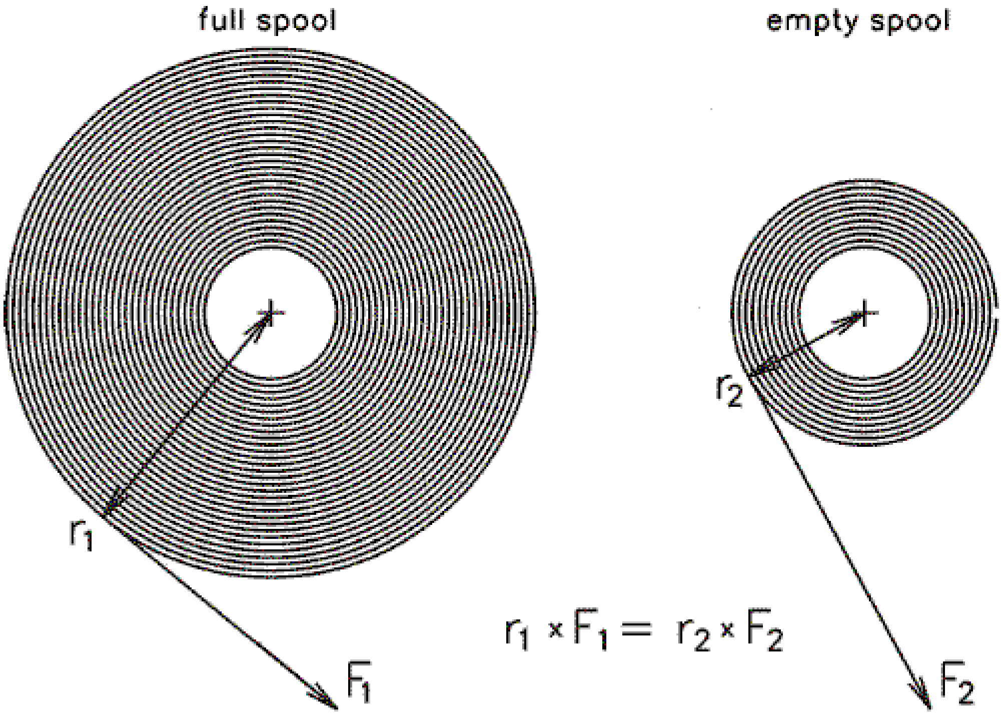
Constant tape tension will also keep "slip" to a minimum. **Slip** is the result of the tape slipping (usually backwards but possibly also forwards) between capstan and pressure roller. There will always be a small amount of tape slip. However, this should be fairly constant over the whole length of one large spool of tape.

Ideally the take-up tension and the supply tension should be **approximately equal and constant**, so that the capstan **moves** the tape, but does **not pull it**. This can be easily tested by holding back the pinch roller in the play mode. The tape should then easily be moved back and forth, but should neither speed forward nor be held back strongly.



The take-up tension and the supply tension should produce approximately the same force in the play mode.

When no servo system provides constant tape tension, **the tape tension will increase** as less and less tape remains on the supply spool.



*The relationship between spool radius r and the tape tension F. If the torque (r*F) remains constant, the tape tension F will increase as the spool radius decreases.*

As the spool diameter is decreasing, it is being pulled (by the tape) to higher and higher rotational speed on a "lever" which becomes shorter and shorter as the diameter of the spooled-up tape becomes smaller. This will cause increasing "slip" towards the end of the tape spool. More slip means effectively lower tape speed.

When a recording is made under such conditions, the actual tape speed will be higher at the beginning of the spool and lower at the end.

If now this recording is played back on another machine with constant tape tension, or worse: if a portion near the end is cut and transferred to the beginning of the tape, and so the edited tape is played back on the original machine, the cut-out section will now be reproduced at a higher speed and therefore on a higher pitch.

The procedure for measuring **slip** further explains this effect: a full spool of tape of the largest diameter to be used (1000m on German equipment) has a constant frequency (typically 3kHz) recorded at the beginning of the tape; either full track or on both stereo tracks.

The two tape spools are then turned over (exchanged) so that the nearly empty spool is now on the left. During play-back, the recorded frequency is now measured and the change of frequency (drift) is measured and read out in %.

Some tape machines simply apply a **constant torque** to the supply reel and the take up reel (e.g. Ampex 440, Studer PR99). This produces strong variations of the tape tension for different spool diameters. To avoid slip, these machines will generally require a higher pinch roller pressure.

Some of these machines (e.g. Ampex 440) have selector switches for different inner reel diameter. This is necessary to reduce the torques on the reels when small reel diameters are used.

2.2.1. THE TAPE TENSION SERVO PRINCIPLE

The tape tension should be fairly constant over the whole length of the tape, in good machines within 10% of the nominal value. Devices are necessary to sense (measure) the tape tension on the supply and take-up side. Usually these are sensing levers which are spring-loaded and displaced by the tape. The tape tension is thus controlled by the position of these levers.

The "signal" from such levers may,for instance, be:

a) purely mechanical, operating a brake for the left spool and a variable friction clutch on the right (Nagra)

b) a change of resistance (e.g., Studer A80 or C37)

c) a change of light intensity

d) a change of RF coupling (e.g. Studer B67)

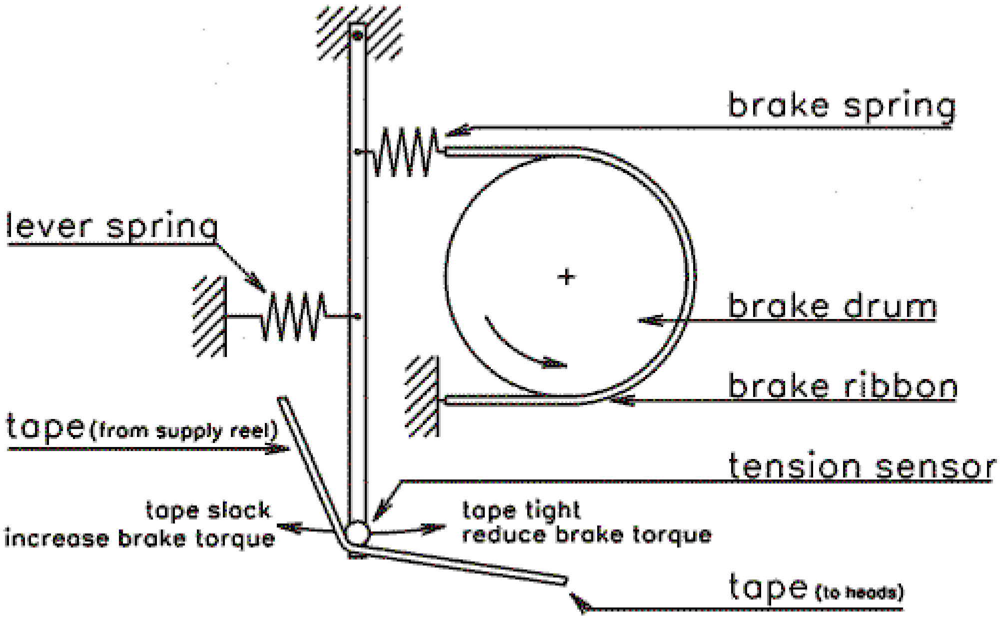
e) a change of core position in the coil of a discriminator (e.g., Nagra IS)

There are several ways how the correct tape tension can be set:

1) Mechanically by brake drum and ribbon linked to the sensor lever (Telefunken M15, Nagra)

2) By powering both spooling motors, whereby the voltage on the motors depends on the sensor position (e.g. Studer B67, A807)

3) Tension before capstan can also be set by feeding a controlled amount of DC into the AC supply motor; the DC makes the motor act as eddy current brake (e.g. Studer A80)

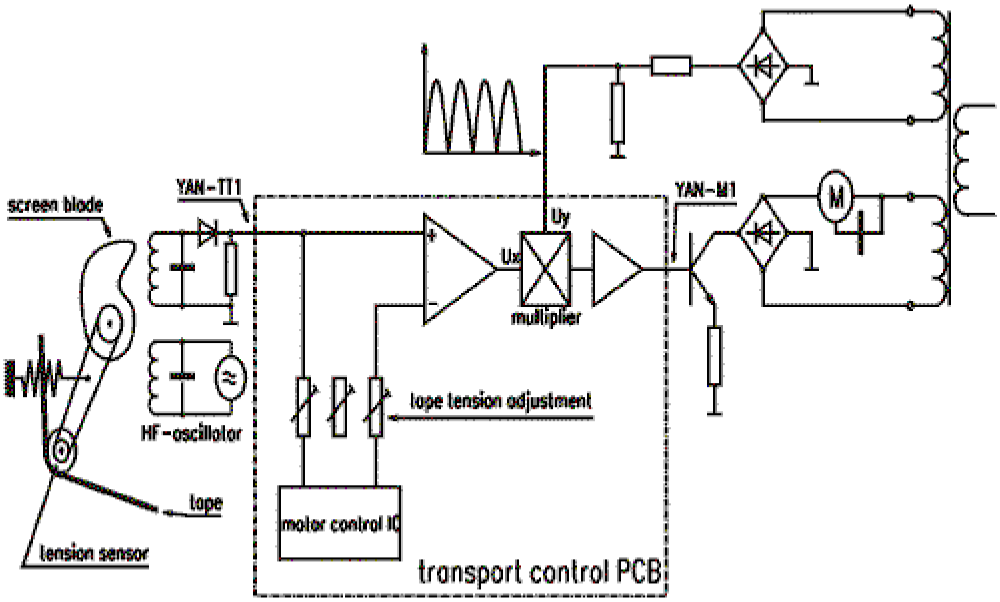


Principle of mechanical supply reel tape tension servo.

Example of an electronic tape tension control

(Studer B67)

The tape tension sensor consists of a high frequency oscillator coil and a coupling coil. There is an aluminium vane between the two coils which acts as a shield. The shield moves with the tape tension sensor. The output voltage depends on the position of this shield.



Principle of the tape tension control of the Studer B67.

The signal obtained passes to the motor control PCB. The tape transport logic switches different resistors to the error amplifier to provide different tape tensions for the different operational modes such as PLAY, WIND FORWARD, REWIND, and BRAKING.
The error amplifier produces the signal Ux.

The signal Uy originates from an ac voltage of 20V. Rectification results in a sinusoidal half-wave voltage. The error signal Ux is used to modulate (multiply) the voltage Uy. The signal YAN-M1 is a sinusoidal half-wave with an amplitude proportional to the control voltage Ux.

The current through the motor is therefore controlled sinusoidally. The tape tensions can be adjusted separately on each side in the PLAY mode (R201 and R204).

During fast winding, the restraining tensions can be adjusted for both directions (R202 and R205). The point at which the tape tension limiter comes into operation (peak tension) can be set on the appropriate take-up side with potentiometers R203 and R206.

The supply motor continues to be controlled during the braking phase, and is switched off when the tape stops. During braking, the tape tension on the supplying side does not exceed the value set for the PLAY mode.

2.2.2. TAPE TENSION FORWARD REGULATION

Some tape machines do not use a tape tension feedback system, but use a control system which **computes** the required reel torque to achieve constant tape tension.

To achieve constant tape tension, it is necessary to **reduce the reel torque as the spool diameter decreases**. Because the rotation speed of the supply or take up spool is inversely proportional to the spool diameter, **the speed of rotation can be used to compute the required reel torque**.

For this purpose the spooling motors carry **tachometer systems**. The motor speed (reel speed) is used to compute the required motor current. Higher reel speeds will result in lower motor torques. The control circuit will also consider the tape speed. Analog and digital control circuits are in use.

Examples: Studer B62, A807

2.3. TAPE TENSION MEASUREMENTS

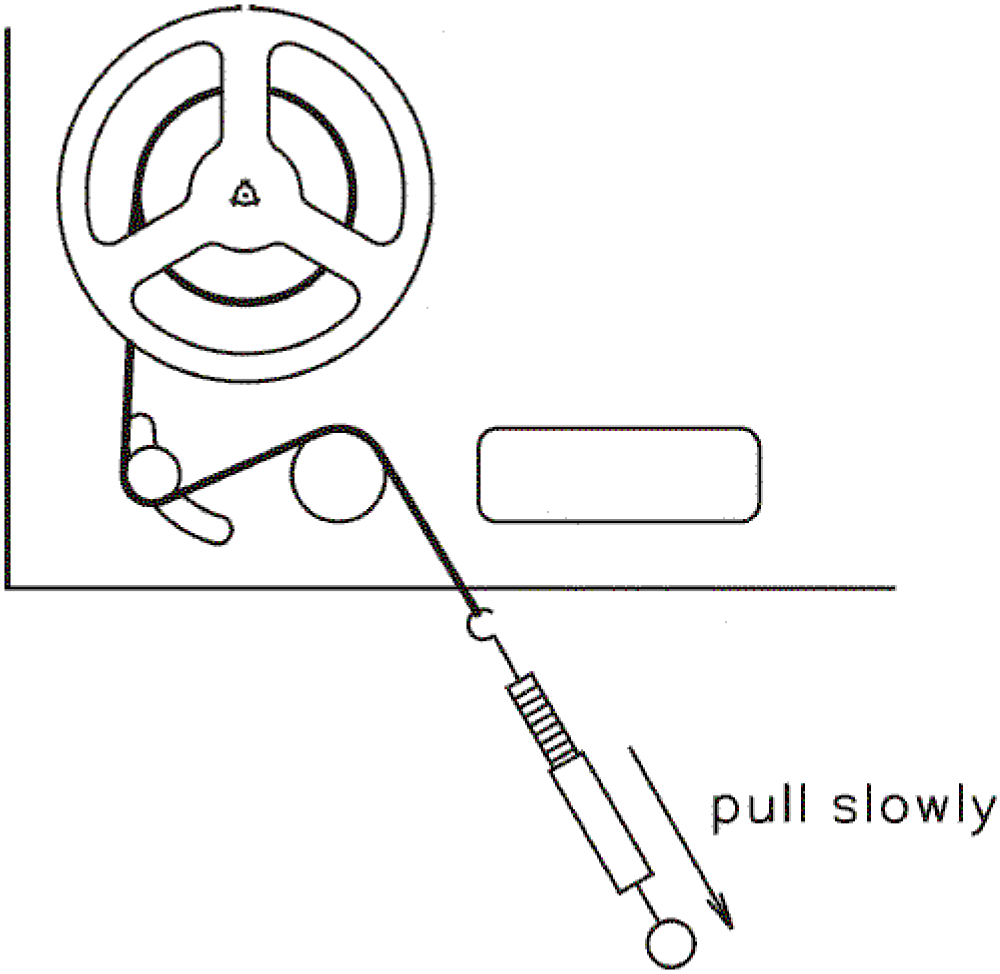
The tape tensions of a tape machine must be regularly checked in order to maintain a constant quality of the tape transport. For this purpose, the tape tensions must be measured to ensure that they are in line with the manufacturer's specifications.

Tape tensions can be measured with spring balances and spools of old tape.

2.3.1. SUPPLY TENSION

The spool is put to the supply spooling motor and the tape is threaded through the left-hand, tape tension sensor idlers. A suitable spring balance (e.g. 200gr = 2N) is knotted to the end of the tape.

While the machine is in PLAY mode, the tape is pulled slowly but steadily from the supply reel while the force on the spring balance is read. This measurement should be performed with a full and an empty reel to see if there are differences.



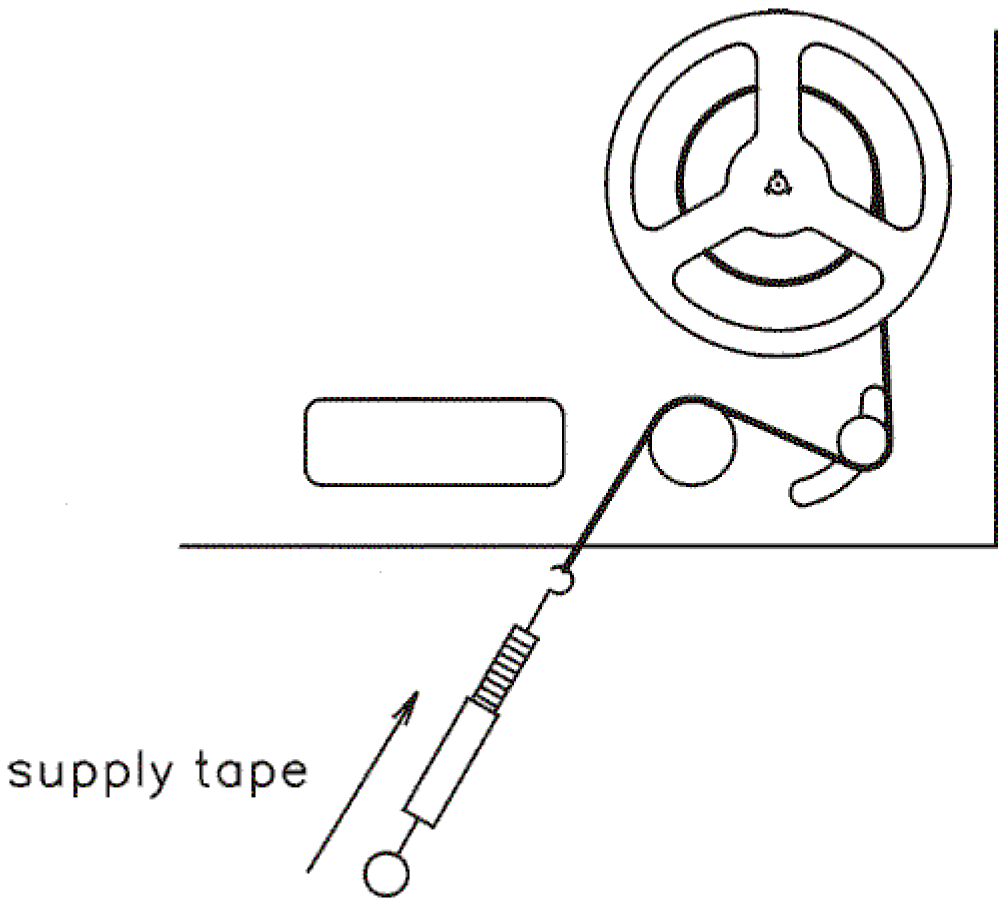
Principle of the supply tension measurement.

2.3.2. TAKE-UP TENSION

The spool is put to the take-up spooling motor and the tape is threaded through the right hand-tape, tension sensor and idlers. A suitable spring balance (e.g. 200gr = 2N) is knotted to the end of the tape.
The tape may not pass the capstan.

The tape is first pulled from the reel for several meters. While the machine is in PLAY mode, the tape is then slowly but steadily spooled up by the reel, while the force on the spring balance is read.

This measurement should be performed with a full and an empty reel to see if there are differences.



Principle of the take-up tension measurement.

2.4. THE SPOOLING TENSION

During fast forward or reverse winding the tape tensions have to fulfil the following requirements:

(Note: The terms "take-up" and "supply" depend on the spooling direction.)

1. Acceleration:
The take-up motor should **accelerate as fast as possible**.
At the same time, **the stress on the tape** during acceleration should remain within safe limits.

Therefore, the take-up motor torque has to be controlled by the take-up tension sensor.

2. Steady winding (after the acceleration phase):
The supply reel motor should provide a reverse torque to provide a certain tape tension. The tension should not be so high as to reduce **the spooling speed**, but should be high enough to **produce a densely wound cake** on the take-up spool, especially when open reels are used.

The supply motor torque has to be controlled by the supply tension sensor.

3. Deceleration

During fast wind, when the STOP button is pressed, the tape should **come to complete stand-still quickly**, but without straining the tape. In some machines this is achieved with the brakes only. In other machines the spool motors are used for **braking by applying reverse torque**. The torque of the supply motor is increased and the take-up motor is switched off. The supply motor torque will be controlled by the supply tension sensor to optimum values.

A "tape motion sensor" (see later) is required to detect when the tape comes to **stand still**, in oder to switch off the motors and apply the mechanical brakes.

The tape tensions during spooling can be measured in the same way as described in 2.3.1 and 2.3.2.. As the tensions are usually higher as in play-back mode, a spring balance for 500gr (5N) or 1000gr (10N) is required.

2.5. TAPE MOTION SENSORS

Tape motion sensors give information about whether or not the tape is moving and in which direction it is moving. The logic circuit of the tape machine requires this information for the following purposes:

1. When braking is motor-assisted, the tape transport control has to switch off the spooling motor currents and apply the mechanical brakes after the tape has come to a stand-still.

2. When switching from WINDING to PLAY directly (programmed play), the tape transport control will brake the tape first. Only after the tape motion sensor has reported **full stand-still of the tape** will the pressure roller engage with the capstan, and the machine will switch to the PLAY mode.

3. The TAPE COUNTER must know whether to count forwards or backwards.

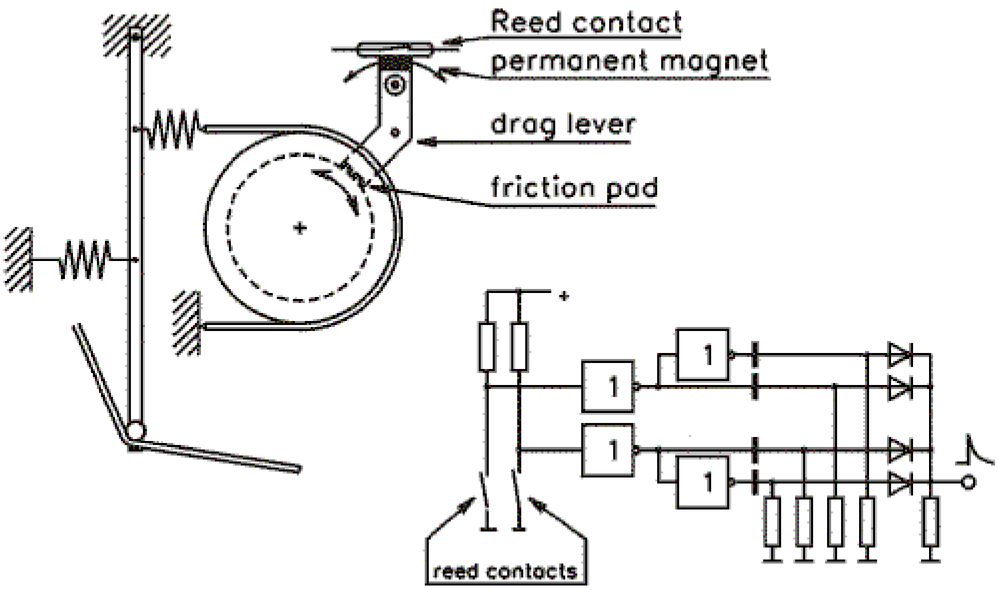
Tape stand still may be detected in two different ways:

- A detector (e.g. light barrier on an idler or spooling motor) detects no motion of the tape

- A direction detector detects a change of motion direction of spooling motors or tape. The moment when the tape changes direction the tape is assumed to be at a stand-still.

Example 1

Motion direction sensors in Telefunken M15, M15A



Principle of the motion direction sensor of the Telefunken M15. It consists of a "drag-switch" and an associated logic circuit.

The "drag switch" as fitted below the supply and take-up reels. The lever has a permanent magnet at the end, which is dragged to or away from a reed contact (inert gas contact) by the rotation of the spool motor.

Depending on which switch has been dragged to "reed open" and which to "reed closed", various functions can be initiated by the tape transport control circuit. One of the drag switches is always closed. Which one depends on the direction of tape motion. Upon a change of direction, both switches exchange their position.

The control logic uses the information from these drag-switches.

Example:
The machine is runing in FAST FORWARD mode. The PLAY key is pressed. Power-assisted braking begins with high power on the left-hand motor until the tape comes to a stand-still and just begins to move backward. This is detected by the drag switches. Braking is now ended and the machine switches to PLAY.

The reversing of reed conditions indicates that tape motion has just ended, in other words, the tape has stopped.

