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Understanding Magnetic Tape Specifications—Part I

An overview of magnetic tape operation and "spec" terminology

THE TYPICAL STUDIO ENGINEER is a skilled professional who relies on his "golden ear" to transfer one medium to another. Although he is probably well-trained and skilled in the practical operation of recording and reproduction equipment, he may have but a surface knowledge of the true "physics" of the recording process. His skill with the equipment comes through verbal instructions, day-to-day experiences, and the few facts that can be coaxed from equipment manuals. This surface knowledge may be sufficient for the basic operations of the studio, but with a little further insight into the inter-relationship between tape and machine, the engineer can, without too much trouble, no doubt make a much better recording.

COPING WITH "SPECS"

The recording or broadcast engineer may look at the specifications of a certain device, understand perhaps three-out-

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of-ten pieces of data, and then make a decision based on a limited grasp of the information presented. All too many times, people choose one product over another for a totally non-technical reason, which in the end may lead to disaster, or at least, a little discomfort.

One of the most blatant trouble spots is tape selection and usage. With this particular software, some of the most horrendous double-talk is found, and the least amount of facts are readily available. The problem seems to lie in testing methods, and the interpretation of data by various manufacturers. Each company has its own standards, references, and methods of determining electro-acoustic and other data.

The first part of this article will deal with the technical terms and definitions found in most specification sheets for audio tape software. It is the intent to help prepare the engineer for the deluge of facts (and fables) he will uncover when trying to decipher a data sheet on magnetic tape.

MAGNETIC TAPE PRODUCTION

Let's begin with a brief discussion of what comprises magnetic tape. First, there is the base material, usually made out of polyester. Polyester is commonly supplied in 26-inch-wide rolls, which are many thousands of feet in length. This base material is then coated with a solution called "slurry"—a suspension of a solid (oxide particles) in a liquid. The slurry contains billions of tiny particles of iron oxide, plus solvents and binder products. It is coated onto the base material extremely smoothly, and with precise tolerances for thickness. Before the slurry dries, a strong magnetic field orients the oxide particles in the same physical direction.

Next, the combination of base material-plus-coating is immediately passed through a dryer, and then proceeds through a calendering process, in which highly-polished rollers polish the tape so that it has a beautifully-smooth surface sheen.

THE PHYSICS OF MAGNETISM

In order to understand the facts, figures, curves and graphs found on a magnetic tape specification sheet, it is necessary to have a fundamental understanding of the physics of magnetism and the recording process.

To produce sound, movement of some kind is required. And, to alter a magnetic field, again one needs movement. The entire science of tape recording is based on alternating magnetic fields. To help visualize these alternating fields, think of a magnet having a north (positive) pole and a south (negative) pole. Then, imagine these poles reversing their polarity at varying speeds. You end up with a series of alternating positives and negatives; some changing quickly—others slowly.

The faster the poles change polarity, the higher the frequency. The slower the changes, the lower the frequency. Visually, a sine wave illustrates the changing polarity over a period of time. The sine wave shows an alternating current, with a positive polarization followed shortly by a negative polarization. As mentioned earlier, the speed at which the polarization changes determines the frequency.

If we wrap a coil of wire around a changing magnetic field, an electric current is induced within the coil. This current can be amplified, so that an audio reproduction of the alternating magnetic field is heard. Or, if an alternating electric current is passed through a coil of wire wrapped around an iron bar, the opposite effect occurs; a magnetic field is produced.

TAPE HEADS AND MAGNETS

In reality, the heads on a tape machine are simply two C-shaped pieces of hard metal, with a coil wrapped around the

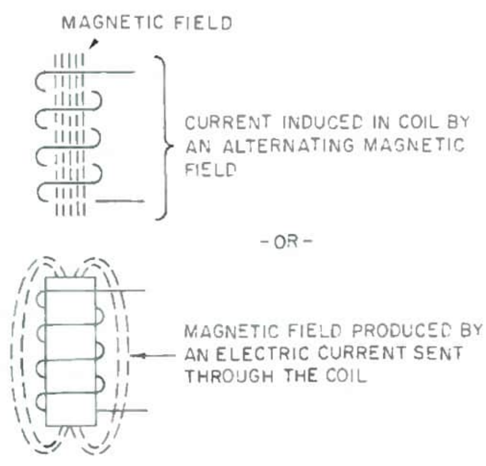


Figure 1. The physics of magnetism.

rear. The front section of the head has a tiny gap between the two C-shaped halves. This is the record, or playback, gap.