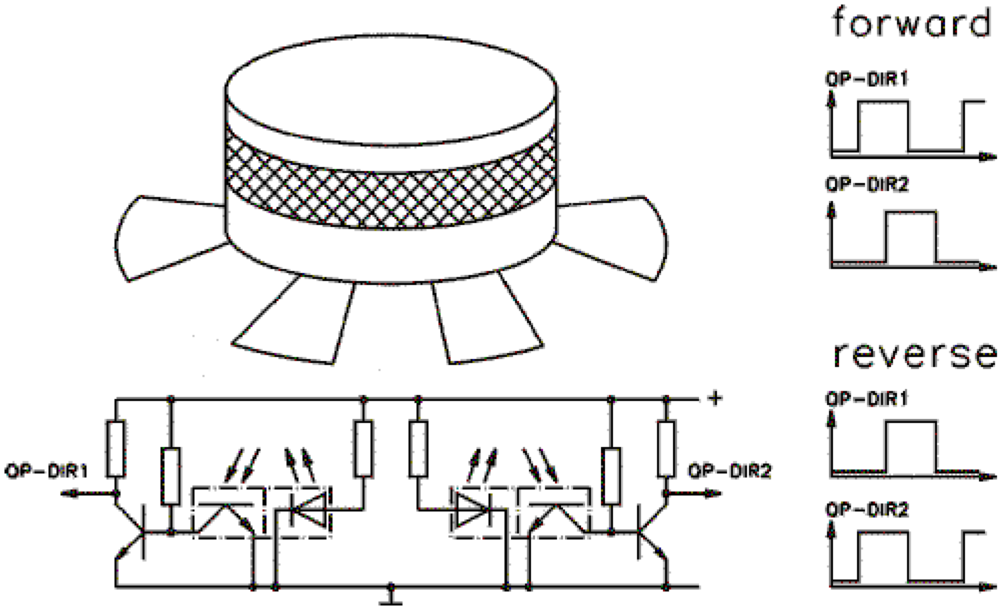
The left-hand switch informs the counter of the tape direction.

Example 2

Tape motion sensor of Studer B67.

A tape-driven idler between capstan and take-up spool has four blades attached. These blades reflect IR light from two reflection light barriers. When these blades rotate, the light reflections are interrupted. The light barriers are positioned at a distance equal to the half width of the reflector blades.

Therefore the signals from the light barriers will always be 90° out of phase as the idler rotates.



Construction and circuitry of the tape motion sensor of Studer B67.

Depending on the direction of rotation, QP-DIR1 leads QP-DIR2 or vice versa, which is used in the digital tape counter circuit to determine the tape direction.

QP-DIR2 is also used to give the MOVE indication. A circuit detects the pulses from QP-DIR2 and puts the MOVE signal to low if there are no more pulses.

3. THE PRINCIPLE OF MAGNETIC RECORDING

Magnetic recording serves the purpose of storing and reproducing audio signals. Audio signals are **analog time varying signals**. Therefore magnetic recording must provide a system to represent the varying air pressure (sound) and the constantly varying time.

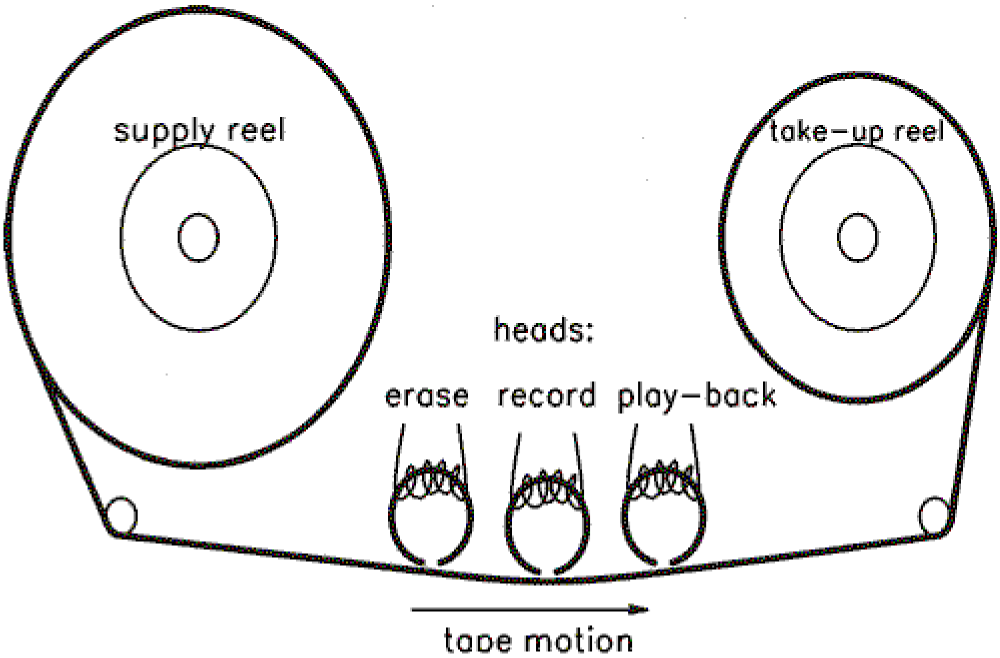
The varying **air pressure** is converted to electrical signals (microphone) and then **to magnetic field strength (H)** in the recording head. The field strength causes a proportional residual flux (Φ_r) in the tape. The play-back process is the inverse of the recording process.

The **constantly varying time is converted to length** by passing the tape at constant speed along the heads.

The steps of the recording process always follow the same sequence:

- Erase the tape
- Record the new signal
- Reproduce the signal.

This sequence requires the tape to be moved past the heads in this order.



The arrangement of tape and heads on a tape machine.

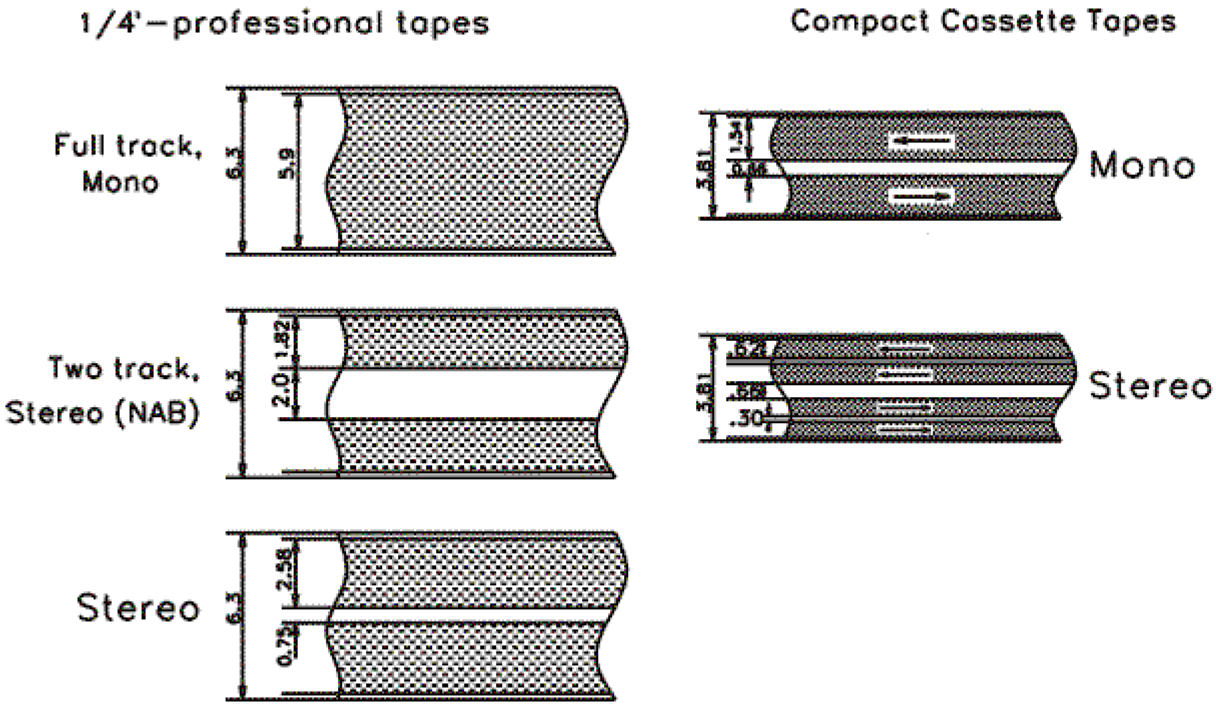
3.1. TAPES AND TRACKS

Normal tapes for mono, stereo and two channel recordings are ¼" wide, having a total thickness of about 50µm (micrometers). The magnetic coating (emulsion) is 15µm or less. Special high level tapes may have coatings up to 25µm thick. The coating is iron oxide in needle-shaped particles which are pre-orientated for lowest noise. Coatings other than iron oxide, e.g. chrome-dioxide or pure iron may be used in some special tapes for non-professional, digital or video recordings.

The reverse side of professional audio tapes is covered with a special rough surface to allow air to leave between the layers during fast winding, and to prevent slipping of the layers of the spool layers.

Other tape thicknesses:
Long Play: 35µm,
Double Play : 25µm.

Other tape widths:
Multi-track machines: ½", 1" and 2",
Compact cassettes: 3.81mm (approximately 0.15").



Track arrangements for different tapes

The tape speed is a compromise between the sound quality, tape consumption, running time and reel size. There is a direct relationship between the tape speed and the shortest magnetic wave length on the tape. Reduced tape speeds require more sophisticated tape machines or else they lead to reduction in sound quality.

Here is a list of common tape speeds used for analog magnetic sound recording and the resulting wavelength at 15kHz:

Used for	inch/sec.	cm/sec.	wavelength at 15kHz
Historical Studio, master Studio Semi-professional Compact cassette	30 15 7.5 3.75 1.875	76cm 38 19 9.5 4.75	50µm 25µm 13µm 6µm 3µm

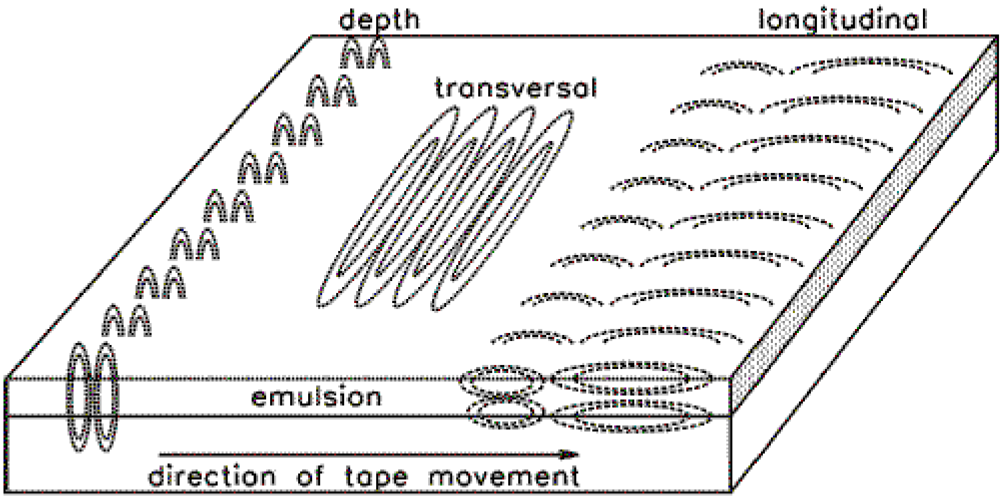
3.2. MAGNETIZING MODES

There are three possible ways of placing the N-S-poles when magnetizing the tape:

1) Longitudinal mode.
The gap is vertical to the tape movement and parallel to the tape surface. This is the standard mode.

2) Depth mode.
This mode is not used.

3) Transversal mode.
Here, the field lines run along the tape surface but at right angle to the longitudinal system. This mode is used as a "pilot system".

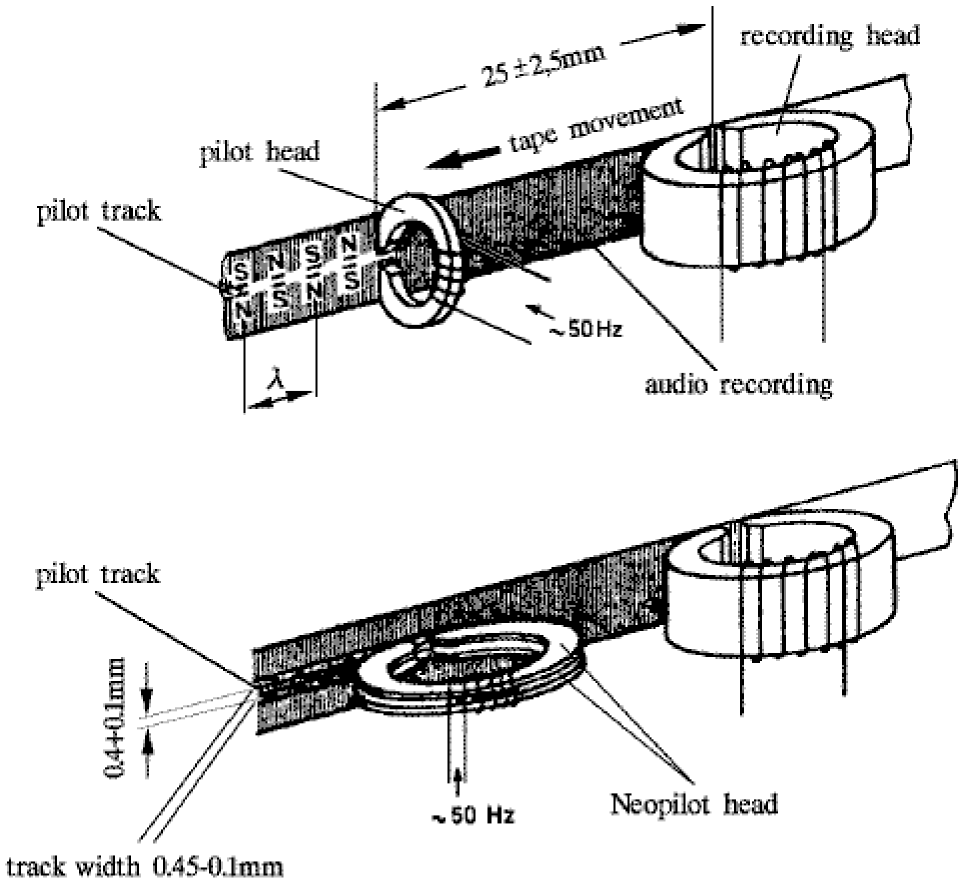


Different ways of magnetizing the tape.

The different types of magnetizing mode require, a different arrangement of the recording and play-back heads. One head can only read or write the type of magnetizing mode it was designed for. This makes it possiable to record information in different modes on one tape without influencing each other.

Transversal recording is used e.g. in portable tape recorders fitted for pilot recording from a cine camera. The camera drives a generator which produces 50Hz (or 60Hz) when running at standard speed, i.e. 25 frames per second. These 50Hz are recorded as transversal magnetization in the centre of a full track (longitudinal) sound recording. The two magnetization modes are at 90° to each other. If well aligned, they do not interfere with each other. They can be played back separately at the same time. The pilot recording then serves as an indication of the camera speed and is used for manual or automatic synchronization when transferring the sound onto magnetic film.

Pilot recording and play-back can be done with a transversal head having a horizontal gap, or, more efficiently, with a 'Neopilot' head; this has two small vertical gaps with two windings operating in push-pull fashion. The two systems are compatible. Nawadays Neopilot heads are usually used. The pilot head is positioned between the recording head and the play-back head.



Head arrangement for a pilot system.
a.) With transversal pilot head,
b.) With Neopilot head.

3.3. MAGNETIC RELATIONS OF THE TAPE

The main magnetic quantities used are:

Magnetic Flux Φ (unit: Wb)
Flux Density B (unit: T)
Magnetic Field Strength H (unit: A/m)

They are related by the equations:

$$B = \mu \cdot H \qquad \Phi = B \cdot A \ \ (A: area)$$

The saturation flux density of professional tapes is <100mT

A typical value for the maximum value of the recorded flux density in the emulsion of a magnetic tape is 50mT. This would be reached at the peak value of a recording at full recording level.

The rms value of this flux density is then

B_{rms} = 0.71 * 50mT = 35mT

The total flux in the emulsion of the tape is then the product of the flux density and the area of the magnetic surface. This area is the product of the tape width and the thickness of the emulsion.

$A = 6.3mm * 14\mu m = 9 * 10^{-8} m^2$

$\Phi_{rms} = 35mT * 9 * 10\text{-}8\ m^2 = 3150pWb$

This total flux in the emulsion is normally related to the track width. Therefore we state it in terms of flux per mm of track width:

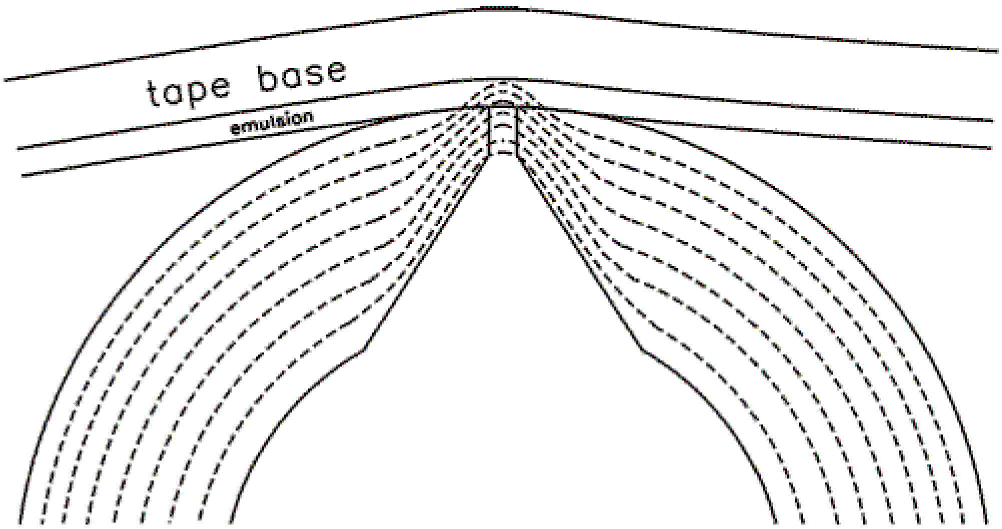
$\Phi_{rms}/width = 3150pWb/6.3mm = 500pWb/mm$

This is a typical value for the flux level used in modern tape recording.

4. THE RECORDING PROCESS

During recording, the tape passes constant speed at the recording head.

The recording head consists of a core with a coil. The core has an air gap at the front side. When current flows through the coil, a magnetic flux is produced in the core. At the gap the flux will be forced out of the gap. The tape is moved at constant speed while it is in close contact with the working gap of the recording head.



The flux of the recording head leaves the core at the gap and penetrates into the tape.

The magnetic field strength H in the recording head will cause a certain magnetic flux density B in the core and in the tape at the gap. When a certain point of the tape moves away from the gap, the residual flux B_r will remain in the tape.

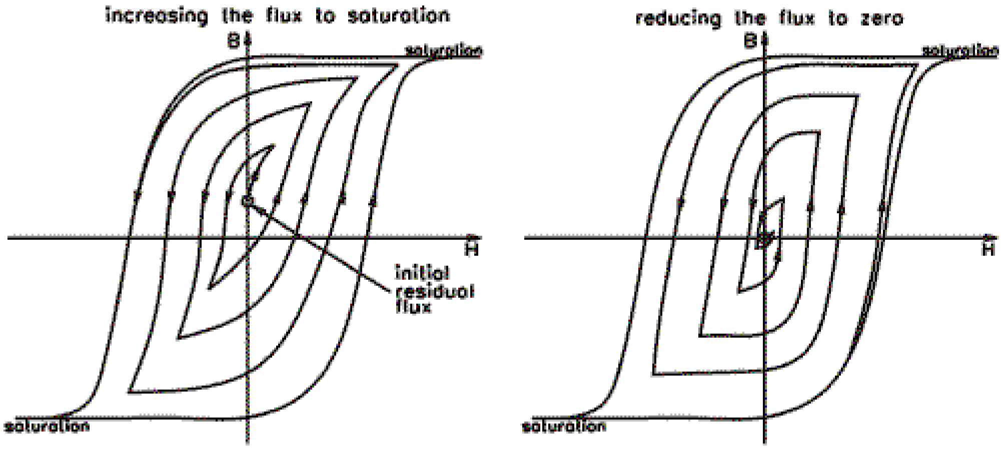
Tapes must have a relatively high remanence in order to store as much magnetic energy as possible.

4.1. ERASING

Before a signal can be recorded on a tape, the tape must be magnetically fully neutral (virgin). This is achieved by erasing. Erasing can also be understood as recording the tape with a zero-signal.

One could erase the signal on a tape by applying a strong magnetic field to the tape, which drives all magnetic particles to full and equal remanence. As a result the tape will no longer contain any signal any more, but it is permanently magnetized and not magnetically neutral. Recording on such tape would result in strong DC noise.

To produce a neutral magnetic tape we will proceed as follows:
The tape will be fully driven into saturation to both polarities by an ALTERNATING MAGNETIC FIELD. Then the magnetic field will DECAY IN AMPLITUDE in order to run the tape through many hysteresis loops of decaying amplitudes. Finally zero-remanence is reached by approaching zero in some spiral way.

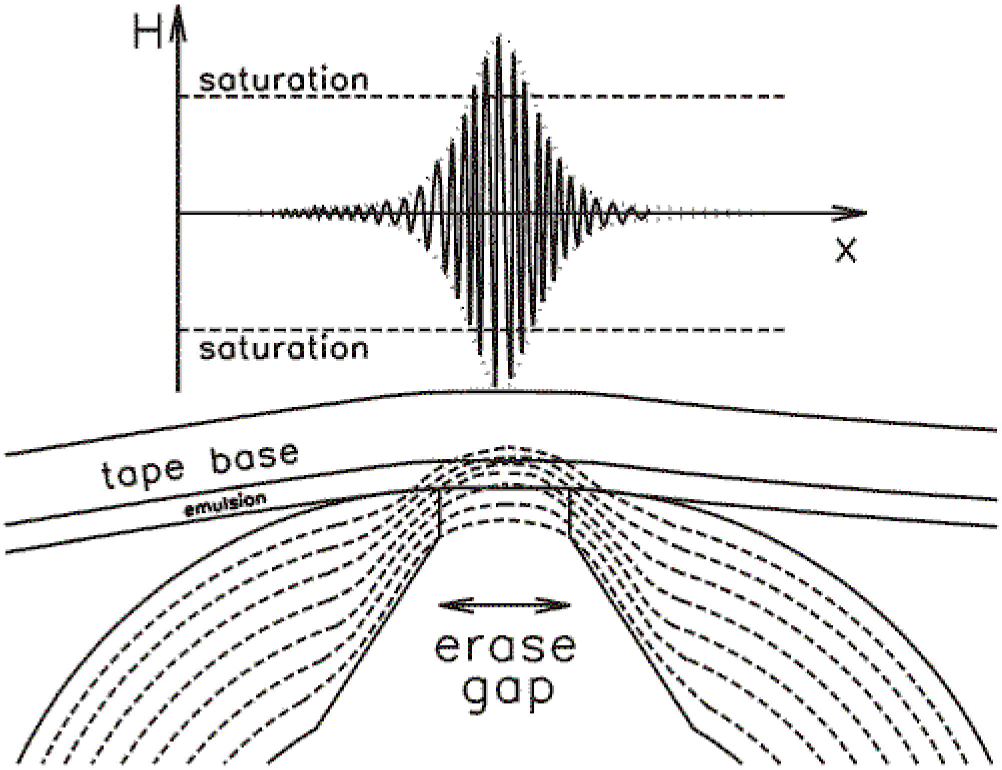


The process of erasing shown on the hysteresis loop.
A certain flux on the tape is first driven to saturation.
Then the flux decays. Zero-remanence is reached by running the tape through the hysteresis loop several times in some spiral way.

In the tape machine the erasing is done by the erase head, which is fed with the h.f. signal, which is also used for biasing. The erase generator frequencies for different machines range from 70kHz to 150kHz, but within one machine the frequency has to be kept stable.

The erase signal is normally relatively strong, to ensure the tape is driven into saturation while it passes the erase head. Due to the high frequency and the inductance of the erase head, the signal voltage is often several tens of volts at the erase head.

The gap of the erase head is relatively wide (100µm to 400µm). Sometimes multi-gap heads are used. This ensures that the tape is driven several times (10 to 50 times) into saturation while it passes the gap.



The variation of the field strength in the tape while it passes the erase head. It can be seen that while the tape approaches the erase head gap the field strength increases and drives the tape flux into saturation. While the tape is leaving the gap, the flux decays over several periods and finally approaches zero.

Tapes can also be "bulk-erased". A heavy 50Hz coil with an open core is brought close to the spool of tape. The tape or coil are then moved to cover all parts of the tape. The coil or tape are then very slowly removed, so that a decreasing magnetic field passes through the tape. Bulk erasers vary from small hand-held coils to large erasing machines.

Suggestion: For important recordings, specially on outside location using a portable battery-recorder, the tapes should be pre-erased with a bulk-eraser.

The same method as used for erasing tapes can be used to remove any magnetism from any type of magnetic equipment. The de-magnetizing spools all use the same method. Using them, it is important that you move SLOWLY AWAY from the object you want to demagnetize in order to allow the magnetic field to decay slowly.

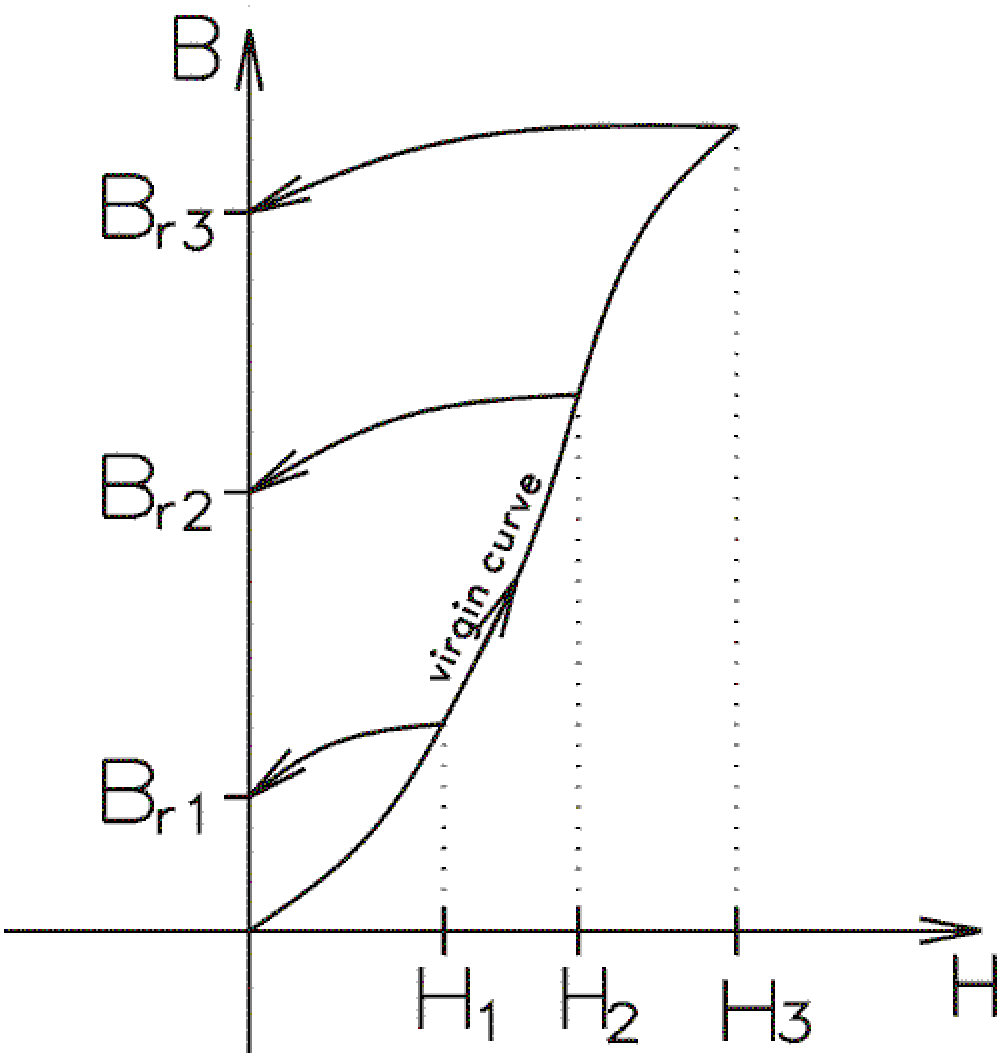
Never switch off the current to a de-magnetizing spool while near the object to be de-magnetized.

4.2. FUNDAMENTAL MAGNETIC PRINCIPLES

The tape must be magnetically completely neutral (de-magnetized) when it approaches the recording head.

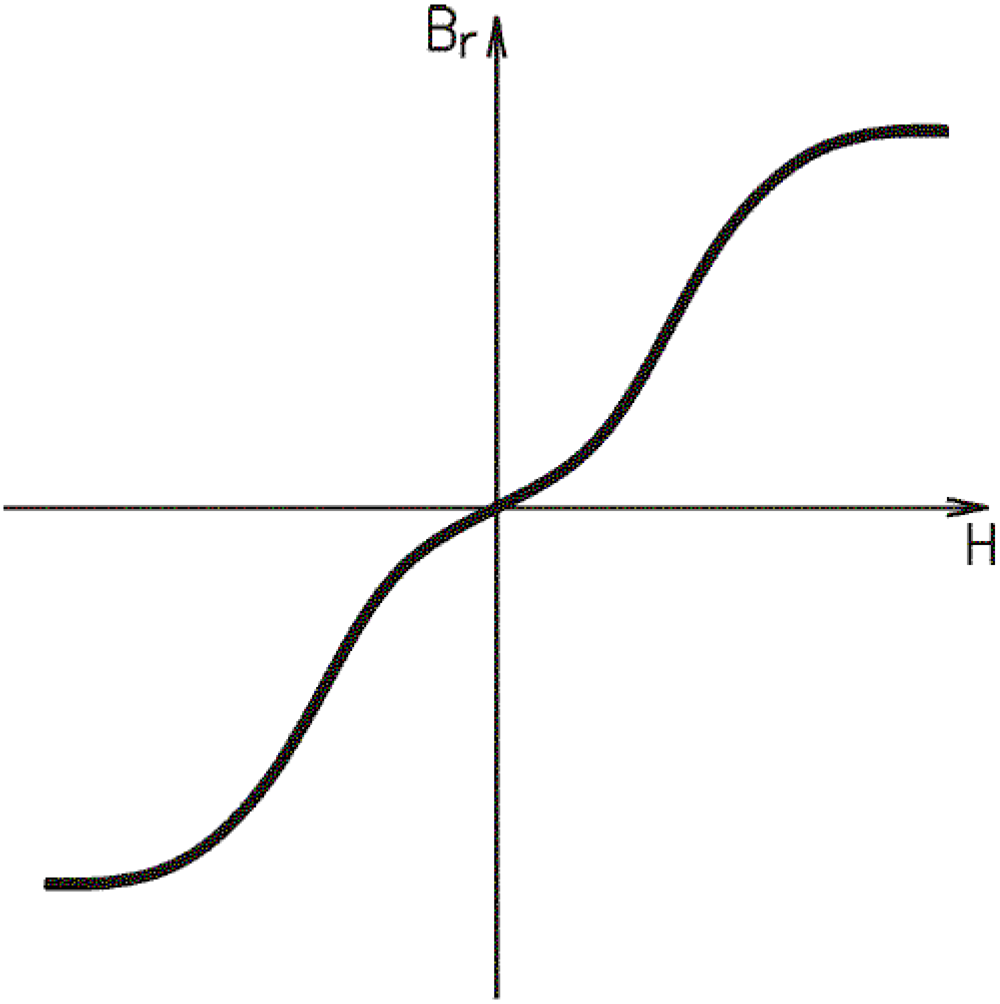
Let us assume that the gap of the recording head has a stationary magnetic field, for instance by feeding DC into the head, producing a certain field strength H. As a section of the tape approaches the gap, the magnetic density B on the tape increases from zero to maximum. As this portion of the tape leaves the gap, B decreases as H goes to zero. On the tape is left the remanence B_r.

If we do this for different field strengths in the recording head, we find the following relationships:



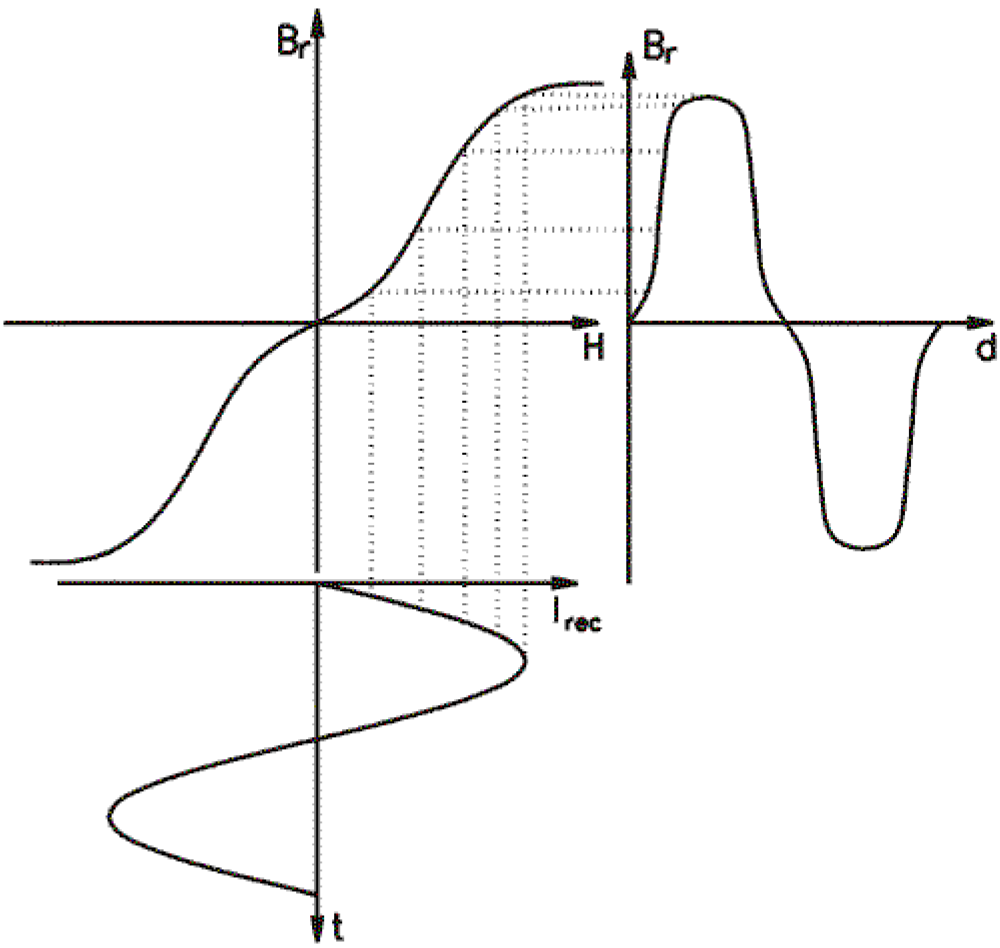
The residual flux density B_r will remain in the tape after it has passed the recording head gap with its magnetic field strength H.

Plotting the relationships between H and B_r gives the **remanence curve** or **transfer characteristic.** The name indicates that it explains how the recording current is transfered to remanent magnetism to the tape. This curve is not at all linear. It is strongly curved near zero and near saturation. In other words, the relationship between field strength H and residual magnetization B_r of the tape is not linear. H is proportional to the recording current, therefore the tape magnetization has a "distorted" relationship to the recording current.



The transfer characteristic for a magnetic tape is found by applying different field strengths to a tape and finding the resulting residual flux after the field strength is removed.

When an AC current is applied to the recording head, the resulting field strength H is proportional to it. Plotting the sine function against the non-linear transfer characteristic, the resulting magnetic image on the tape is no longer sine-shaped. It is badly distorted. Therefore magnetic recording is not possible by simply feeding signal current to the recording head.



The resulting residual flux on a tape if a sinusoidal current is fed to the recording head. The flux on the tape is no longer a true representation of the signal current.

Because the deformation of the signal is symmetrical, the distorted signal contains only odd harmonics, mainly the third harmonic.

BIASING is used to prevent this form of distortions.

4.3. BIASING

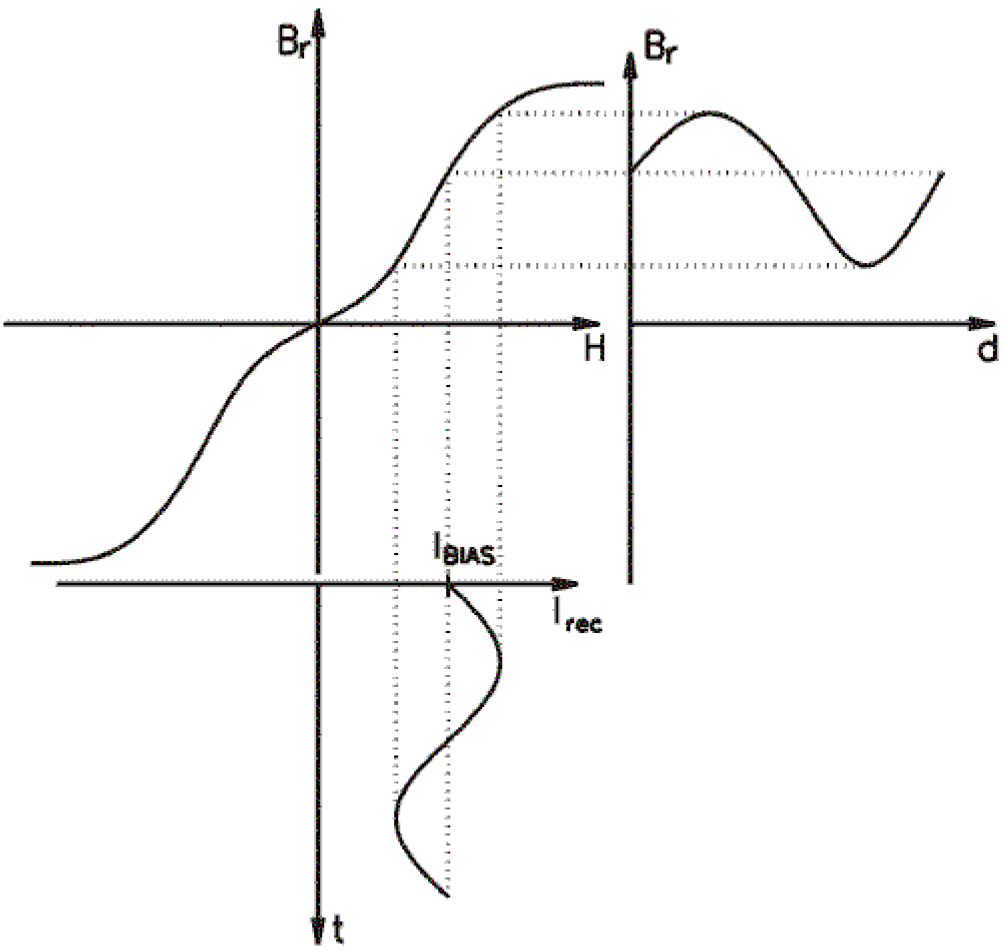
All methods of magnetic biasing SUPERIMPOSE a magnetic field on the signal field in order to avoid the non-linearity of the transfer characteristic,

4.3.1. D.C. BIASING

This is the simplest form of biasing .

DC through the recording head shifts the working point (similar to transistor biasing) into the centre of the upper or lower part of the transfer characteristic. This part is fairly linear. But because the transfer characteristic is not symmetrical in this area, the recorded signal will contain a considerable amount of even harmonics (mainly 2nd order).

Furthermore d.c. biasing is a very delicate process, because the working area is not clearly defined and even minor changes of the biasing current or the tape parameters will result in an inadequate working point.



The working point on the transfer characteristic for d.c. biasing. The recorded signal may only have a small amplitude and will contain even harmonics.

Disadvantages:

a) only a small portion of the transfer characteristic can be used, resulting in a low recording level and high S/N-ratio,

b) the adjustment of the biasing is sensitive,

c) it produces considerable second order distortions

d) the DC-magnetized tape produces strong noise on play back (see chapter 4.3.)

DC-bias was only used in some early low-price cassette recorders and is used today only in some small cassette dictating recorders. It is never used in professional recorders.

4.3.2. HF BIASING

It is used in all cases of magnetic analog sound recording.

The function of the HF bias is fairly complex, but in practice it is easily adjusted for optimum performance.

HF bias gives

a) high magnetization level
The positive and negative parts of the transfer characteristic are used for recording the audio signal.

b) low tape noise.
When there is no audio signal, the HF removes most of the residual remanence that causes noise.

In the recording head HF and AF are SUPERIMPOSED (not modulated).

Regarding HF bias, note the following:

1. The biasing HF is usually near 100kHz.

2. The biasing HF is fed directly or via a suitable transformer into the recording head. It must be stopped from reaching the last stage of the recording amplifier. This is often achieved by using an LC rejector circuit tuned to the bias frequency

3. The bias current is normally 3 to 6 times the peak AF current.

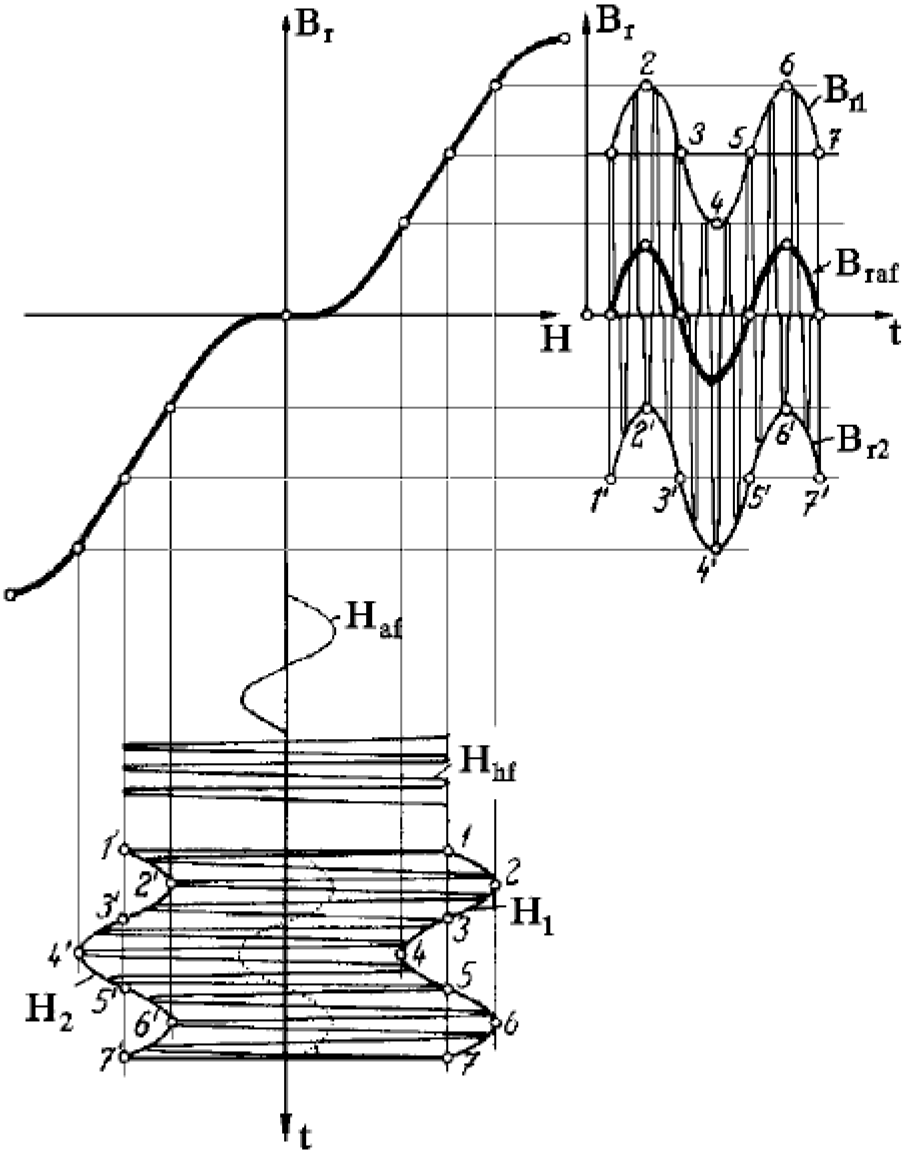
4. The HF is sine-shaped; the signal must be of good symmetry (i.e. positive and negative half-waves must be equal), otherwise tape noise (d.c. noise) will increase.

5. The bias must be properly adjusted (for a given gap width of the recording head) for each tape speed and EACH TYPE OF TAPE.

6. The level of the HF bias affects:
a) the distortion on the tape (3rd harmonic),
b) the signal level on the tape (play-back level)
c) the frequency response,
d) the modulation noise.

The basic idea of hf-biasing is that the hf-bias is "carrying" the audio signal. The hf-bias will be distorted during the magnetization of the tape, but its "envelope" the audio signal, will remain unaffected by the nonlinear remanence characteristic. This is because the strong hf-signal is always driving the magnetization through the critical zero-remanence area.

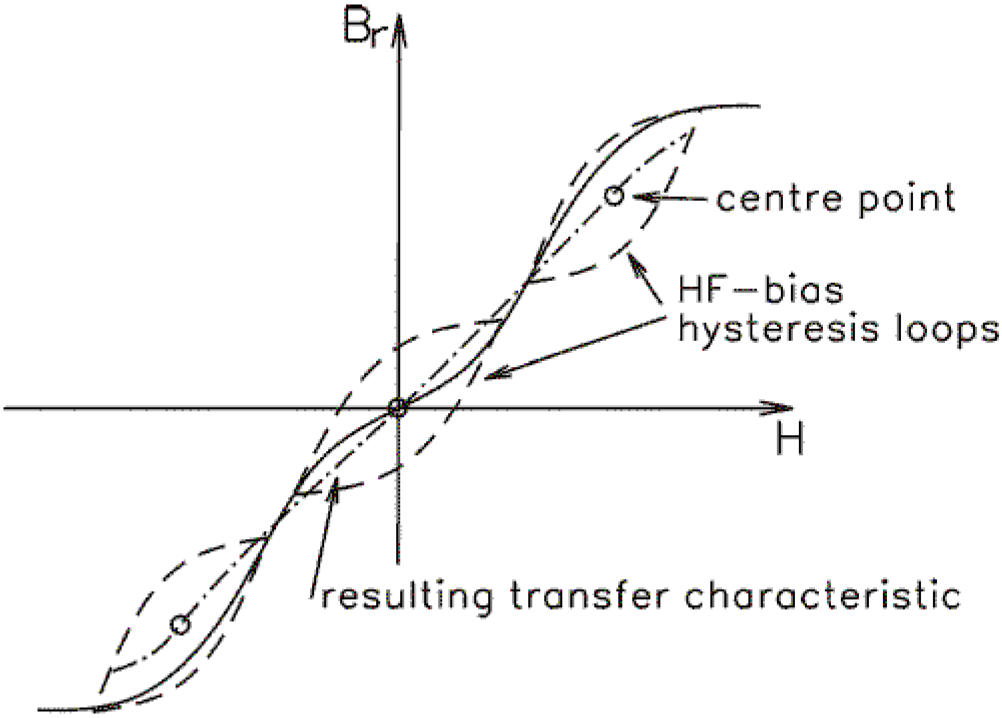
But the frequency of the biasing HF is much too high to be actually recorded. When the tape moves away form the recording head gap, the HF is erased and only its mean value, the audio signal, remains on the tape.



The super-imposition of HF and AF magnetization on tape. When plotted against the non-linear remanence, the resulting magnetic super-imposition (top/right) shows distortion on the HF, but an undistorted "envelope", namely the audio magnetization.