Recording heads also have another gap in the rear, approximately ten-times wider than the front gap. The reason for this rear gap is to help prevent the magnetic saturation of the head. However, this rear gap would result in too-low a sensitivity for optimum playback head performance, so these heads have a front gap only.

When the coil is energized with an alternating electric current, a magnetic field is generated within the metal of the head. Magnetic lines of force, or "flux lines" pass through the head, and across the head gap. Without tape, the magnetic flux has its maximum strength between the two poles of the gap. However, if a tape is present at the gap, the field lines will "detour" through the tape, because the oxide coating offers less magnetic resistance than does the air gap of the head.

When the magnetic tape, filled with tiny particles of iron oxide, passes across the head gap, the magnetization of the particles becomes fixed as they leave the magnetic field in front of the gap. But contrary to popular belief, the oxide particles do not actually move, since they have been permanently locked in position by the binder material. They merely receive a magnetic charge from the gap (either plus or minus), depending upon the moment that they leave the head gap area.

Playback is, for the most part, the reverse process, in which the oxide particles on the tape—which are now tiny magnets—pass across the playback gap and induce a magnetic field within the head that generates an electric current in the coil, which is then amplified.

COERCIVITY AND RETENTIVITY

When one speaks of magnetic tape, coercivity and retentivity are two frequently-heard terms. Coercivity, measured in oersteds (Oe) is the amount of magnetism necessary to change the magnetic charge of a given particle. Retentivity, measured in gauss (G), is the amount of magnetic flux that remains on the tape after the magnetic field is removed. Coercivity and retentivity are proportional to the particular oxide material and the size of the particle.

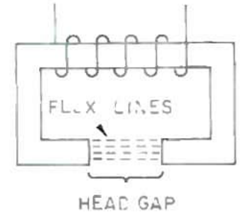
THE HYSTERESIS LOOP

The so-called hysteresis loop may be used to better illustrate the relationship between coercivity and retentivity. In FIGURE 3, an increasing magnetic field has brought the tape to positive saturation. As the field collapses, the tape loses some of its magnetization, but retains the amount shown as B_r, when the field is reduced to zero. This is the tape's retentivity.

Now, as the field strength increases in the opposite direction, the tape is eventually demagnetized. The field strength required is shown by H_c. This is the coercivity of the tape. Further increasing the field strength eventually brings the tape to negative saturation.

The general shape of the hysteresis loop is an indication of the performance of a magnetic tape—the "squarer" the loop, the better the tape.

Figure 2. A record head. The flux lines across the head gap will bend to flow through a tape passing by the gap.



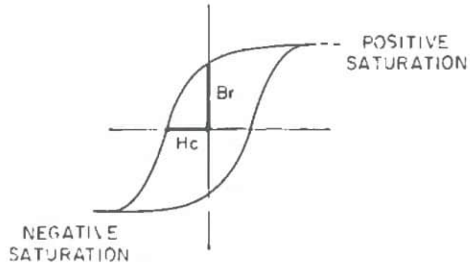


Figure 3. The hysteresis loop.

IMPROVING COERCIVITY AND RETENTIVITY

"Doping" is the insertion of the element cobalt into the iron-oxide crystal structure. The result is a tape with a higher coercivity and, usually, a slightly-higher retentivity. However, there is an important drawback to cobalt-doped tapes. Compared to iron oxide, the cobalt is more-easily affected by temperature variations and mechanical stress. Therefore, if cobalt-doped tape is left in a heated environment, or placed under great physical stress, the results will be a tape with loss of level.

So as usual, "all that glitters is not gold." At this time, the only other known method to increase the coercivity of a tape is to use pure metal particles instead of an oxide. Pure metal powder may have a coercivity of up to 1500 oersteds, yielding approximately 3000 gauss. Tapes made with metal-powder particles have an extremely-high signal-to-noise ratio, and good high frequency characteristics.

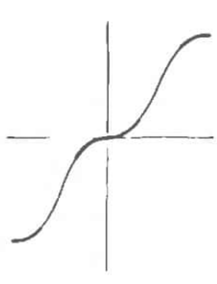
Metal tapes are hard to coat, due to the fact that pure metal powder is pyrophoric (capable of igniting spontaneously in air—Ed.). Therefore, the material is extremely dangerous to work with in its raw state. At the moment, metal-particle tapes are still quite expensive.