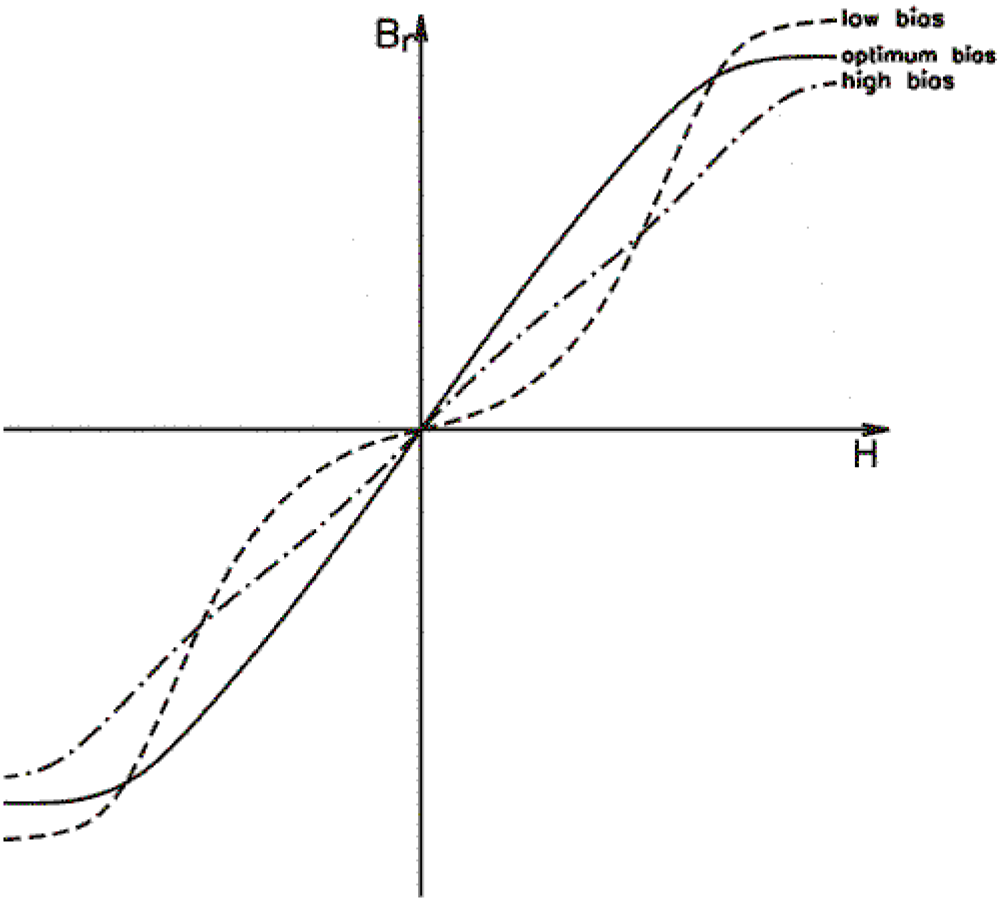
The method of hf biasing can be understood as erasing the tape to a certain instantaneous value of the audio signal.

Therefore, another way to illustrate HF biasing is as follows:
Due to the HF, the flux on the tape moves several times through a hysteris loop. With the audio modulation the loop moves up and down (positive and negative) the transfer characteristic. The finally recording on the tape is the centre point of the hysteris loop. If the magnitude of the HF biasing (size of the loop) is selected correctly, the centre point of the loop follows a linear curve.



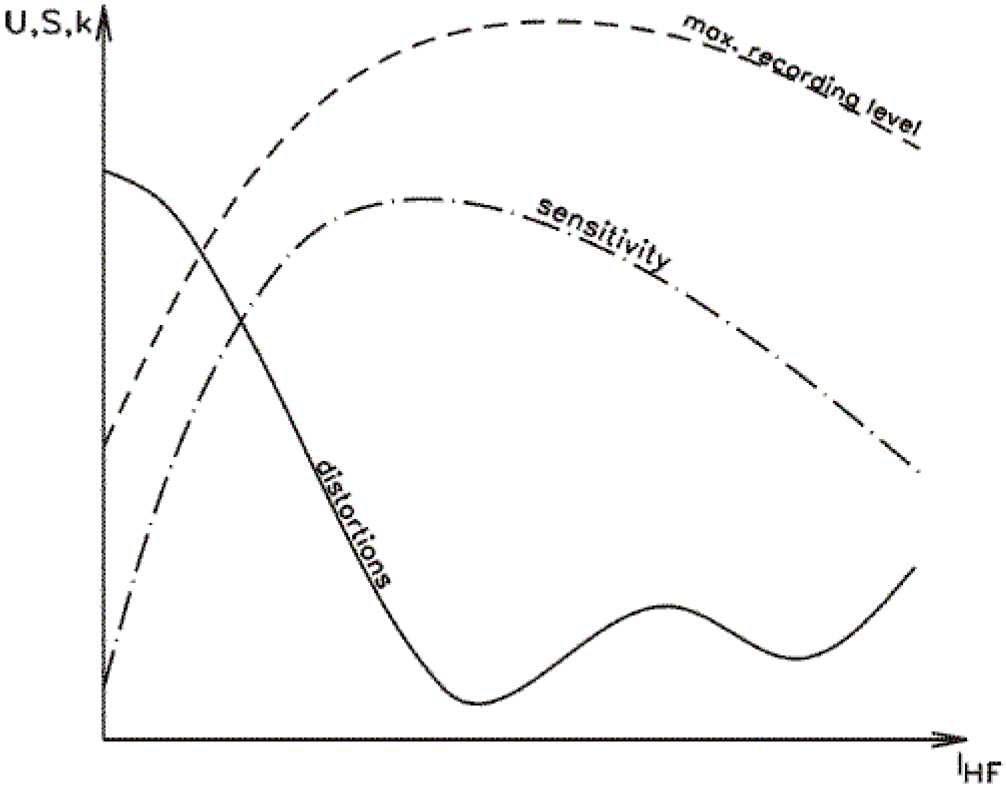
HF bias will magnetise the tape several times through the hysteresis loop, leaving the residual flux equal to the centre point. The resulting transfer characteristic is produced by all centre points.

The elimination of the distortions requires for a certain remanence curve a certain biasing level. Too little or too much biasing will not give optimum results.



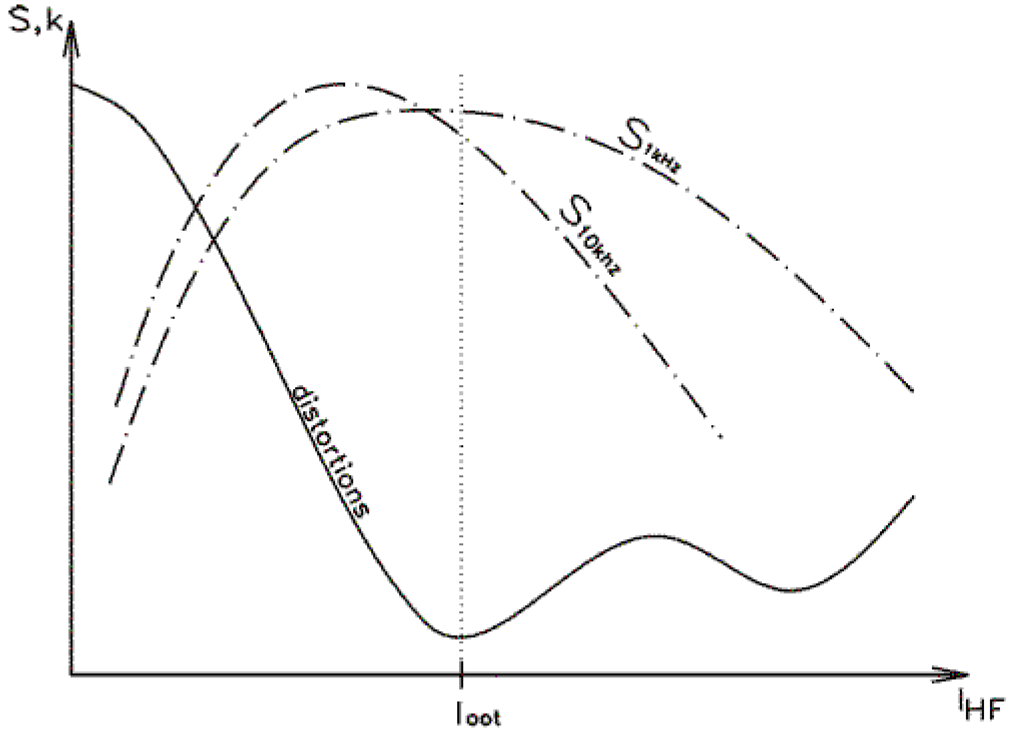
These curves show the "effective" tape transfer characteristic with hf-bias. Only for a certain hf-bias level is a linear curve achieved.

From Fig. 4.3.3. it can also be seen that the biasing level influences:
- the slope of the curve, which affects the recording sensitivity,
- the length of the linear range, which affects the maximum recording level.



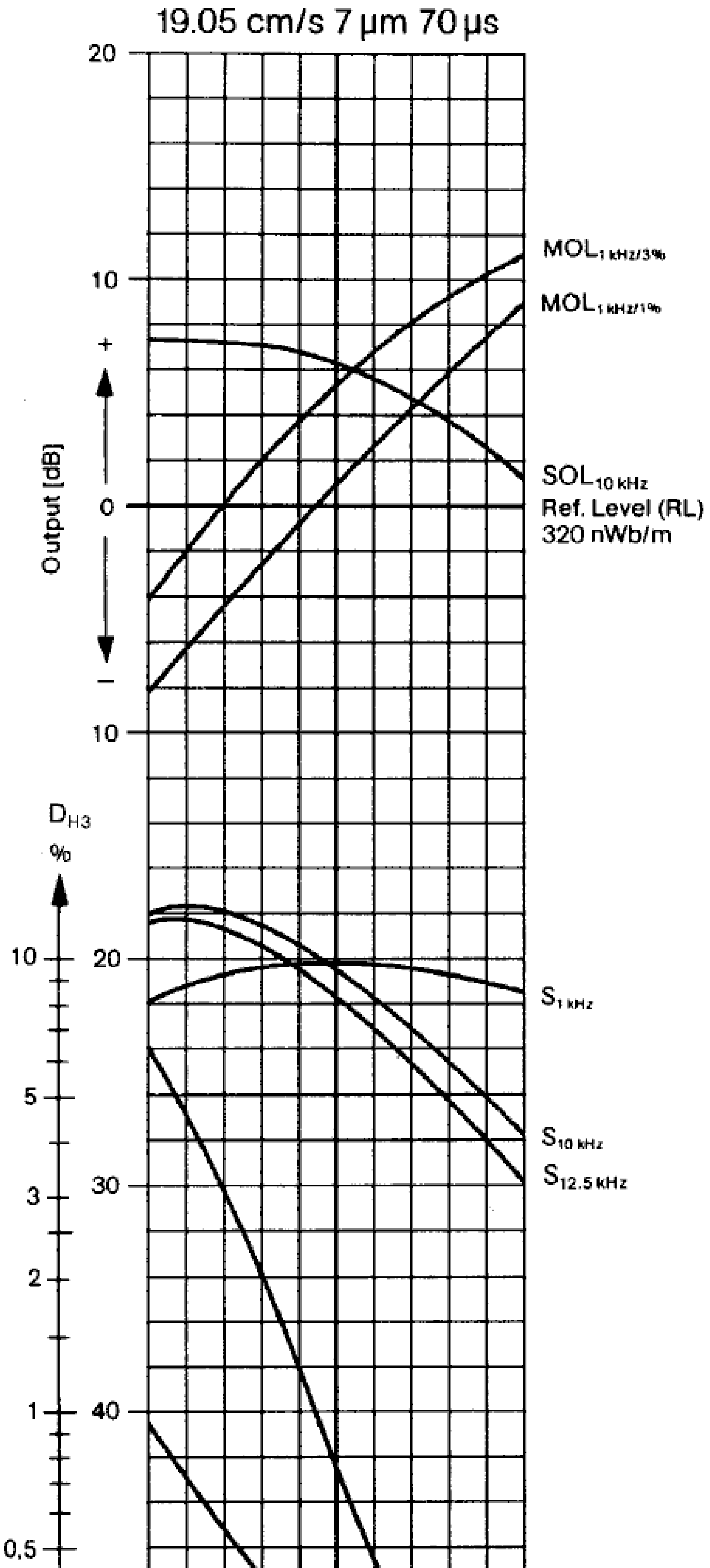
These curves show the relationship between the bias level, the distortion factor k and the recording sensitivity S.
The bias level is usually set for sufficient sensitivity together with low distortion, sometimes just for lowest distortion.

The relationship between bias level and tape sensitivity will be different for different frequencies. It will furthermore depend on the type of recording head, on the tape speed and on the tape material. In general, the recording sensitivity will have different maximum levels for different frequencies.



The general relationship between bias level, distortion factor k and the recording sensitivity S for different frequencies (e.g. 1kHz and 10kHz). It can be seen that at the bias level for the lowest distortions, the sensitivity S_1 has reached approximately its maximum, while for S_{10} it is already beyond the maximum.

The manufacturers of magnetic tapes provide data sheets for their tapes which give the above curves from which the optimum bias setting of the tape machine can be determined.


19.05 cm/s 7 µm 70 µs
20
10
+
0
−
10
20
30
40
Output [dB]
D_H3
%
10
5
3
2
1
0,5
MOL 1 kHz/3%
MOL 1 kHz/1%
SOL 10 kHz
Ref. Level (RL)
320 nWb/m
S 1 kHz
S 10 kHz
S 12.5 kHz

Example of manufacturer's tape data sheet (Agfa PEM368/268) for two tape speeds.

The abbreviations used have the following meaning:

RL REFERENCE LEVEL
(e.g.32OpW/mm,
CCIR/MONO).

MOL MAX. OUTPUT LEVEL
at 1kHz producing
producing 1% (3%)
third harmonic
distortion.

SOL_{10max} SATURATION OUTPUT LEVEL
at 10kHz, regardless of
distortions.

S_{1kHz} RELATIVE SENSITIVITY
at 1kHz (10kHz, 12.5kHz)
of a signal of -20dB
below RL .

D_{H3} DISTORTION
3. harmonic,
at RL

BN BIAS NOISE level
weighted (CCIR or IEC),
the noise of a neatly
erased tape.
(both for DIN and NAB
measuring methods)

DCN DC NOISE level

There are two vertical scales: one in dB relative to RL (reference) and additionally one in % for 3rd harmonic distortion.

Horizontal scale: Variation of HF bias current, ±5dB maximum. The 0dB, which is the "recommended" setting, is not the optimum setting for all cases.
The bias level scale has little importance in practice.

From the tape characteristics, the effects of various bias level settings can be seen: At 0dB bias level setting, the play-back output at frequencies near 1kHz is maximum (see S1kHz). The distortion (DH3) is then not at absolute minimum but below 1% (this refers to 1kHz recorded at reference level RL). If the bias level was reduced to -5dB the distortion would rise to near 7%. At bias level +3dB distortion would be minimum, about 0.2%.

Distortions of 3% are considered "permissible" in studio work but in practice, recorders will have much lower distortions.

The curves MOL, SOL and DCN can be useful when comparing different brands of tape, but they are not considered when adjusting the bias.

4.4. SETTING THE BIAS

To set the bias level, the horizontal scale of the tape characteristic is not helpful because in practice, we have no means of measuring the bias.

(Note: Some tape machines (e.g. Ampex 440) provide means to read the "bias level" on the VU-meter. The reading obtained has nothing to do with the bias level of the tape characteristic.)

We have to find some other means to find the suitable bias setting for the particular tape. In practice there are two methods in use.

The methods for the bias alignment require separate record and play-back heads and amplifiers and are therefore only applicable to professional tape machines.

4.4.1. THE 1KHZ METHOD

This method uses the fact that for most tapes, the sensitivity curve S1kHz has its maximum and the distortion curve has its minimum for the same bias setting. So, by finding the bias setting which gives best tape sensitivity, we get lowest distortions.

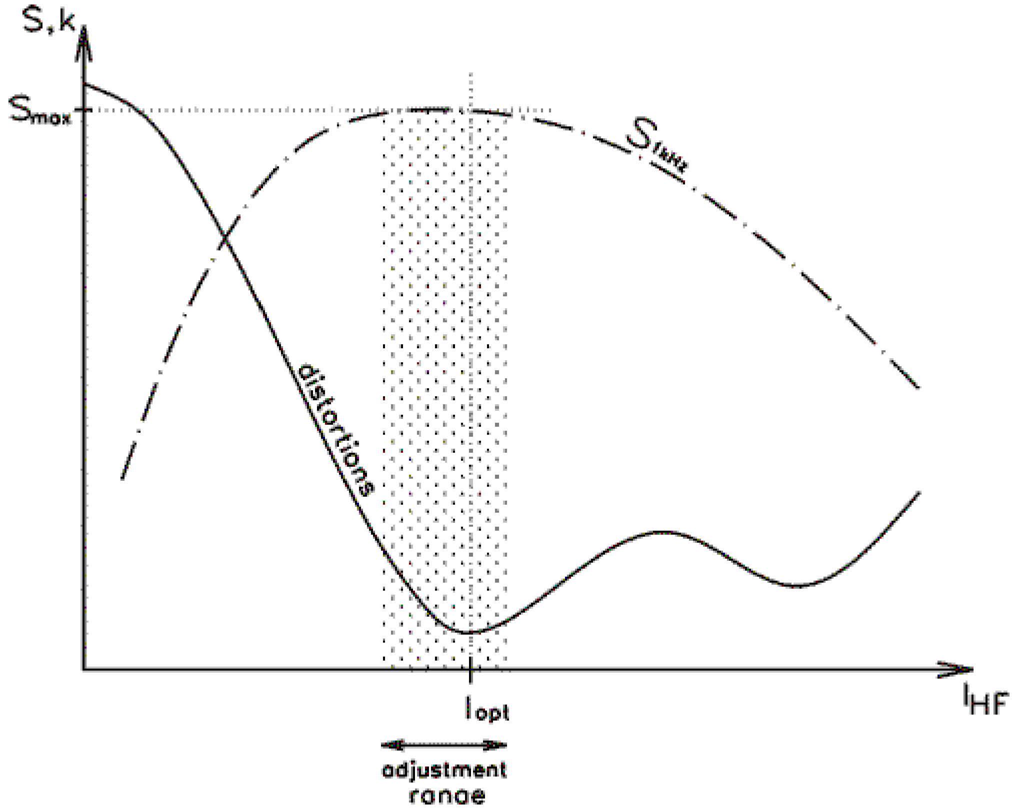
Steps of employing the 1kHz method:

1. Apply an audio signal of 1kHz **at 20dB below normal recording level** to the recording input of the tape machine.
(Attempting the adjustment with full level will result in wrong bias settings!)

2. Connect a level meter to the output of the tape machine.

3. Run the machine on "Record".

4. Adjust the bias setting to achieve maximum reading of the output level.



Using the 1kHz-method, the bias level is adjusted so that the maximum recording sensitivity is achieved at 1kHz. Because the maximum of the sensitivity is relatively wide, the bias setting is not very accurate.

It will be found that the maximum output level will be achieved at a relatively wide range of bias settings. Therefore, this method is not very accurate.

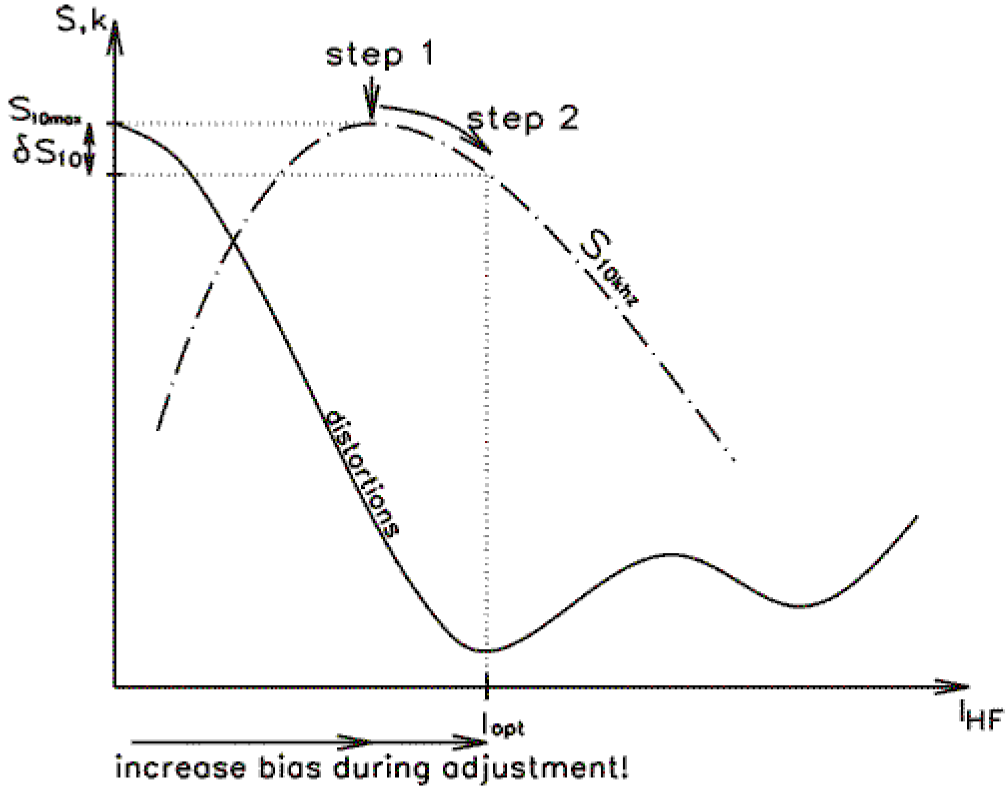
The advantage of this method is that it is simple and it requires no information about the tape used. It is therefore an adequate method if the tape is unknown or if the tape characteristics are not available.

Nevertheless:

The bias adjustment is only valid for one type of tape.

4.4.2. THE 10KHZ METHOD

This method is more precise than the 1kHz-method and is therefore preferred by German radio stations. It uses the fact that at high frequencies, e.g. at 10kHz, the recording sensitivity is already decaying at the bias setting for minimum distortion. So, if the amount of sensitivity reduction is known, the bias can be set in such a way that just this reduction is achieved.
This gives a clearly defined bias setting.



The steps of 10kHz-method.
1. Find the maximum sensitivity at 10kHz
(at -20dB),
2. Increase the bias level until the sensitivity has dropped by δS_{10}.

This method requires information about the reduction in sensitivity δS_{10}.
It depends on
- The type of tape,
- The type of recording head,
- The tape speed.

This information must be obtained from the tape machine handbook, from the data sheet of the audio tape or from the tape machine manufacturer.

Using the 10kHz-method requires information about the tape used.
The achieved bias setting is only true for this tape.

Working steps to employ the 10kHz-method:

1. Apply an audio signal of 10kHz **at 20dB below normal recording level**
to the recording input of the tape machine.
(Attempting the adjustment with full level will result in wrong bias settings!)

2. Connect a level meter to the output of the tape machine.

3. Run the machine on "Record".

4. Adjust the bias setting to achieve maximum reading of the output level. Memorize or note this level.

5. **Increase the bias level** (normally: turn the control clockwise) until the output level has dropped by δS_{10} below the maximum reading. (Note: By turning the control in the wrong direction, the same reduction in sensitivity may be obtained, but the distortions will then be very high!)

4.5. NOISE

Next to distortions noise is one of the biggest problems in magnetic recording. Great care has to be taken to reduce the noise level to the minimum possible.

There are basically two different sources of noise during the magnetic recording and play-back process: the tape noise and the modulation noise. Both have different causes and have to be handled differently.

4.5.1. TAPE NOISE

The cause for this type of noise lies in the tape itself. In a fully erased tape the elementary magnets of the magnetic tape particles are in a random order. But this random order still allows that there is a statistical distribution of particles having similar polarity, supporting each other. These areas then induce a signal in the play-back head, resulting in a random noise signal during play-back.

Except for selecting high quality tape which provides low tape noise, it can be influenced by the following parameters of the play-back process:

Track Width:
The wider the track, the more magnetic particles are in front of the gap and the bigger the chance is that random magnetic fields will cancel out to zero. Furthermore, the wider track produces a higher useful signal flux which gives a better S/N-ratio.

Tape Speed:
With increased tape speed the random noise spectrum is shifted towards higher frequencies and thus out of the audio range. This noise spectrum then no longer contributes to the total noise power.

Recording Level:
The tape noise level is fixed. Recording the signal at the highest possible level will increase the signal-to-noise ratio of the recording.

4.5.2. DC NOISE

This type of noise is only produced if the tape is DC-magnetized.

The cause of this noise is as follows:
When the tape is magnetized, not all the magnetic particles will drop into the same magnetic state. There will be a random distribution of residual flux on the tape. The random differences in the remanence levels are much larger than on the fully erased tape. Due to this, the noise level of a DC-magnetized tape is much higher than the tape noise (approximately 5 to 10dB).

DC noise is normally produced by badly maintained tape machines or the improper handling of tapes.
It can be avoided if the following causes of DC noise are considered:

Permanent Magnetized Parts of the Tape Machine.
Any permanently magnetized part of the tape machine will produce DC magnetism on tape coming in to contact with it. These parts are the:
- tape guide,
- heads,
- capstan.

Regularly demagnetize these parts and take care not to touch them with magnetic tools. (Any steel tool may be magnetized!)

Un-symmetry of Erasing Current.
If the erasing current is not a pure sine wave but contains (even) harmonics, it will contain a DC component which will result in a DC magnetization of the tape. The recording will then contain excessive DC noise.

Align the erasing current according to the requirements of the service manual.

Exposing recorded tapes to a permanent magnetic field.
Only a very strong permanent magnetic field will be able to erase a recorded tape. But even relatively weak magnetic fields are able to bring some DC magnetism on the tape and thus irreversibly degrade the quality of a recording.

Therefore take care not to put tapes (even temporariy) close to permanent magnetic fields like

- load-speakers,
- mc instruments,
- transformers,
- tools.

DC magnetization on a recorded tape cannot be removed and increases the noise level permanently.

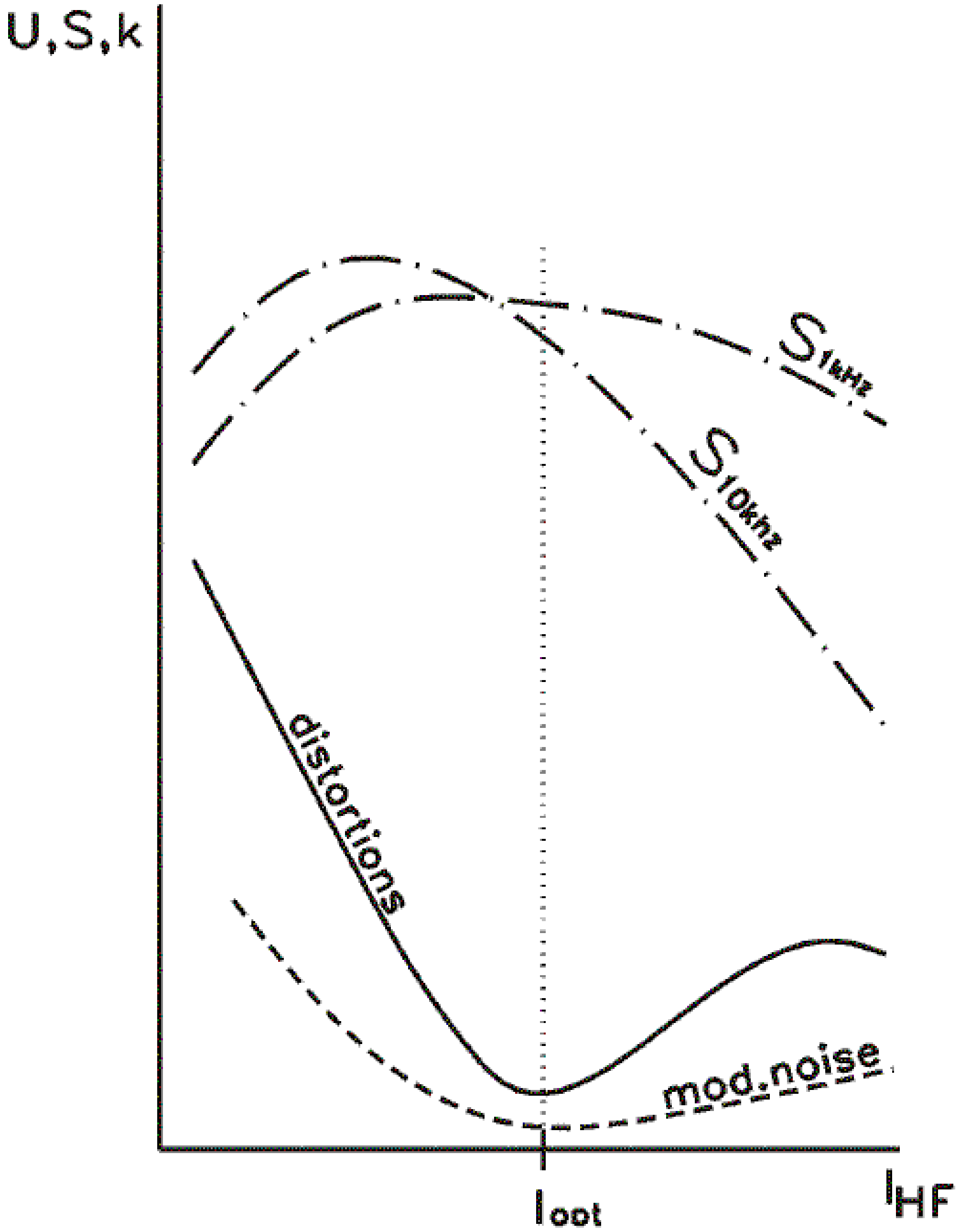
Some cheap cassette recorders which erase the tape using permanent magnets or even use d.c. biasing consequently produce recordings with a high noise level.

4.5.3. MODULATION NOISE

Modulation noise is from its physical cause identical to DC noise.
But it occurs inevitably during the recording process.

Recording a signal on the tape can be considered as recording varying DC-magnetism. With this recorded DC magnetism DC-noise is produced which is inter-modulated by the recorded signal. The magnitude of the noise is similar to the pure DC-noise. But as it occurs only in conjunction with the signal, it is not so disturbing, because it is concealed by the signal.

The modulation noise level depends mainly on the biasing of the recording head. Fortunately, the modulation noise has a minimum at the same biasing level for which the minimum of the distortions is achieved.



The relationship between biasing level, distortions and modulation noise. Distortions and modulation noise reach their minimum at the same biasing level.

Measuring the modulation noise is not easy because the normal procedure for noise measurement (output signal without input signal) cannot be employed.

There are two methods available:

1. Record a low frequency signal (e.g. 100Hz) at full level on the tape. Measure the output level using a high quality, high pass filter, cutting of the 100Hz. Only the resulting noise, which has higher frequencies, will be measured.

2. During recording apply a d.c. current of the same value as the effective value of the full audio level to the recording head. Measure the signal level on the play-back output. As the DC current will not produce a signal on the play-back, head only the modulation noise will be

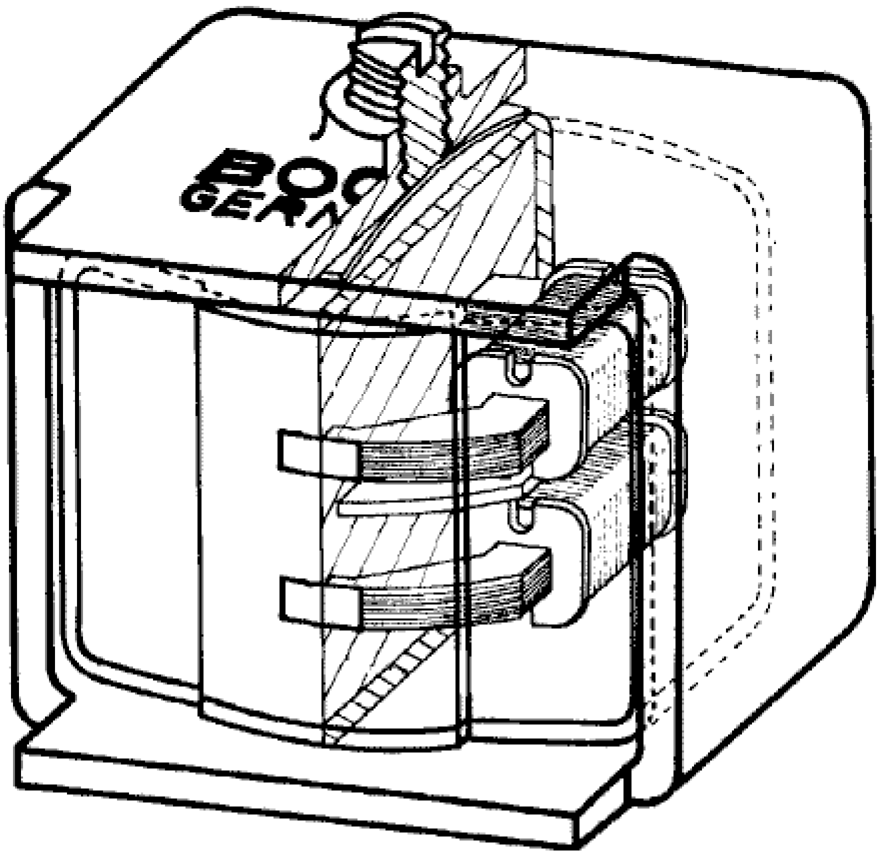
measured.
This method requires manipulations at the recording head.

Because of the difficulties of these measurements, the modulation noise measurement is normally not included in maintenance measurements.

4.6. THE RECORDING HEAD

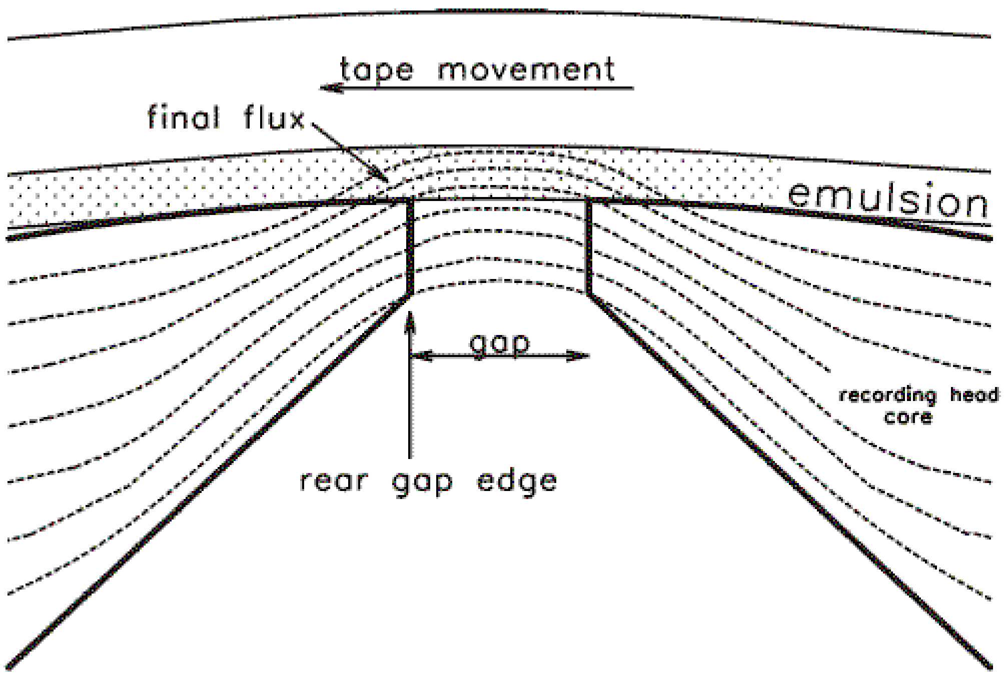
The recording head consists of a soft iron or ferrite core with one or two windings. The core has two gaps, one at the front and one at the rear (internally). The front gap is relavant for the recording properties. It is normally filled with some non-magnetic material like brass, aluminium or glass (for ferrite heads) to define the gap width.

The gap must be large compared to the gap of the play-back head; this allows the field lines to fully penetrate the emulsion. Penetration at high frequencies is reduced if the gap is small (narrow). Modern recording heads have gaps 8 to 12µm wide.



The construction of a recording head.
(Here: two track head)

The actual and final magnetism that remains on the tape when it moves away from the gap is defined by **the rear edge of the gap**. It may well be that at high frequencies, the strength or polarity of the magnetic field changes while the tape is in front of the gap. It is the magnetic situation of the rear edge of the gap which will impose the final magnetism.



The final remanence on the tape is defined by the rear edge of the gap. This enables the recording of signals with wavelength shorter than the actual gap width.

There is a second gap at the rear of the core, about 500µm wide. This gap defines the magnetic properties of the head and prevents saturation of the core during high current surges. The impedance (inductance) of the recording head is normally low. This helps to arrange for constant current; it is also easier to pass sufficient HF current through the winding when inductance is reasonably low.
In German recorders the inductance is about 7mH.

4.7. RECORDING LOSSES

The recording process is based on the principle that a current in the recording head winding will produce a proportional residual flux on the tape. In practice, it turns out that this process is associated with some losses so that less flux than expected remains on the tape. These losses depend on the frequency which results in a **non-linear frequency response** of the residual flux.

There are different reasons for the recording losses:

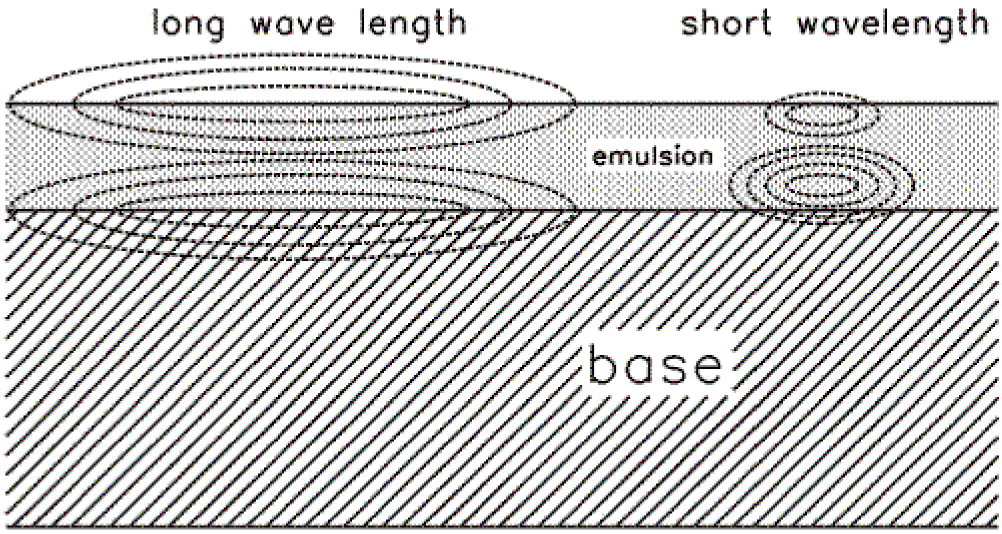
4.7.1. RECORDING HEAD LOSSES

The recording head is constructed like a coil and produces the typical losses of a coil. Energy lost in the recording head will not be recorded on the tape.

These losses increase with frequency, but in practice they are not very important.

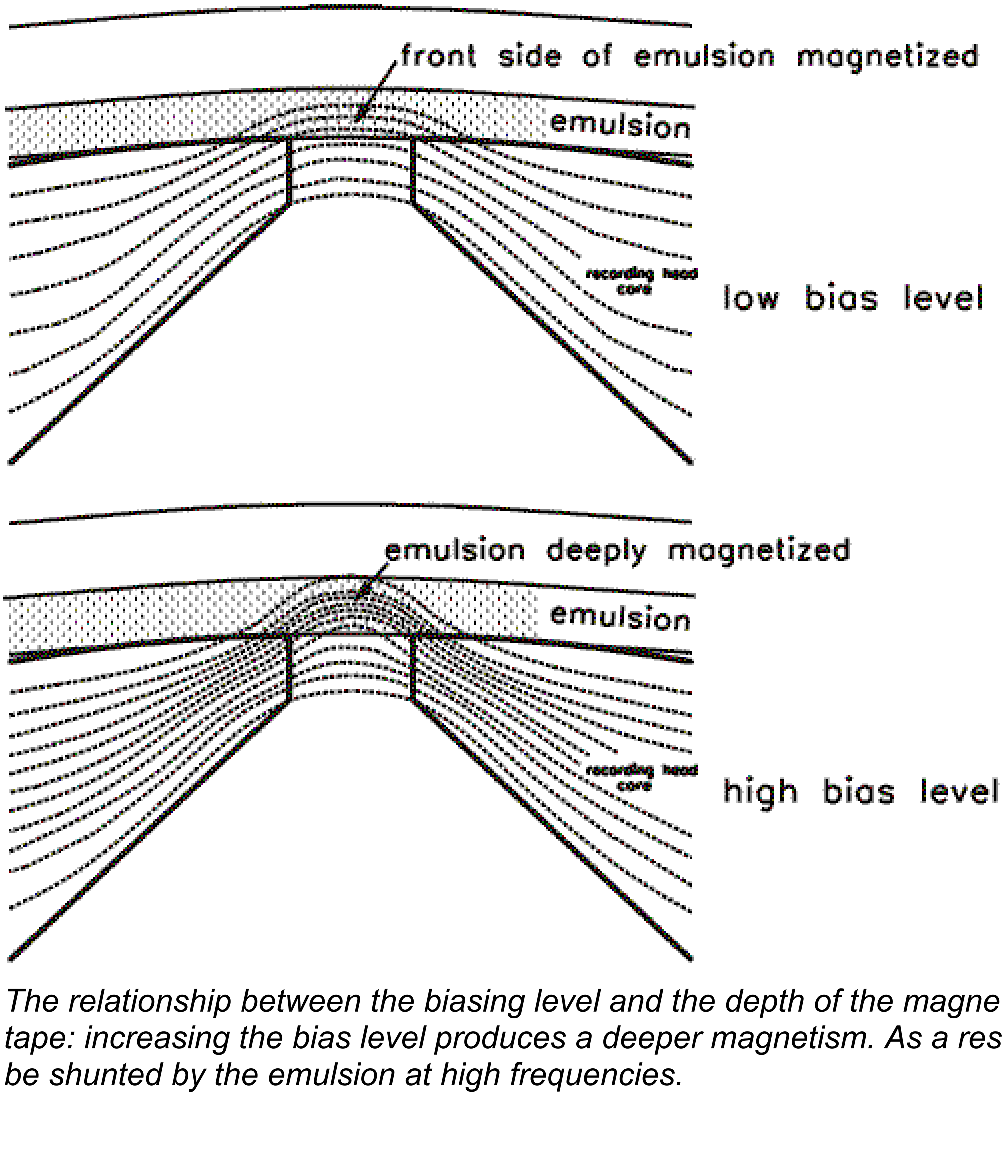
4.7.2. SELF-DEMAGNETIZATION

At short wave lengths (high frequencies) the flux in the emulsion will find a "magnetic shunt path" within the emulsion. This "shorted" flux will not leave the emulsion anymore and can therefore not be picked up by the play-back head. Although this flux is actually recorded and on the tape, it is practically lost.



At short wave lengths the tape flux is partly shorted by the emulsion.

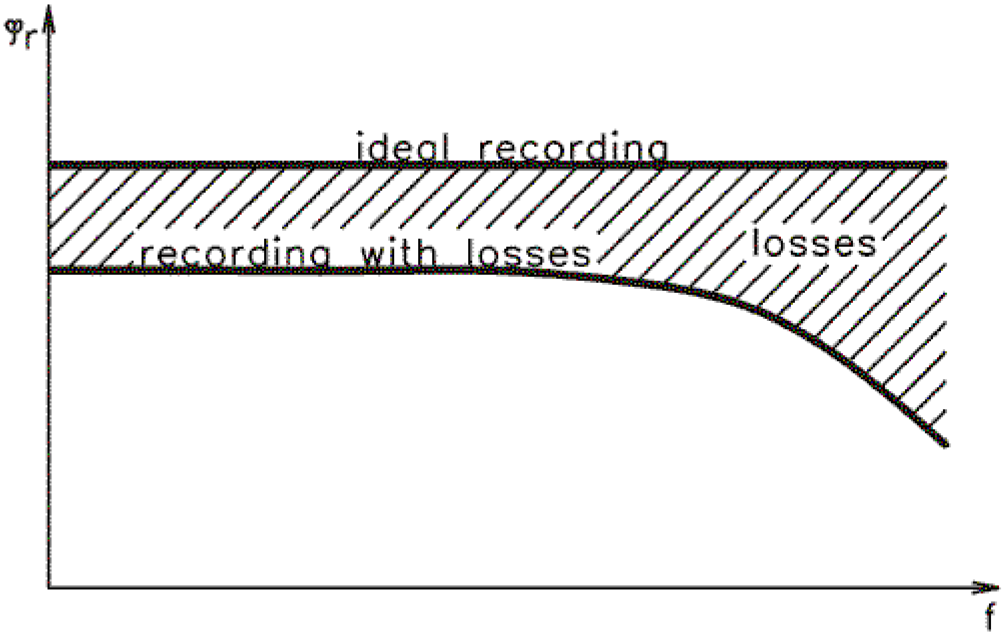
The self-demagnetization losses depend on the characteristics of the tape and on the biasing level. The depend on the strength of the biasing, how deep the magnetism penetrates into the emulsion. The deeper the magnetism penetrates the tape, the "further" the flux is away from the gap. It will therefore rather be shunted by the emulsion than enter the play-back head and induce a voltage in it.



The relationship between the biasing level and the depth of the magnetism in the tape: increasing the bias level produces a deeper magnetism. As a result, the flux will be shunted by the emulsion at high frequencies.

4.7.3. TOTAL RECORDING LOSSES

It turns out that all recording losses affect only the high frequencies.
As a result, the remanence on the tape at high frequencies will be reduced.
From the resulting non-linear frequency response, the amount of the individual losses can no longer be detected.



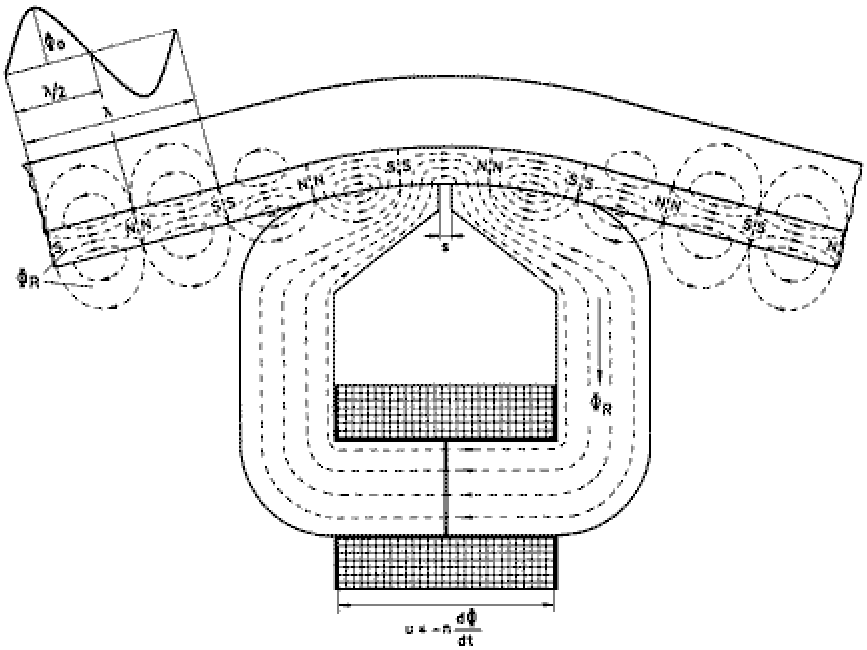
The frequency response of an ideal recording and a practical recording. It is assumed that all frequencies were recorded with the same recording head current level.

To achieve a linear frequency response, an equalization for the losses is necessary during recording or during play-back.

5. THE REPRODUCE PROCESS (PLAY-BACK)

5.1. THE PRINCIPLE

The play-back process uses the law of induction. The residual magnetic field of the tape induces a voltage in the play-back head. Because of the high permeability of the core, the flux of the tape passes through the pole pieces of the head as the tape touches the head. In other words, the tape emulsion closes the head gap. As the tape moves, the flux changes and a voltage is induced in the head coil. The relatively small induced voltage is then amplified to the required studio level.



During play-back the flux of the tape passes through the core of the play-back head, inducing a voltage in the coil.

Following the law of induction, the induced voltage is proportional

a) to the magnetic flux (on the tape)

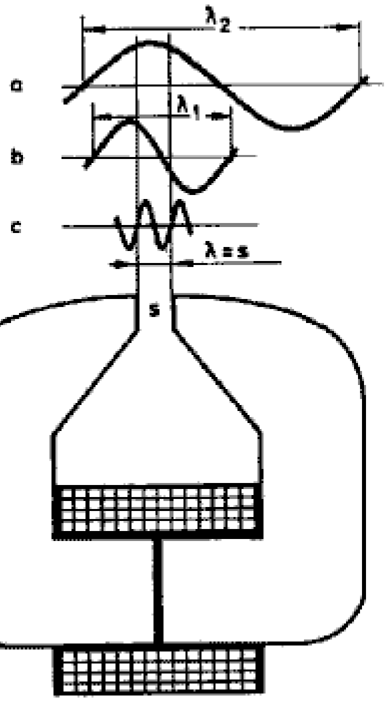
b) to the rate of change of flux.