Another drawback to metal-particle tapes is that, in order to cope with the extremely-high coercivity, one must use special heads and bias oscillators. (The higher coercivity particles require a greater magnetic field in order to record or erase the tape.) This too becomes very costly, and presents compatibility problems when metal-particle and standard-oxide tapes are to be used interchangeably.

ACHIEVING LINEAR RESPONSE

The closer a particle is to yielding a linear response, the better the particle is for magnetic sound reproduction. But so far, all magnetic substances are still quite non-linear. FIGURE 4 shows the transfer characteristic, or remanence curve, of a magnetic tape. Note the non-linear segments at both extremes, and in the center region. Early recording efforts were hampered by these non-linear segments, which caused distortion at low and high recorded levels.

Figure 4.
The remanence curve shows the transfer characteristic of a magnetic tape. The heavy line segments indicate the non-linear portions of the transfer characteristic.



BIAS

Eventually, it was realized that the addition of a d.c.bias current would shift the applied audio signal into one or the other of the linear portions of the transfer characteristic. The result was somewhat less distortion. This was better, but still not quite the answer. Later, it was determined that by using a high frequency bias current, distortion could be greatly reduced, even at higher levels. This is due to the fact that d.c. magnetization only utilized one-half of the remanence curve, whereas a.c. bias affected both the upper and lower segments. The a.c. bias current is of course many times higher in frequency than the highest audio frequencies, and enables the engineer to record at much higher levels with much lower distortion.

DISTORTION VERSUS BIAS

Distortion is the addition of harmonics of an applied frequency. Because of its prominence, the third harmonic is most disturbing to the ear. Therefore, unless otherwise specified, distortion measurements usually refer to third-harmonic distortion (thd).

Symmetrical curves, like the hysteresis loop of magnetic tape, and the curves of push-pull electronics, produce odd-numbered harmonics. Non-symmetrical curves, such as those of class-A and single-stage amplifiers, produce even-numbered harmonics. Since magnetic tape does have a symmetrical curve (as mentioned previously), odd-harmonics are the ones produced. However, any harmonics above the third are usually insignificant, and therefore not measured.

Bias minimizes distortion, by moving the applied audio signal away from the knee (center section) of the remanence curve, into the more-linear segments of the curve. This is shown

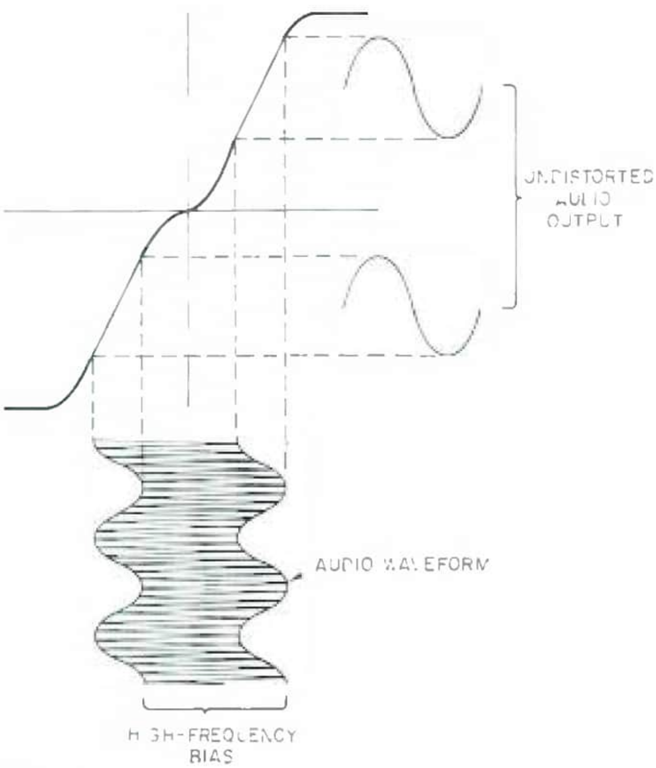


Figure 5.
A.C. bias moves the applied audio signal away from the non-linear portions of the transfer characteristic.

in FIGURE 5, where the bias-plus-audio is shown on the Y axis, and the audio-only is seen on the X axis.

The bias frequency is so high that during playback it is not reproduced, due to the limitations of the playback head.