Therefore, the induced voltage is proportional to the frequency. The voltage rises at 6dB per octave of the recorded frequency. The play-back amplifier must therefore have a frequency response to match the head output, i.e. its gain must increase with 6dB/oct (down to about 30Hz). At very low frequencies very small voltage are induced in the head, requiring very high gain.

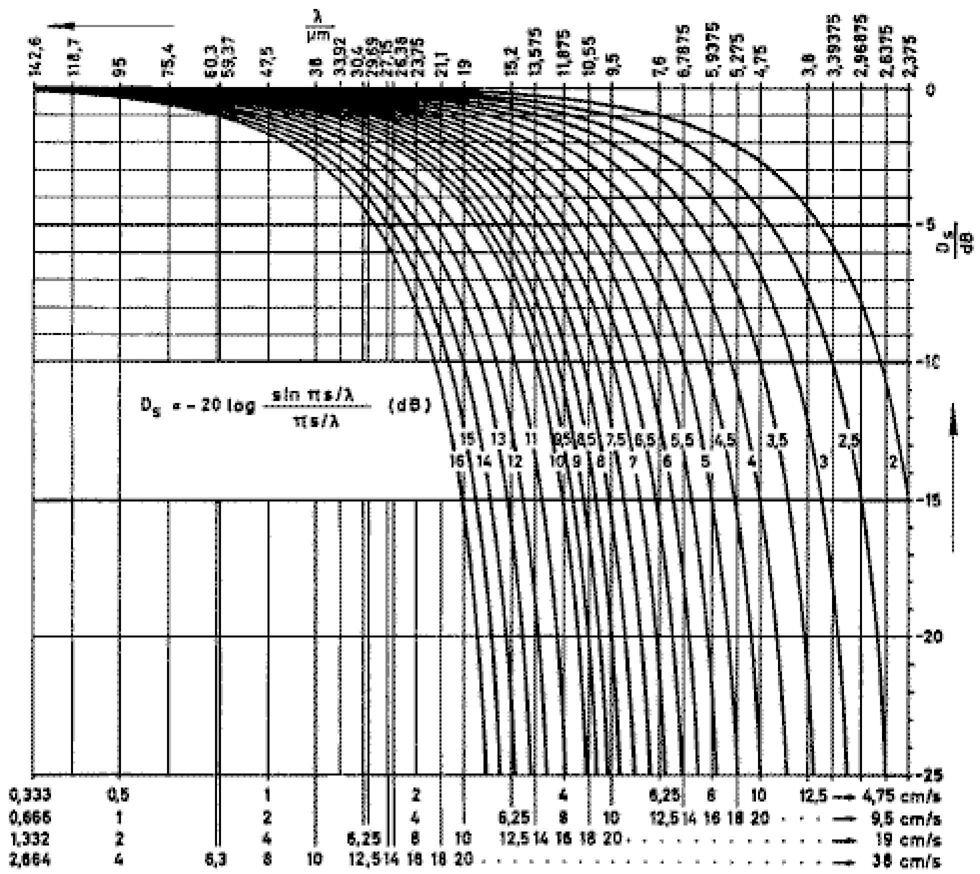
It is also possible to operate the play-back head at constant current mode, in which case the current is proportional to the signal on the tape. The induced current is frequency-independent. This requires near short-circuit operation of the head. Its reactance must be very high and the input resistance of the amplifier must be low. This principle requires a head winding of very low ohmic resistance. This principle is seldom used. The head is usually followed by a stage with high input resistance, which results in constant voltage operation.

5.2. THE PLAY-BACK HEAD

The play-back head is constructed similarly to the recording head, but it has no rear gap. In order to be able to pick up signals of short wave length (high frequencies), the gap must be smaller than the wave length of the highest signal frequency. Typically, gap widths are 3µm to 8µm.



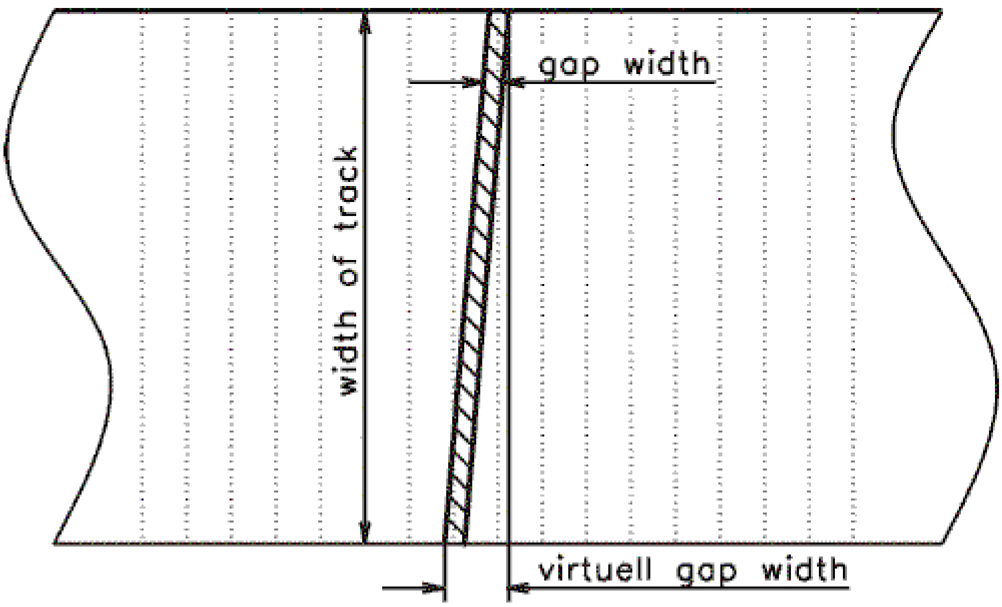
The relationship between magnetic wavelength on the tape and the flux in the play-back head. It can be seen that the flux in the core cancels out if the gap width is equal to the magnetic wave length.



The diagram shows the gap attenuation for different tape speeds, different frequencies and different gap width (curve parameters).

If the gap of the head widens due to wear, the head will fail to pick up the high frequencies of the signal on the tape.

The gap has a certain length (depending on the number of tracks between 1mm and 6.3mm), which detects the flux of the tape over the width of the track. If the direction of the head is not identical to the direction of the flux on the tape, the effective flux in the head will be the mean value of the detected flux of the track.



If the gap is not in line with the flux on the tape, the head will pick up some "mean flux" across its gap. This has the same effect as a wide head gap and thus reduces the head flux of high frequencies.

The effect of the gap mis-alignment is the same as an increased gap width. Therefore, it produces losses of high frequencies.

Theoretically, the play-back head gap has to be in line with the recorded signal, thus with the recording head gap. The absolute angle of the two is not important. In order to have standardized relationships both gaps are aligned to be absolutely perpendicular to the tape movement.

Since the induced signal must be strongly amplified, specially at low frequencies, the head must be well screened to avoid hum problems.

Play-back heads are of high or medium impedance, i.e. they have more turns than the recording head to produce an induced voltage well above the noise level of the following amplifier. In German equipment the play-back heads are of relatively low inductance, about 80mH, and a step-up transformer is used between head and amplifier.

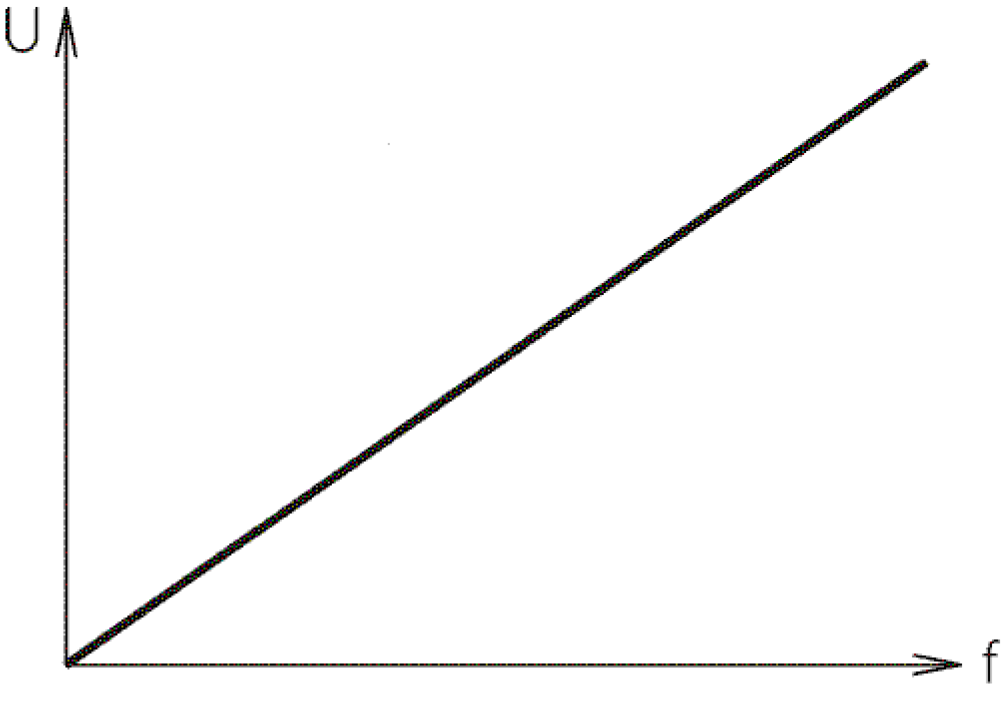
5.3. THE REPRODUCE LOSSES

Not all the magnetic signals on the tape can be reproduced by the play-back head. The losses which occur during play-back are frequency dependent and have different causes.

5.3.1. THE INDUCTION LOSSES

The losses occur due to the law of induction. The induced voltage in the play-back head increases with the frequency. Therefore, low frequencies occur with a low level, and high frequencies with a high level.

DC-signal and very low frequencies cannot be reproduced with a play-back head.

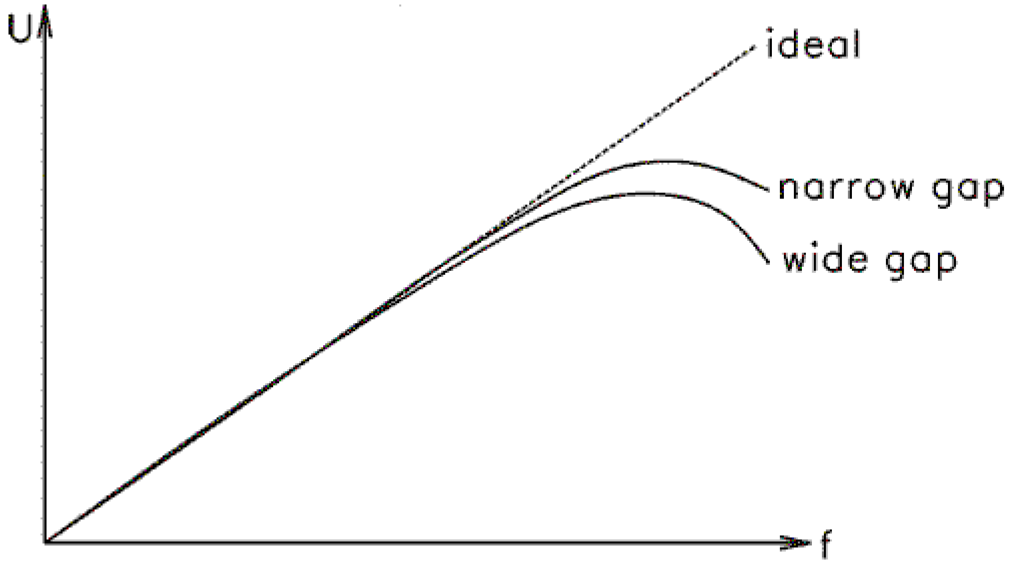


The frequency response at the play-back head due to the law of induction.

These losses at low frequencies are also called "omega losses" due to the factor omega=2π f in the law of induction.

5.3.2. THE GAP LOSSES

The play-back level decays with frequency due to the limited gap width following a sin(x)/x-function. This function has a pole (zero amplitude) at a frequency for which the magnetic wave length is equal to the gap width. For even smaller wave lengths (equal higher frequencies) the signal at the head rises again, but this part of the function is no longer usable.



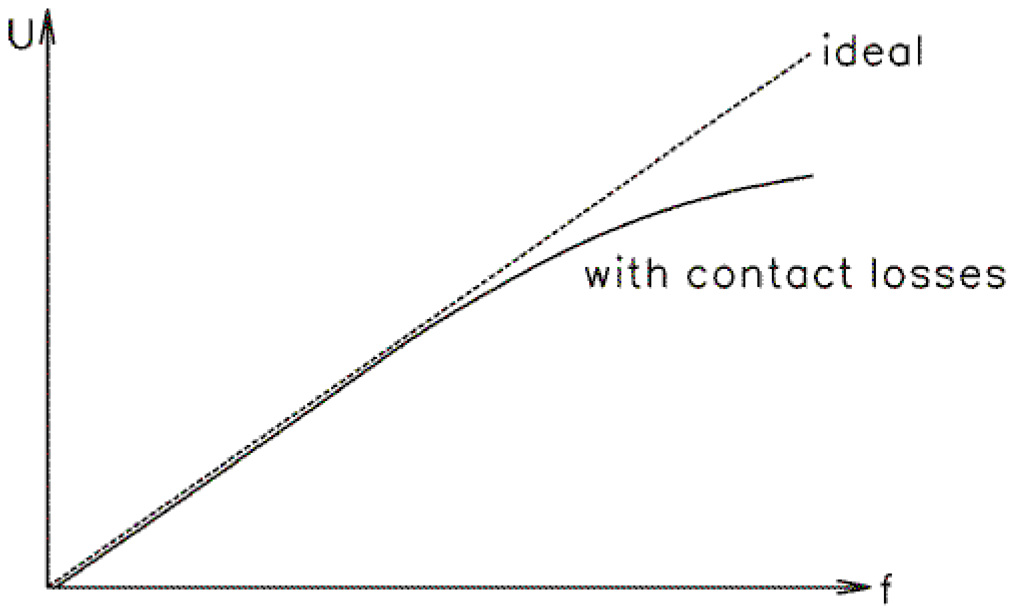
The function shows the reduction of play-back signal at high frequencies, due to the gap losses for two different gap width.

Because the gap width of the head will increase during the life of the head, the gap losses will change.

Note that losses due to gap mis-alignment have the same physical effect as an increased gap width.

5.3.3. TAPE CONTACT LOSSES

The contact between head surface and tape can never be perfect. Especially at short wave-lengths (high frequencies), part of the tape flux will not pass through the head core and will therefore not contribute to the signal. This causes losses at high frequencies.

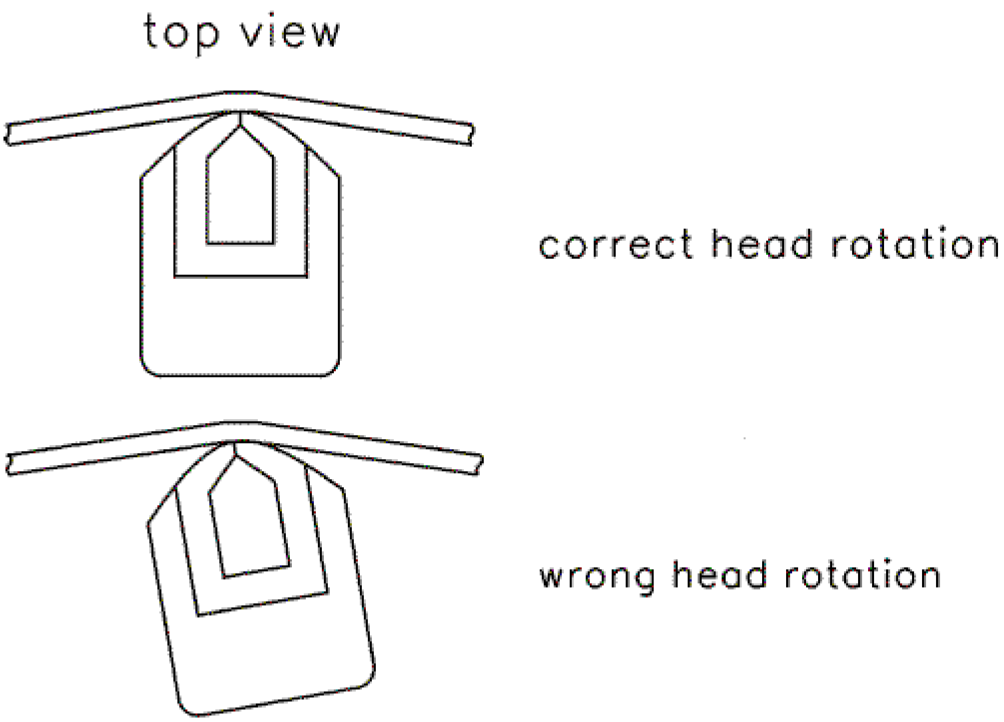


An imperfect tape-head contact will result in bad coupling between tape flux and head core. This will affect mainly the high frequencies.

Especially if the tape contact is reduced due to dirt on the head's surface, a strong attenuation of losses at high frequencies will be experienced.

The mechanical head alignment also has an effect on the tape contact.

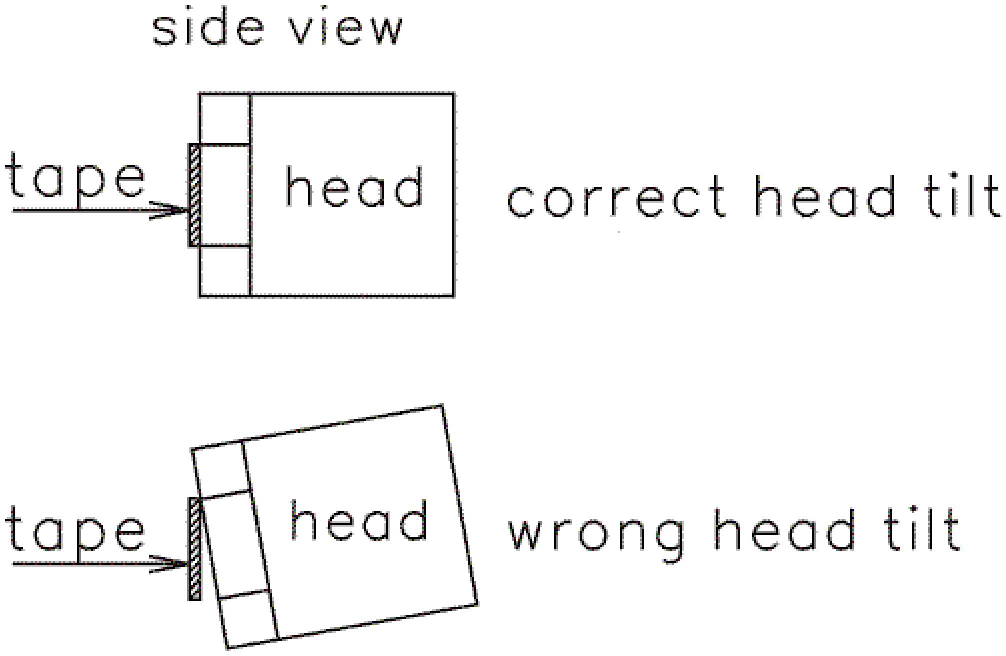
1. Head rotation (zenith)
The head must be mounted in such a way that the gap is in the centre (zenith) of the tape contact area.



The correct head rotation is achieved if the head gap is in the centre of the tape contact area.

2. Head tilt

The head must be mounted parallel to the tape guides to ensure that the tape has the same contact with the head over the entire width of the tape.



The correct head tilt is achieved if the head surface is parallel to the tape guides.

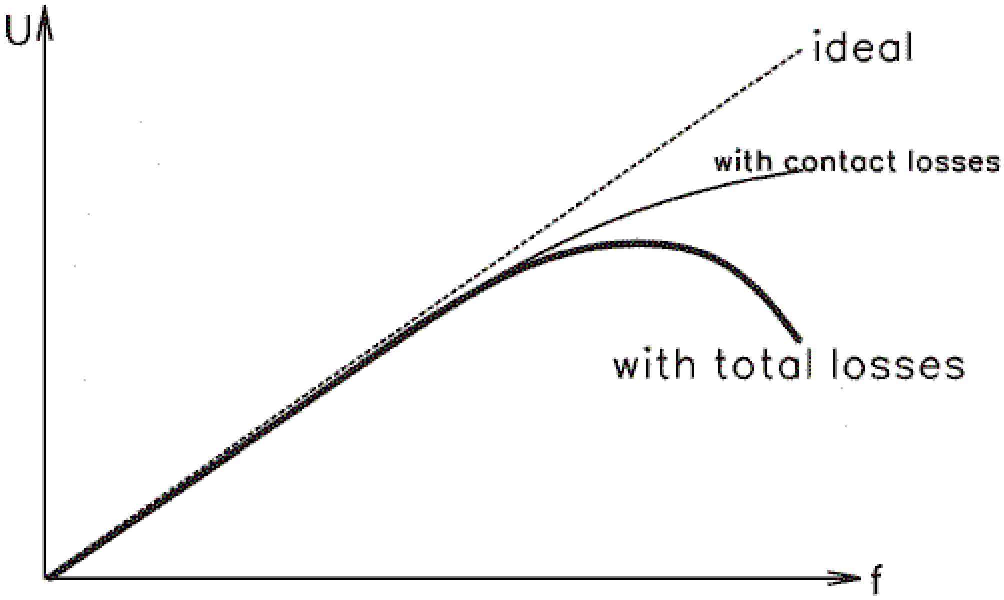
Mechanical head check and alignment only become necessary after the heads have been replaced.

5.3.4. IRON LOSSES

These losses occur in the core of the play-back head. The losses increase with the frequency, but they do not depend on the magnetic wave-length on the tape (they are independent of the tape speed). The losses are caused by eddy currents, stray field and dielectric losses. With modern heads these losses are very small.

5.3.5. TOTAL REPRODUCE LOSSES

All the above losses add up and result in the total reproduce characteristic.

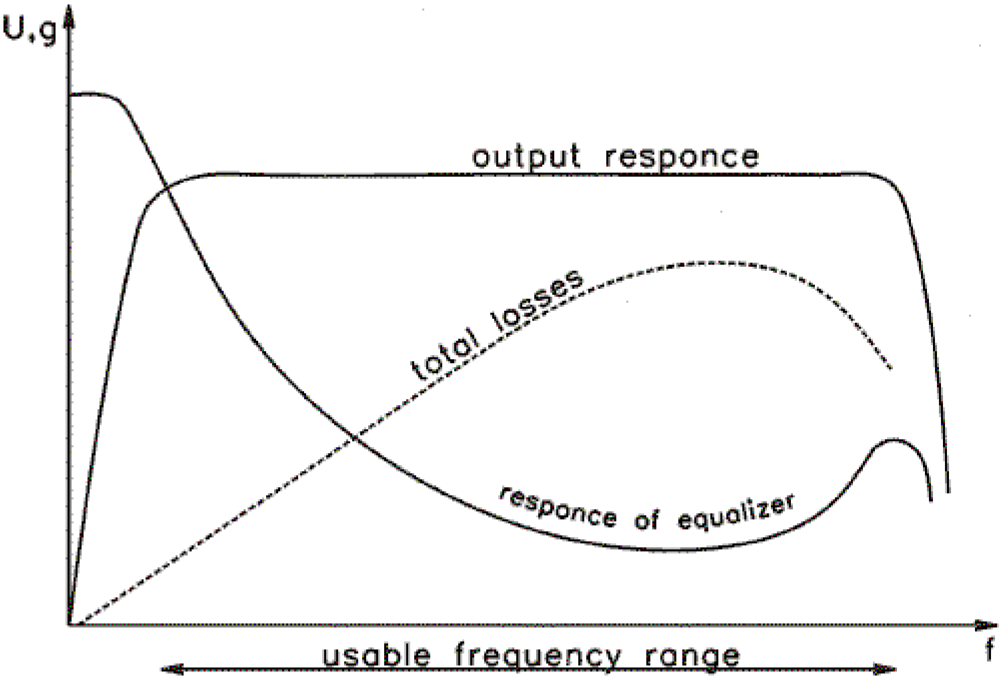


The total reproduce losses are assembled from the individual losses. The total losses produce the overall frequency characteristic of the play-back signal.

To prevent a non-linear frequency response from recording to play-back, the electrical path (recording and play-back amplifiers) must compensate. This process is called **equalization**.

6. EQUALIZATION

In order to equalize for the losses at high and low frequencies one could add to the play-black amplifier a filter which would have just the inverse shape a the frequency characteristic of the signal of the play-back head.



If the frequency response of the play-back amplifier would be the inverse of the frequency response of the play-back head signal, one would achieve an over-all linear response.

This method has some considerable disadvantages:

- Especially the high and the low frequencies of the play-back signal must be boosted. With this, the tape noise (high frequencies) and the hum (low frequency) would be boosted at the same time.

- Not all tapes and not all recording heads will produce the same losses. Therefore, if tapes from different machines are reproduced, different losses will occur and different equalization will be required.

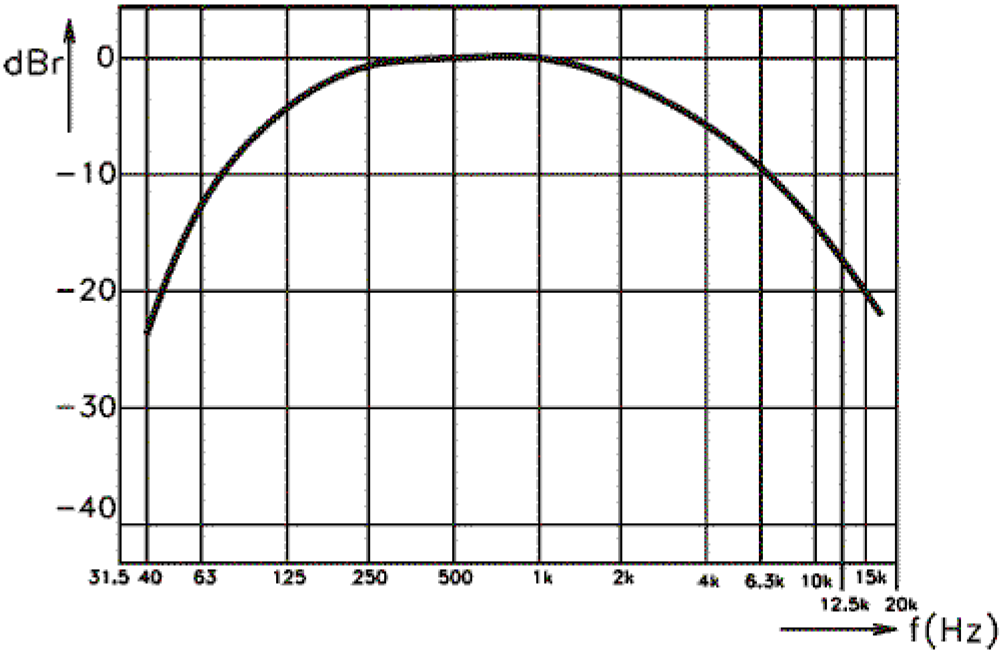
One could also compensate for the losses during recording by boosting the low and the high frequencies during recording. But if the medium frequencies are already recorded with max. level, this might lead to an over-modulation at the boosted frequencies.

In practice, the losses are compensated partly during recording and partly during play-back.

6.1. THE STATISTICAL DISTRIBUTION OF AMPLITUDES

To compensate at least partly for losses, the higher audio frequencies should be **lifted during recording**. This must be done **without over-modulating** (saturating) the tape at these frequencies. This is especially **critical at high frequencies**, because magnetic tapes have a reduced headroom at high frequencies.

In natural sound, however, such as speech and conventional music, it was found that high (and also low) frequencies occur at relatively low amplitudes.



The experimentally-determined curve of the amplitude distribution of the natural sound over frequency. This is a statistical curve. It may well happen that there are occasionally exceptions to this response.

Therefore, high and low frequencies may be lifted during recording by up to 20dB without much risk of over-modulation.

Note: Recent research into such statistical distribution of levels indicates that certain types of music, e.g. electronic sound, do not follow the natural amplitude statistics. The amplitudes of high frequencies may not fall off as indicated, but may even increase. This has not, however, affected international standards.

6.2. STANDARD FLUX CURVES

If the equalization is partly done during recording, it is essential to establish a standardization in order to be able to play back a recording on any machine.

In fact, the organizations failed to produce ONE standard;
unfortunately two different standards have been in use for many years now:

- CCIR (Commité Consultatif International des Radiocommunicatons),
also IEC and DIN Standard.

- NAB (National Associations of Radio and Television Broadcasters, USA)

As different tape speeds have different equalization requirements, the flux curves are different for different tape speed. Different curves are also defined for professional (studio) equipment and for home use.

The standards give clearly defined and relatively easy producible curves for the frequency response of the flux on a recorded tape, the so-called standard flux curve. Such flux curves can only be produced or measured under laboratory conditions.

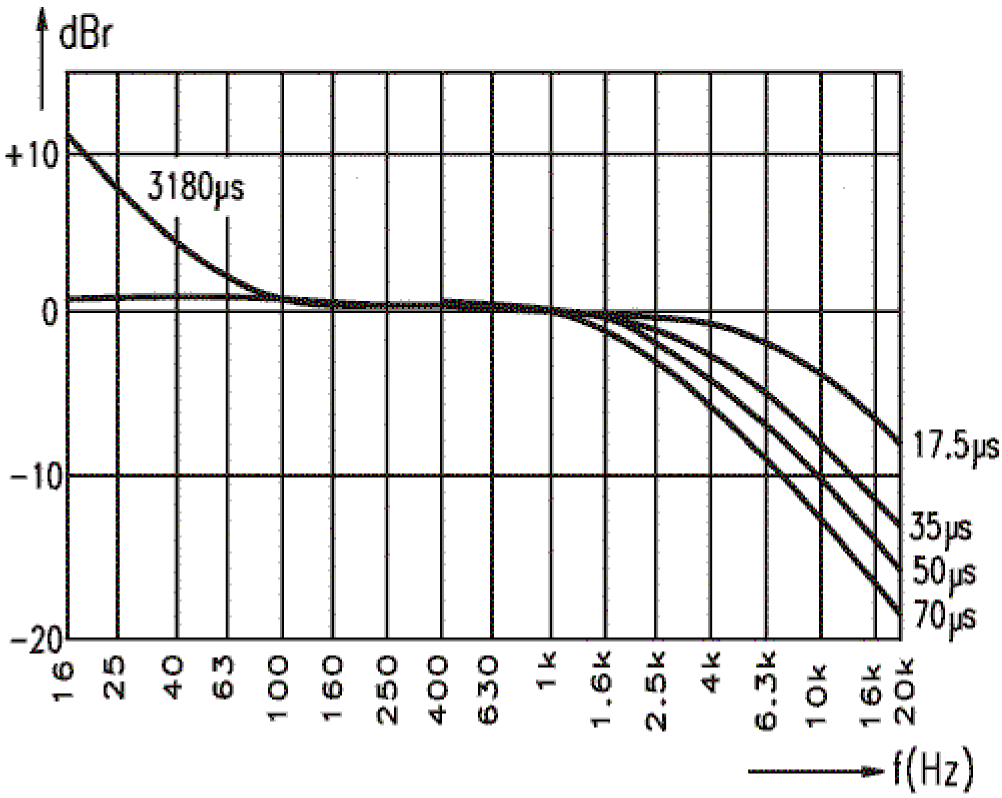
For maintenance and measurement purposes they will be found using COMPARISON.

The flux curves are defined by the characteristics of some first order low and high passes. The critical frequencies of the filters are normally described by their time constant (RC).

Table of characteristics of the standard flux curves for CCIR and NAB for different tape speeds.

Tape speed	CCIR/IEC		NAB	
	bass boost	high roll off	bass boost	high roll off
38 cm/s (studio)	none	35 µs	3180 µs	50 µs
19 cm/s (studio)	none	70 µs	3180 µs	50 µs
19 cm/s (home)	3180 µs	50 µs		
9.5 cm/s (studio+home)	3180 µs	90 µs		
4.75 cm/s (studio+home)	3180 µs	120 µs		
4.75 cm/s (Fe-cassette)	3180 µs	120 µs		
4.75 cm/s (Cr-cassette)	3180 µs	70 µs		

The basic difference between the CCIR and the NAB standard is the bass boost at low frequencies for NAB. This bass boost was meant to improve the hum rejection during play-back. The CCIR standard prefers the simpler equalization and relies on improved screening of the play-back head.



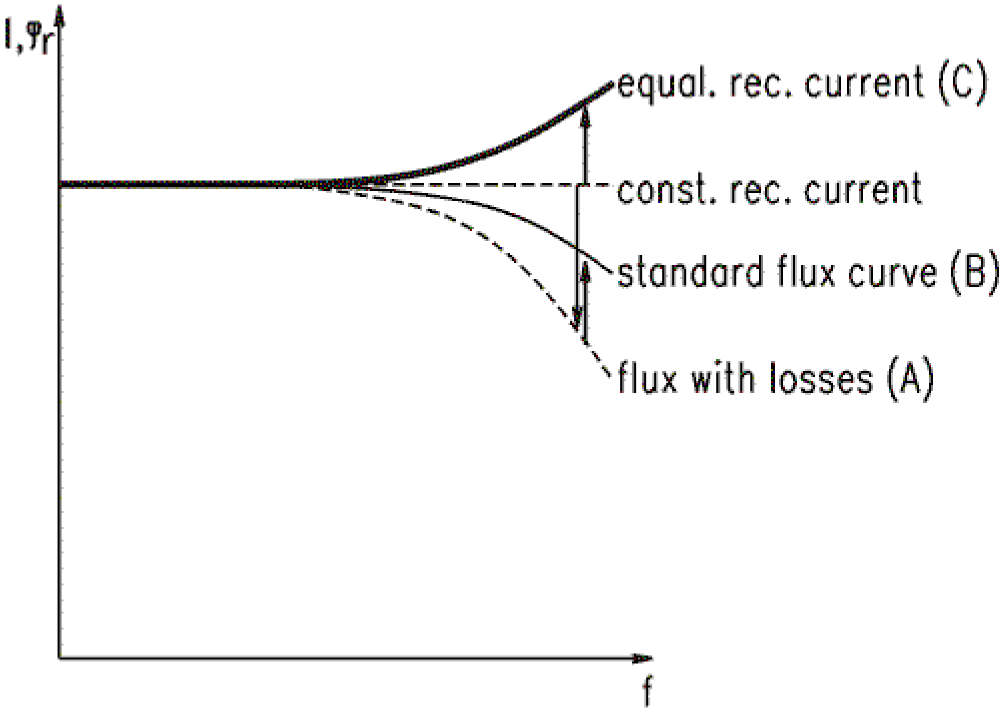
Standard flux curves for the standards used for professional studio equipment.

6.3. RECORDING EQUALIZATION

If all frequencies would be recorded with the same current level, the residual flux on the tape would decay towards higher frequencies. This is due to the recording losses (see 2.6).

The decay at the high frequencies is more than the high frequency roll off specified by the standard flux curves.

To achieve the standard flux curve on the tape, boosting of high frequencies is required during recording. For the NAB standard boosting of the low frequencies is also required.



If all frequencies would be recorded at constant recording head current, flux curve (A) with the magnetizing losses at high frequencies would result. To achieve the standard flux curve (B), the high frequencies have to be boosted during recording. This requires a frequency response of the recording amplifier according to curve (C).

The recording equalization is normally adjustable and has to be checked and aligned after repair or maintenance. The required equalization will depend on:

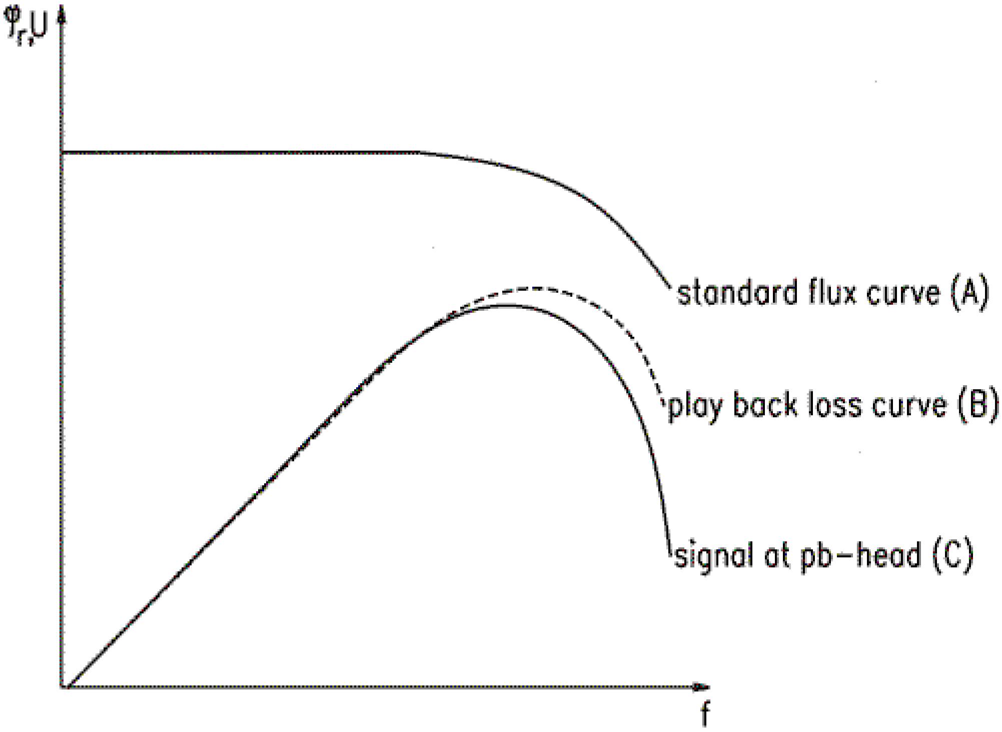
- The standard (CCIR or NAB),
- The tape speed,
- The type of tape used,
- The bias level setting.

Change to any of these parameters requires a new setting of the equalization. All tape machines provide automatic switching of the equalization if the tape speed is changed.
Some machines also allow selection of the equalization standard (CCIR or NAB).

A tape machine can be precisely aligned only for one type of tape and one standard.

6.4. PLAY-BACK EQUALIZATION

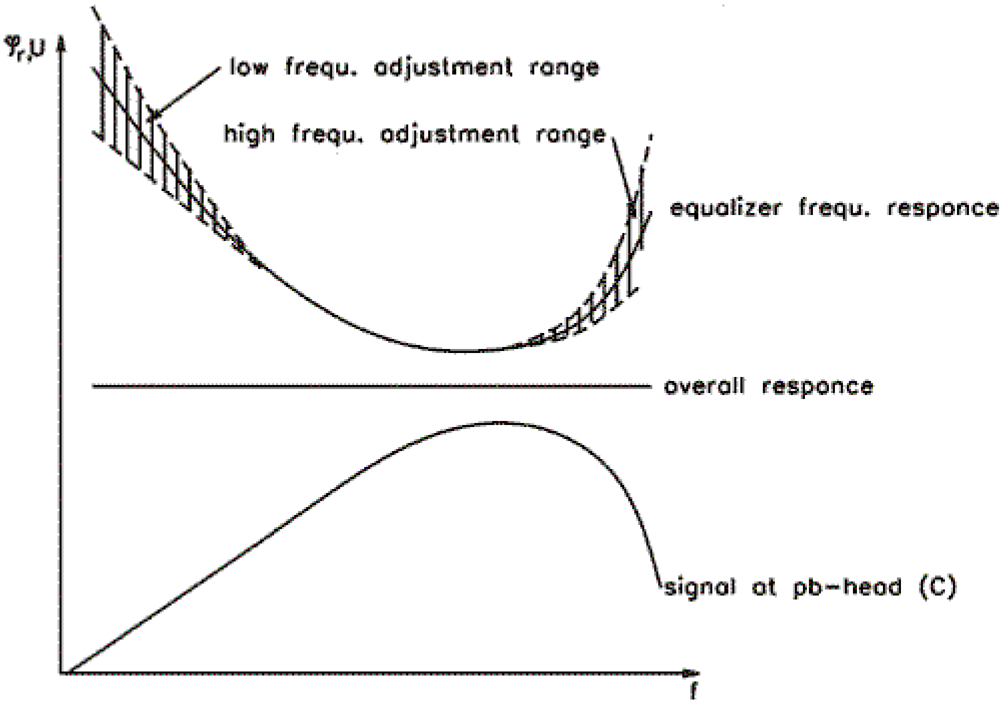
When a recording with a flux level according to the standard flux curves is reproduced, the signal on the play-back head will not produce a linear frequency response at all. This is due to the play-back losses described in 3.3.



If a tape with standard flux is reproduced, the play-back head will produce a signal (curve C) which is composed of the play-back losses (curve B) and the flux curve (curve A).

The play-back amplifier will have a frequency response which will produce a linear frequency response of the output signal. It will mainly boost the low frequencies to compensate for the omega losses, and it will boost the high frequencies to compensate for the gap, iron and contact losses.

The play-back equalization is normally adjustable for the low and the high frequencies to adopt the machine to the actual losses.



The play-back equalization is normally adjustable for the low and high frequencies separately to adopt the machine to the actual losses.

The play-back equalization has to be checked and aligned after repair or maintenance. The required equalization will depend on:

- The standard (CCIR or NAB),
- The tape speed.

All tape machines provide automatic switching of the equalization if the tape speed is changed.
Some machines also allow selection of the equalization standard (CCIR or NAB).

The type of tape has no influence on the play-back equalization because on all recordings, on any type of tape, the flux should follow the standard flux curve.

6.5. THE FLUX LEVEL

When a pre-recorded tape is played back, we expect a standard studio level for the reproduction. This requires that all recordings are made in such a way that the same play-back level is achieved.

The induced voltage in the play-back head depends on the rate of change of the flux on the tape. For a certain frequency, the induced voltage will be proportional to the flux amplitude. Because normally the effective value of signals is stated, for the tape flux, the effective value is also given in Weber (Wb).

The tape flux should be as high as possible to achieve a good S/N-ratio. On the other hand, it has to remain at sufficient distance from saturation in order to keep distortions low and to provide sufficient head room. For a ¼" studio tape with an emulsion of 15µm the flux is approximately 3nWb.

The total flux available for play-back will depend on the width of the track. But independent of the different track width, the same standard output signal is required. Therefore, the tape flux is related to the track width. It is expressed in terms of pWb/mm or nWb/m (both units give the same numerical value).

There are again different flux levels standardized by CCIR and NAB:

CCIR: Mono: 320pWb/mm,
Stereo: 510pWb/mm

NAB: 250pWb/mm.

All home recordings and cassettes use 250pWb/mm.

The difference in flux level between CCIR and NAB is due to the different program meters used. CCIR recommends the use of PPM's while NAB recommends VU-meters. The lower flux level of NAB is required to have sufficient head room on the tape for level peaks.

For the alignment of the tape machines it is essential that all tape machines of the broadcasting house are aligned equally. The standard used is not so important.

A special problem arises if mono and stereo recordings are mixed, because then different track widths will be involved. As the playback level will depend on the recorded track width, this will result in different play-back level.

The track flux is calculated as

track flux = flux density x track width

Furthermore, it has to be considered that a stereo recording, played back on a full track recorder, will produce a signal 3dB lower than the sum of the track fluxes (summing of non-coherent signals).

The following table shows the signal levels which will result if a recording on one type of tape recorder will be played back on another type of machine. The main problem arises if NAB two track machines and full track recorders are mixed.

			play-back			
			mono (full track) (5.9mm track) 320pWb/mm 2000pWb=0dB	CCIR Stereo (2.58mm tracks) 320pWb/mm 820pWb=0dB	CCIR Stereo (2.58mm tracks) 514pWb/mm 1300pWb=0dB	NAB Stereo (1.82mm tracks) 320pWb/mm 580pWb=0dB
recording	Full track	mono 320pWb/mm	0dB	0dB	−4dB	0dB
recording	CCIR Stereo	Stereo 320pWb/mm	−4dB	0dB	−4dB	0dB
recording	CCIR Stereo	Stereo 514pWb/mm	0dB	+4dB	0dB	+4dB
recording	CCIR Stereo	single track 514pWb/mm	−4dB	+4dB	0dB	+4dB
recording	NAB Stereo	Stereo 320pWb/mm	−8dB	−3dB	−7dB	0dB
recording	NAB Stereo	single track 320pWb/mm	−11dB	−3dB	−7dB	0dB

6.6. TEST TAPES (CALIBRATION TAPES)

To align a tape machine, a source producing the standard flux level and the standard flux curve is required. This flux cannot be produced with the normal means of the maintenance workshop. In practice alignment, is done by means of a high quality test tape which carries signals at standard flux level and test frequencies which follow the standard flux curve.

Using such a test tape, the play-back equalization is then aligned so that standard studio level and a linear frequency response is achieved.

For different tape speeds, different test tapes are required.
The test tapes must be for the standard (CCIR or NAB) used in the broadcasting house.

The flux on the test tape for the different frequencies cannot be recorded at full level. Due to the boost of high frequencies during recording, this would lead to an over-modulation and saturation of the tape at high frequencies.

On the test tapes, the part for the frequency response alignment is recorded at 20dB (NAB: 10dB) below standard level.

Standard CCIR-Test tapes contain the following parts:

1. Reference Level Section: (1kHz, 0dB)
This section defines the reference play-back level and is used to adjust the play-back amplifier to nominal output level.

2. Azimuth Alignment Section: (10kHz, -10dB)
This section is used to align the azimuth position of the play-back head.

3. Frequency Response Section: (31.5Hz ... 18kHz, -20dB)
This section is used to check the frequency response of the output signal and to align the play-back equalization.

Often test tapes also contain other signals which make the alignment easier, e.g.:

- For the azimuth adjustment:
An additional 1kHz, -10dB signal for the coarse check of the azimuth setting.

- For the frequency response check:
A repetition of the frequency response part (or parts of it) to check the frequency response after adjustment.

A steadily increasing frequency at -20dB for a quick check (not adjustment!) of the frequency response.

- For the level adjustment:
Because after the equalizer alignment the output level has to be re-checked, the tape may contain a signal of 1kHz, 0dB at the end.

Test tapes are one of the most important TOOLS for the maintenance and service of tape machines. As they are produced at high precision and in small numbers, they are relatively expensive (appr. $200). They should therefore be handled with great care.

Rules for handling test tapes:

- **Finish all repairs and mechanical alignments** and de-magnetize the machine before putting the test tape on the machine,

- Make sure **the machine is not set to recording**; if possible, disable recording,

- **Never do any test recordings** on the test tape,

- After the play-back alignment, **put the test tape back into its box** and store it safely,

- Keep any magnetic fields away from the test tape.

Making copies of test tapes is a dubious process, as the alignment errors of both machines used for copying will be included on the copy. Alignment done with copies of test tapes can therefore not be as precise as made with the original.

7. AUDIO ALIGNMENTS AND TESTS

The audio alignment of a tape machine will follow a logical sequence. To avoid mis-alignments **it is important that this sequence is consequently followed**. This sequence should therefore be custom to anyone doing regular tape machine servicing.

Before starting the audio alignment, the tape transport should have been checked and aligned.

For the standard alignments and tests of the audio path, the following measuring instruments are required:

- Demagnetizer
- Test tape,
- Level Meter
- Audio Signal Generator
- Distortion Meter
- Wow and Flutter Meter

The audio alignments always start with the play-back part of the audio path. This part is aligned using a calibration or test tape.

Afterwards, the recording side is aligned to achieve the optimum performance with the standard tape in use.

The recording side of a tape machine can only be precisely aligned for one type of tape.

7.1. DEMAGNITIZING THE TAPE MACHINE

Demagnetizing is actually mechanical rather than electrical work, but in order to emphasize its importance it will be listed here.

Reasons for demagnatizing:

- To remove all permanent magnetism from any iron part of the tape path

- To avoid distortion during recording and play-back due to permanent magnetism on the heads.