OPTIMUM BIAS LEVEL

The question may now arise; How much bias current is required? This depends on the chemical makeup of the tape, and is determined by the manufacturer. Two important parameters help decide the best bias setting. These are: frequency response and low-frequency distortion. Another consideration may be compatibility with other tapes, so that the user need not constantly re-adjust his tape recorder for every different tape that he is called upon to use. The amount of bias is also dependent on the coating thickness and coercivity of the tape. The thicker the coating, and higher the coercivity, the greater the magnetic field necessary to penetrate the coating. Therefore, the greater will be the amount of bias current that is required.

It is well-known that, as one increases the amount of bias from zero, the output of the tape increases. Then, if the bias continues to increase, after the peak-output point, the high-end response begins to fall off. At the same time the high end is decreasing, the low-end distortion is also decreasing. And now we have a conflict-of-interest. One wants a beautiful high-end response, *and* low, low-end distortion. Therefore, there must be a compromise as to the amount of bias used, especially at lower tape speeds.

Another factor—coating thickness—also brings with it a conflict-of-interest. A thicker coating will yield a greater low-end response, and a thinner coating (requiring less bias) will yield a better high-end response. The thick coating yields a better low-end response because a low frequency has a longer wavelength. Therefore, the entire coating is used in playback for lower frequencies, whereas only the outer layer of the coating is used for playback of the higher frequencies, due to the shortness of the wavelength. The following formula illustrates the coating-thickness phenomenon;

$$DA = 54 \times \frac{A}{\lambda}$$

DA = Damping factor, in dB
A = Distance between magnetic particle and playback head.
λ = Wavelength.

Example: The lower part of a coating has a ten-micron distance from the reproduce head. The wavelength of an applied audio signal is 38 microns. Compared to the surface of the tape, what is the attenuation of a signal from this area of the tape?

$$DA = 54 \times \frac{10}{38} = 14.2 \text{ dB}$$

To review, we can say that the factors which determine bias setting of a given tape are:

1. coating thickness.
2. coercivity.
3. high-end frequency response.
4. low-end distortion.
5. bias compatibility and record equalization.

MODULATION NOISE

Still another factor is modulation noise. This type of noise occurs from coating inhomogeneity and transversal vibration of the tape as it passes the head gap, causing extraneous noise while the tape is being recorded. It happens as an interaction between head and tape, resulting in mechanical oscillations, especially noticeable on low frequencies.

Agglomerations, as well as shortages, of particles accentuate modulation noise, as these areas pass across the head. The amount of bias also affects modulation noise, or, to put it another way, modulation noise varies with bias setting. Luckily, modulation noise usually follows the curve of low-end distortion. Therefore, if the bias is set properly for low-end distortion, then it is also set properly for modulation noise.

OUTPUT LEVEL VERSUS HEAD GAP

Head gap has been mentioned before, but needs some further comment here, since it too can greatly affect the output level from the playback head. In playback, the narrower the head gap, the better the high frequency response, because the head gap must be less than one-half as wide as the shortest wavelength it is to play back. When the head gap dimension equals a given wavelength, and that wavelength passes before the head, there will be no flux change. If there is no flux change, there is no current induced in the winding—hence, no sound.

Therefore, an extremely-narrow gap is necessary to reproduce those very high frequencies, especially at slower speeds. As far as the record gap is concerned, a wider gap permits a greater penetration of the magnetic field into the tape, and a somewhat lower modulation noise.

Most older studio recorders had a record gap of about 20 microns (0.8 mil) and a playback gap of 5 microns (0.2 mil). Modern multi-track machines, which use the record head simultaneously as a playback head, may have a record gap of 5 to 8 microns, while the regular playback head has a gap width of about 3 microns.

MAXIMUM OUTPUT LEVEL

The maximum output level curves for 3 per cent and for 1 per cent thd reach their maximum at the bias setting where the minimum thd (at some fixed output level) occurs. If the maximum output level at 3 per cent thd reaches a maximum and then drops more than 1 dB without rising again, one can rest assured that the record head is saturated by bias and record current, and what you are in reality measuring is the distortion of the head.

The curve for maximum output level at 1 per cent thd must follow the thd curve at the reference level. In other words, when the thd at reference level is at a minimum, maximum output level at 1 per cent thd is at its maximum.

Part II of this article will be based on the information presented above. So before continuing, the reader should make sure he thoroughly understands what has been covered so far. ■

(To be continued next month)