- To prevent the reduction of sound quality of a tape due to exposure to magnetic parts.

Rules for Demagnetizing:

1. Remove any tape from the machine and its vincinity

2. Switch off the power to the machine

3. Switch on the demagnetizing coil and move it slowly along all parts of the tape path.
Switch off the coil only after moving it some distance from the machine.

7.2. PLAY-BACK PART ALIGNMENT

7.2.1.PLAY-BACK LEVEL ALIGNMENT

The output of the tape machine must produce the standard studio level at the output with the standard flux level on the tape. For this purpose, all tape machines provide means for setting the output level.

For the adjustment of the output level a test tape with standard flux level is required.

Procedure:

1. Find the control for the output level on the play-back amplifier.
2. Connect a level meter to the output of the play-back amplifier.
3. If the machine has a control console; set the output level control to "Calibrated".
4. Select the section for level adjustment of the test tape (1kHz, 0dB) and switch the machine to play-back.
5. Adjust the output level at the output amplifier to achieve standard studio level at the output.
6. Repeat steps 1 to 5 for all channels.

In case the standard flux level of the test tape is different from the standard flux used in the broadcasting house, a correction factor must be considered during the output level adjustment.

The correction factor is calculated from the relationship:

$$\delta\ (db_r) = 20 \cdot \log \frac{\textit{Flux level of test tape}}{\textit{Standard flux required}}$$

The output level using the test tape is then adjusted to:

Output level with test tape (dB_u) = Standard studio level(dB_u) + δ

Example:

Standard studio level: +6db_u

Standard flux level required: 514pWb/mm

Flux level of test tape: 320pWb/mm

The correction factor is -4dB.
The output level using the test tape is to be adjusted to +2dB_u.

7.2.2. PLAY-BACK AZIMUTH ADJUSTMENT

This alignment is done using the 10kHz part for azimuth alignment of the test tape. For multi-speed machines, the alignment should be done at the lowest speed only.

Procedure:

1. Connect a level meter to the output of the tape machine.

2. Find the right screw to adjust the play-back head azimuth.
BE SURE NOT TO TURN ANY OTHER SCREW. Position the proper tool at the screw.

3. Run the test tape in play-back mode at the section for azimuth alignment.

4. Turn the screw left and right to find the maximum output level.

For multi-track and stereo machines, an additional fine alignment of the azimuth is needed for minimum phase difference between the channels. This requires additional steps of alignment:

5. Connect a two-channel scope to the outputs of each channels.
(For multi-track machines: to the output of the top-most and bottom-most track.)

6. Align the azimuth for minimum phase difference between the channels.

If the approximate head azimuth position is not known (e.g. after a head replacement), the above procedure can result in an azimuth setting to one of the side maxima of the sin(x)/x-curve. This would give a totally wrong setting of the azimuth. In these cases it is advisable to make a coarse azimuth adjustment first.

The coarse azimuth adjustment is done **at the 1kHz part** of the test tapes and follows the same steps 1 to 4 as described above.

7.2.3. PLAY-BACK EQUALIZATION ALIGNMENT

During this procedure the play-back equalizer is aligned to produce a linear frequency response on the standard flux curve of the test tape.

The test tape must have the same flux curve standard as used in the broadcasting house.

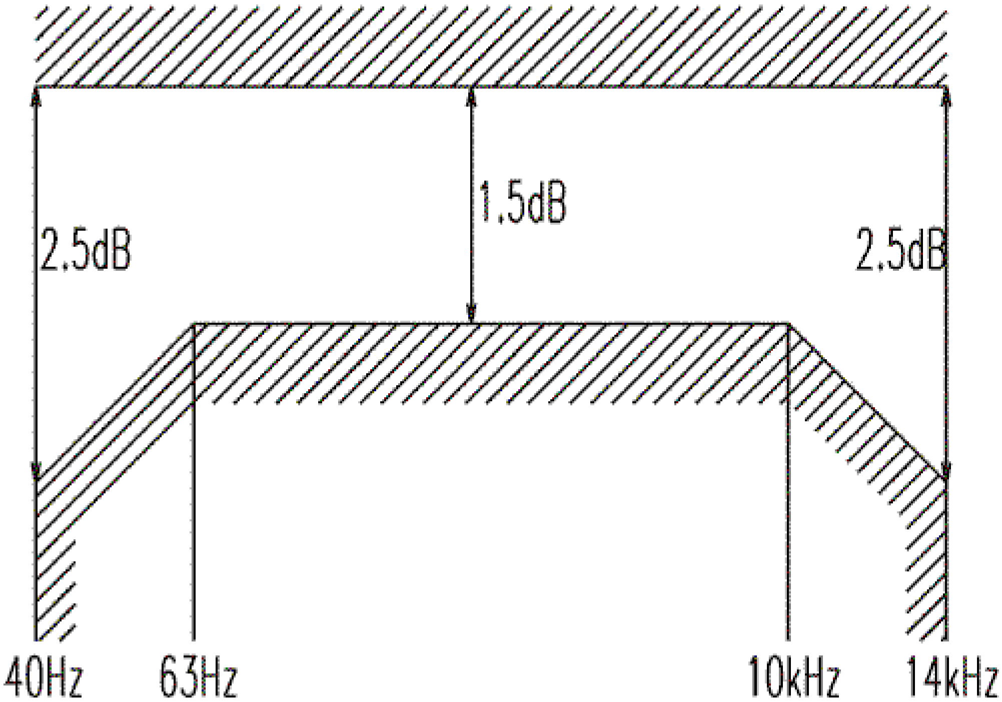
Most tape machines have controls (trim potentiometer) for low frequencies (bass) and for high frequencies (treble). Some have two separate trimmers for the high frequencies (e.g. M15A).

The test tape provides many test frequencies. It makes no sense to re-adjust the equalizer for every frequency. Instead it should be evaluated at which frequency (key frequency) the adjustment should be made to achieve a satisfactory frequency response.

Example:
It might be found that the bass-equalization is best adjusted at 125Hz and the treble-

equalization at 8kHz. All of the other test frequencies are then just used to check if the tolerance requirements are fulfilled.

Note:
If the frequency response is within the tolerances, don't change the equalizer settings. It makes no sense to try to adjust the machine better than its specifications.



Frequency response tolerance scheme for studio machines according to IEC-Standard.

Procedure:

1. Connect a level meter to the output of the play-back amplifier. Set the meter sensitivity to -20dB below standard studio level.

2. Select the section for frequency response alignment on the test tape and switch the machine to play-back.

3. Check the output level at the test frequencies. If necessary, adjust the equalization at the key frequencies which were found for this machine.

4. If changes were necessary, run the section for frequency response alignment of the test tape a second time and check the overall frequency response.

7.2.4. FINAL PLAY-BACK LEVEL ADJUSTMENT

As the equalizer adjustment might affect the output level, the output level has to be checked once again. Follow again the procedure of 7.2.1.

Note that the output level must be checked and adjusted at standard flux level. Therefore, only use the section for the level adjustment (1kHz, OdB) and not the 1kHz,-20dB test frequency of the frequency response part.

After this check, the play-back alignment is done. The test tape should be taken from the machine and should be stored in its box in a safe place.

7.3. RECORDING PART ALIGNMENTS

The recording side of the machine is aligned using the play-back side for reference. If the same quality is then achieved as with the test tape, the recorded signal on the tape will follow the standard given by the test tape.

During the adjustment of the recording side great care must be taken not to change any setting of the play-back amplifier.

Any accidental change to a control of the play-back part requires redoing this part of the play-back alignment.

All of the following tests and alignments are to be done with the type of tape normally in use. The tape should be in good condition.

7.3.1. RECORDING HEAD AZIMUTH ADJUSTMENT

The azimuth adjustment cannot be checked without making an alignment. For a multi-speed machine the alignment should be done at the lowest speed only.

Procedure:

1. Connect a level meter to the output of the tape machine.

2. Apply an input signal of 10kHz, -10dB to the input.

3. Find the right screw to adjust the recording head azimuth.
BE SURE NOT TO TURN ANY OTHER SCREW.
Position the proper tool at the screw.

4. Run the machine in recording mode.

5. Turn the screw SLOWLY left and right to find the maximum output level.

For multi-track and stereo machines an additional fine alignment of the azimuth is needed for minimum phase difference between the channels. This requires additional steps of alignment:

6. Connect a two-channel scope to the outputs of each channel.
(For multi-track machines: to the output of the top most and bottom most track.)
Apply the signal of the signal generator to the same input channel amplifiers.

7. Align the azimuth for minimum phase difference between the channels.

If the approximate head azimuth position is not known (e.g. after a head replacement), it may happen that the above procedure leads to an azimuth setting to one of the side maxima of the sinx/x-curve. This would lead to a totally wrong setting of the azimuth and will later not allow the level and the equalization to be adjusted. In these cases it is advisable to make a coarse azimuth adjustment first.

The coarse azimuth adjustment is done by applying 1kHz to the input and follows, except for that, the same steps 1 to 4 as described above.

7.3.2. BIAS ADJUSTMENT

As explained in 2.3., there are two methods to adjust the bias setting.

The bias adjustment cannot be checked without making an alignment.

Procedure A: 1kHz Method.

1. Apply 1kHz, -20dB to the input of the recording amplifier.

2. Turn the bias-adjustment screw SLOWLY left and right to find the maximum output level.
This is then the required bias setting.

3. Repeat steps 1 and 2 for all channels and tape speeds.

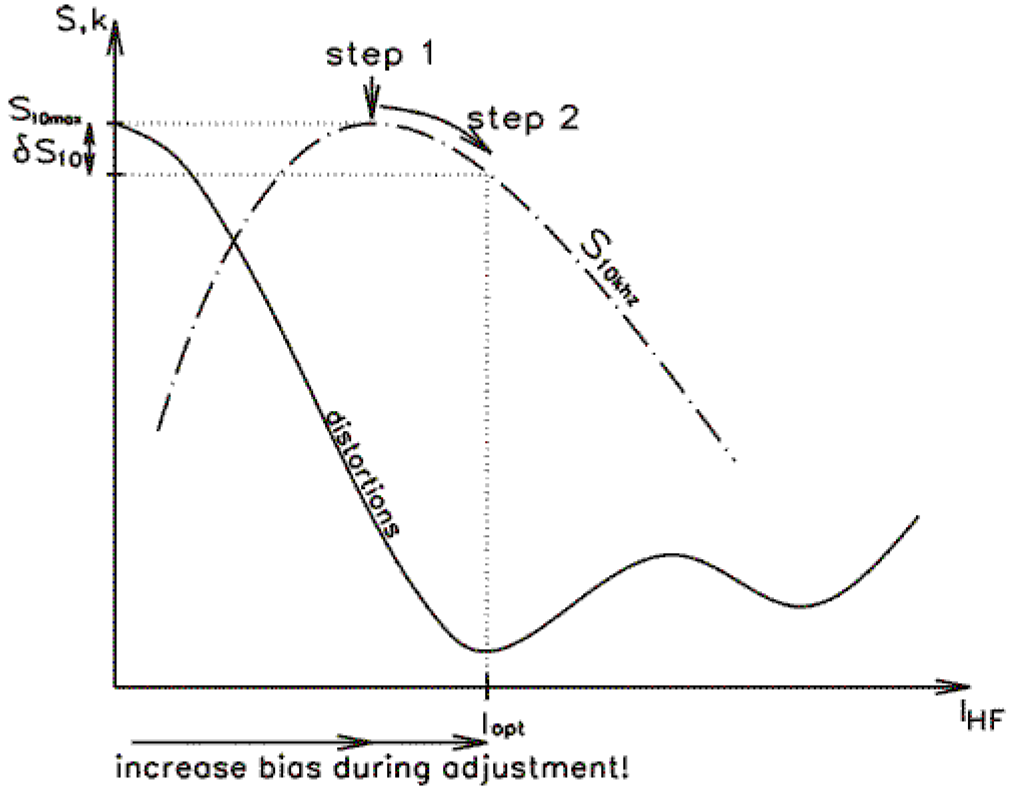
Procedure B: 1OkHz Method.

This method requires information of the level drop δS_{10} for the type of tape used and for the tape speeds.

1. Apply 10kHz, -20dB to the input of the recording amplifier.

2. Turn the bias-adjustment screw fully to low bias (counter- clock-wise).
Turn the bias-adjustment screw SLOWLY to increase the bias (clockwise). The output level will rise until a maximum S_{10max} is achieved.
Memorize the value of S_{10max}.
Further INCREASE THE BIAS CURRENT (clockwise) until the output level has dropped to S_{10max}-δS_{10}.
This is the correct setting of the bias level.

3. Repeat steps 1 and 2 for all channels and tape speeds.



A graphical representation of the bias level adjustment using the 10kHz method.

7.3.3. RECORDING LEVEL ADJUSTMENT

This adjustment ensures the correct standard tape flux of a recording on that machine.

Procedure:

1. Connect a level meter to the output of the play-back amplifier.

2. Apply a 1kHz signal at your standard studio level to the input of the recording amplifier.

3. If the machine has a control console: set the input level control to "Calibrated".

4. Adjust the level adjustment potentiometer at the recording amplifier to achieve standard studio level at the output.

5. Repeat steps 1 to 4 for all channels and tape speeds.

Note that during the recording level adjustment NO correction factor has to be considered as with the play-back level adjustment.

7.3.4. RECORDING EQUALIZATION ALIGNMENT

During this procedure the recording equalizer is aligned to produce a linear over-all frequency response. As the play-back equalizer was aligned before on the standard flux curve, this will ensure that the machine produces a standard flux curve during recording.

Most tape machines have controls (trim potentiometer) for low frequencies (bass) and for high frequencies (treble).

During the alignment, different test frequencies are applied **at -20dB** to the recording input.

It makes no sense to re-adjust the equalizer for all frequencies. Instead, it should be evaluated at which frequency (key frequency) the adjustment should be made to achieve a satisfactory frequency response.

E.g., it might be found that the bass-equalization is best adjusted at 125Hz and the treble-equalization at 8kHz. All of the other test frequencies are then just used to check if the tolerance requirements are fulfilled.

Procedure:

1. Connect a level meter to the output of the play-back amplifier.
Set the meter sensitivity to -20dB below standard studio level.

2. Connect an audio signal generator to the recording input of the tape machine. Set the input level to -20dB below standard studio level.

Attempting the recording equalizer adjustment with full studio level produces totally incorrect results.

3. Set the generator to 1kHz and check the output level. Then check the frequency response in steps towards the low frequencies and towards the high frequencies. If necessary, adjust the equalization at the key frequencies which were found for this machines.

4. If changes were necessary, run through the whole frequency range once again and check the overall frequency response.

7.3.5. FINAL RECORDING LEVEL ADJUSTMENT

Because the equalizer adjustment might affect the output level, the output level has to be checked once again. Follow again the procedure in 7.3.3.

7.4. FINAL SOUND QUALITY TESTS

The following measurements are made to ensure that the previous alignments were successful. They are purely a test and are not associated with any further alignment.

7.4.1. DISTORTION MEASUREMENT

This measurement is done with a test frequency of 1kHz (sometimes 315Hz or 400Hz) at full studio level. The result should meet the requirement of the manual for that machine. In practice values between 0.3% and 1% can be achieved.
A measurement giving bad values could be due to the following reason(s):

- Wrong bias setting,

- Machine not properly de-magnetized,

- Recording and play-back level mis-aligned, so that the tape is over-modulated.

7.4.2.NOISE MEASUREMENT

With no input level applied, the output level is measured using a CCIR weighting filter. The result should meet the requirement of the manual for that machine. In practice, values of more than 50dB below studio level should be achieved.
A measurement giving bad values could be due to the following reason(s):

- Machine not properly de-magnetized,

- Recording and play-back level mis-aligned, so that the tape is operated at a low flux level.

7.4.3. WOW AND FLUTTER MEASUREMENT

This measurement gives a information about the **mechanical condition** of the machine. It should be done with a suitable Wow and Flutter meter which allows a weighted measurement. The result should meet the requirement of the manual for that machine. In practice, values of less than 0.2% can be expected.
A measurement giving bad values could be due to the following reason(s):

- Capstan, pinch roller and tape guides were not properly cleaned,

- The tape tensions are not properly adjusted,

- The pinch roller pressure is not properly adjusted,

- Problems with the capstan bearing or capstan motor bearing,

- Not properly adjusted tacho system.

- Defective capstan servo control.

7.5. SPECIAL ALIGNMENTS

The following alignments and tests are **not standard alignments**.
They may become necessary after the heads have been replaced or disassembled.

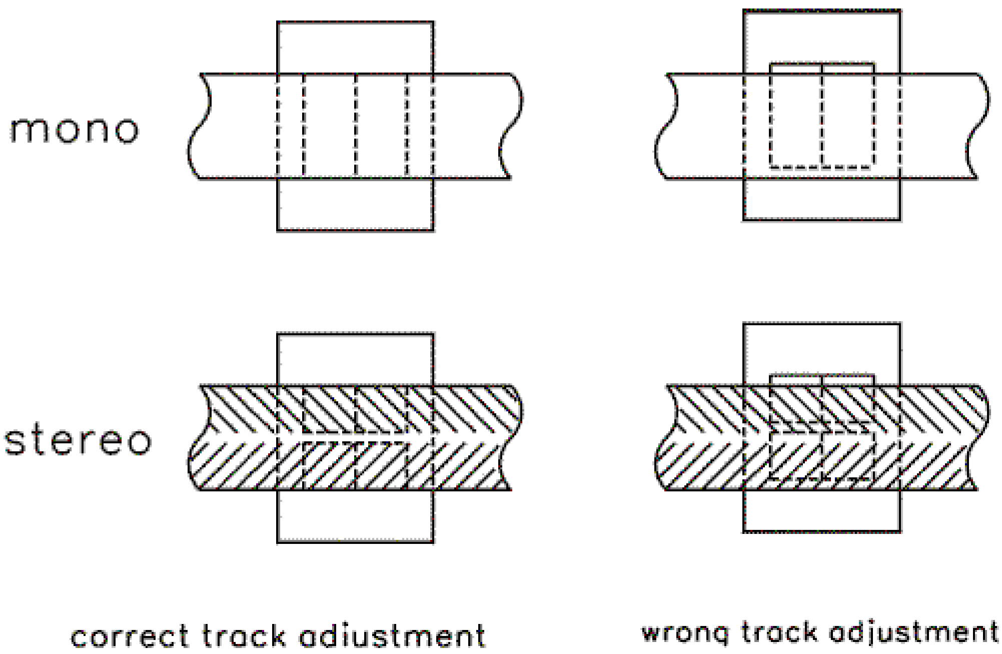
Any adjustment should only be made if it is really required.

7.5.1. TRACK ALIGNMENT

This alignment ensures that the heads are in the right height in respect to the tape. The tape position is fixed by the tape guides.

If the head was replaced, adjust the head's position; if the tape guides were replaced, adjust the tape guide's position.

The track alignment is especially critical in two-track and in stereo machines. It will influence the cross-talk between the channels.



Effect of wrong track alignment.

There are special test tapes available which allow the track alignment. If these are not available, visual checks may be sufficient.

Procedure:

1. Run the tape in play-back mode.

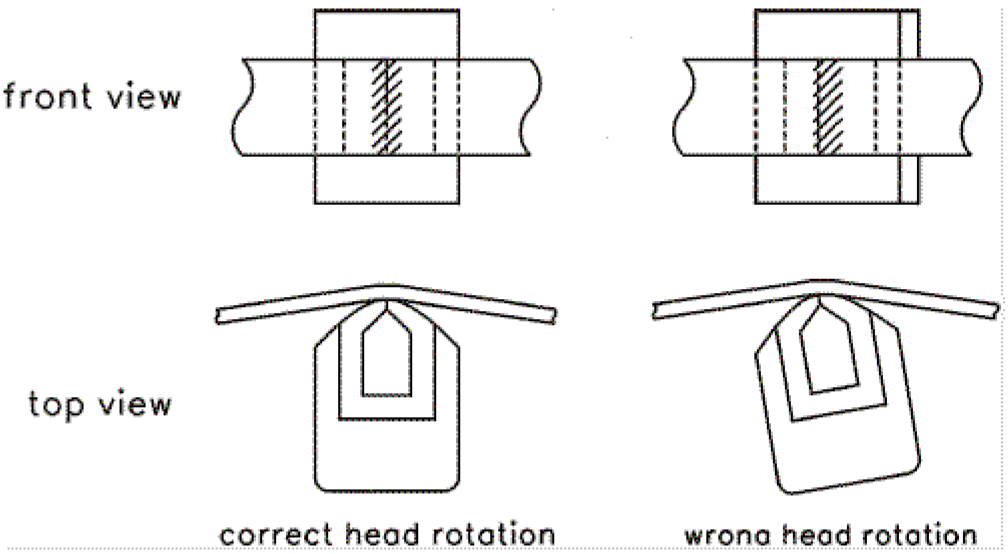
2. Observe the head surface.
The tape should precicely cover the core area of the head.

3. Adjust the head position only if the tracking is not correct.

7.5.2. HEAD ROTATION ALIGNMENT

This alignment ensures that the tape has good contact with the head gap. Wrong head rotation results in a poor frequency response of the tape machine.

Some tape machines have fixed head rotation position and do not allow and require such alignment.



Effect of wrong head rotation alignment.

Procedure:

1. Color the head surface with a suitable grease pen.

2. Run the tape for several seconds.

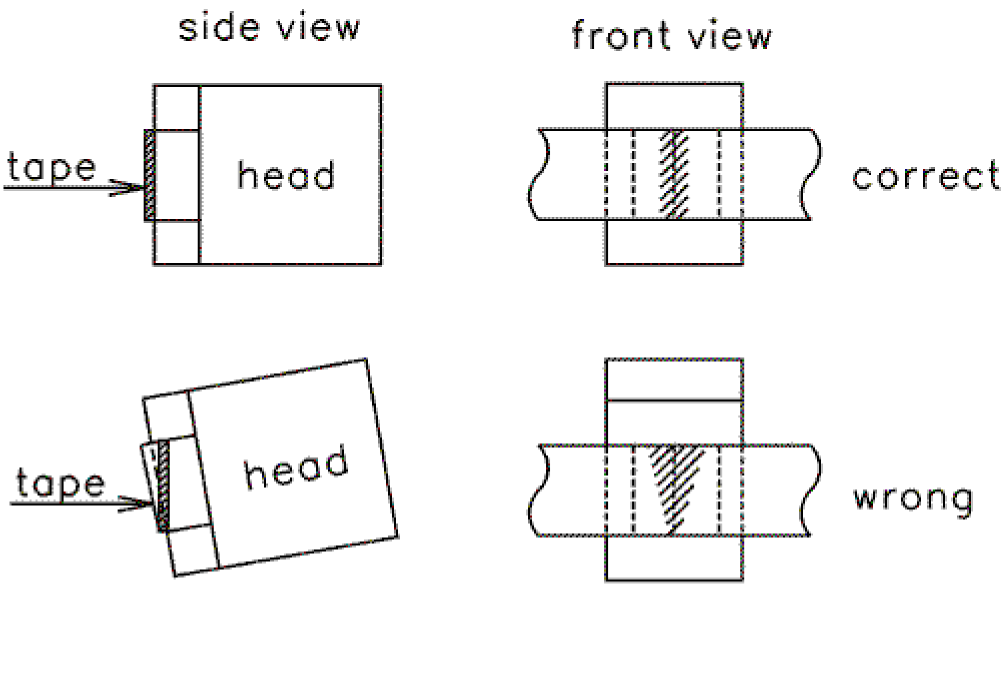
3. Remove the tape and observe the area which was wiped by the tape on the head surface. The gap should be in the centre of the area. If not, rotate the head and repeat the test.

It might be necessary to try the test several times if it does not produce clear results.

7.5.3. HEAD TILT ALIGNMENT

The correct head tilt ensures that the head surface is parallel to the tape guides. This is necessary to have good tape contact over the whole length of the head gap and for all tracks. Wrong head tilt results in a poor frequency response of the tape machine.

Some tape machines have fixed head tilt positions and do not allow and require such alignment.



Effect of wrong head tilt position.

Procedure:

1. Color the head surface with a suitable grease pen.

2. Run the tape for several seconds.

3. Remove the tape and observe the area which was wiped by the tape on the head surface. The area should be equally wide at the top and at the bottom. If not, correct the head position and repeat the test.

It might be necessary to try the test several times if it does not produce clear results.