Chapter

8.1

Properties of Magnetic Materials

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8.1.1 Introduction

The performance of a magnetic tape recorder depends heavily on the properties of the magnetic materials used to make the recording heads and tapes. Today's magnetic materials are the product of sophisticated metallurgy and advanced manufacturing techniques, which in large measure are responsible for the advancement of magnetic recording technology.

Magnetic materials are classified as either magnetically *hard* or magnetically *soft.* Both types are used in magnetic tape recorders.

The hard magnetic materials are so-called because of their ability to retain magnetism after being exposed to a magnetic field. The measure of this property is called *remanence.* These materials may be further characterized by high coercivity and low permeability. *Coercivity* is the resistance of the material to being magnetized or demagnetized. *Permeability* is a measure of the magnetic conductivity relative to air.

In magnetic recording, hard magnetic materials are used chiefly in the manufacturing of recording tape and other related media. Some examples are gamma ferric oxide (γ-ferric oxide), iron oxide, and chromium dioxide. Hard materials are also used to make permanent magnets for use in loudspeakers, electric motors, and other applications.

On the other hand, soft magnetic materials such as Alfesil, hot-pressed ferrite, and Permalloy exhibit low coercivity, low remanence, and relatively high permeability. These materials are used to make cores for magnetic heads.

Ferromagnetic materials have permeabilities much greater than unity and show a strong magnetic effect. Ferromagnetism is exhibited mostly by metallic elements such as iron, cobalt, nickel, and magnetic metals that are alloys of these elements. With the exception of ferrites [1, 2], most magnetic materials used in tape recorders are ferromagnetic.

Paramagnetic substances have permeabilities that lie between 1.000 and 1.001. These materials do not show *hysteresis*, and their permeabilities are independent of field strength. Some examples of paramagnetic materials are sodium, potassium, oxygen, platinum, and ferromagnetic metals above the *Curie temperature* [1].

Diamagnetic materials have a relative permeability slightly less than 1. Many of the metals and most nonmetals are diamagnetic [1].

Magnetic anisotropy is the term applied to magnetic materials that exhibit preferred directions of magnetization. These preferred and nonpreferred directions are referred to as the *easy* and *hard* axes of magnetization, respectively. The higher the magnetic anisotropy, the harder it is to change the magnetization away from the preferred direction. In most polycrystalline materials, the crystals are randomly oriented and are magnetically isotropic. Single crystal ferrites and magnetic particles used in tape coating are examples of magnetic materials that are anisotropic [1, 3].

Table 8.1.1 shows properties of materials commonly used in magnetic heads and tapes. Throughout this chapter CGS units are used. Conversion factors to change to MKSA (or SI) units are given in Table 8.1.2.

8.1.2 Basic Principles of Magnetism

Magnetism results from two sources: orbital motion of electrons around the nucleus and the spinning of the electrons on their own axes (see Figure 8.1.1). Both the orbital and spin motions contribute to the *magnetic moment* of the atom, although in most magnetic substances almost all the magnetic moment is due to the spin motion. As the electron spins on its axis, the charge on its surface moves in a circular pattern. This moving charge, in turn, produces a current that creates a magnetic field. This phenomenon occurs in all substances. However, the electrons of the atoms in nonmagnetic materials occur in pairs with the spins in opposite directions, balancing each other and rendering the atom magnetically neutral. The atoms can produce the external effect of a magnet only when the electron spins are unbalanced.

The iron atom, for example, has 26 electrons in rotation around its nucleus (Figure 8.1.1). These orbiting electrons occur in regions called *shells.* According to quantum theory, the maximum number of electrons that can exist in each shell is $2N^2$, where N is the number of the shell. Starting from the nucleus, the first, second, third, and fourth shells could have a maximum number of 2, 8, 18, and 32, respectively. The maximum number of electrons in each shell may not be reached before the next shell begins to form. The iron atom actually has two electrons in the first shell, the second has eight, the third and fourth shells have fourteen and two, respectively. The plus and minus signs show the direction of the electron spins. The electron spins in the first, second, and fourth shells balance each other, and produce no magnetic effect. It is the third shell that is of particular interest in the iron atom. In this shell there are five electrons with positive spins and one with a negative spin, which gives the atom a net magnetic effect.

Thermal agitation energy, even at low temperatures, would prevent the atomic magnets from being aligned sufficiently to produce a magnetic effect. However, powerful forces hold the electron spins in tight parallel alignment against the disordering effect of thermal energy. These forces are called *exchange forces.*

The parallel alignment of the electron spins, due to the exchange forces, occurs over large regions containing a great number of atoms. These regions are called *domains.* Each domain is magnetized to saturation by the aligned electron spins. Because this magnetization occurs with no external field applied, it is referred to as *spontaneous magnetization.* When the magnetic material is in the demagnetized state, the direction of the magnetization of the saturated domains is distributed in a random order, bringing the net magnetization of the material to zero. The domains are separated from each other by partitions called *Bloch walls* [1, 3]. The domain wall pattern is determined by the strains within the material and its composition.

In soft magnetic materials the magnetization takes place by the displacement of the domain walls [1, 3]. The wall movement is not continuous but occurs in discrete steps called *Barkhausen*

Table 8.1.1 Properties of Soft and Hard Magnetic Materials

Material	M_s, G	$B_s = 4\pi M_s$, G	H_c, O	B_r, G	μ (dc) initial	Resistivity, $\Omega \cdot cm$	Thermal expn.	Curie temp.	Vickers hardness
				Soft magnetic materials					
Iron Fe	1700	21,362	1	......	20,000				
Hi-Mu 80 80% Ni, 20% Fe	661	8,300	0.02	......	50,000	65	12.9×10^{-6} cm/(cm°C)	733 °C	127
Alfesil (Sendust) 85% Fe, 6% Al, 9% Si	796	10,000	0.06	......	10,000	90	11.3×10^{-6} cm/(cm°C)	773 °C	496
Mn Zn, Hot-pressed ferrite	358	4,500	0.02–0.2	≈900	2000–5000	10^4	$10–15 \times 10^{-6}$ cm/(cm°C)	100–300 °C	650–750
Ni Zn, Hot-pressed ferrite	238	3,000	0.15–3	≈1800	100–2000	10^{10}	$7–9 \times 10^{-6}$ cm/(cm°C)	150–200 °C	700–750
				Hard magnetic materials					
				Squareness ratio					
γ-Ferric oxide	400	5,026	300–350	1300†	0.75†				
Chromium dioxide	470	6,000	300–700	1600†	0.9†				
Metal particles	800	10,000	1000	3500†	0.8†				

†Value typical for finished tape.

Table 8.1.2 Conversion Factors from CGS to MKSA or SI Units

Parameter	CGS units†	Multiply by	To obtain MKSA or SI units†
Flux Φ	Maxwell	10^{-8}	Webers (Wb)
Flux density B	Gauss	10^{-4}	Webers/meter^2 = 1 tesla (T)
Magnetization M	Gauss (1 gauss = 1 emu/cm^3)	10^3	Ampere turns/meter (At/m)
Permeability μ_0 of free space	1	$4\pi \times 10^{-7}$	Henry/meter (H/m)
Magnetomotive force F	Gilbert	$\frac{1}{0.4\pi}$	Ampere turns (At)
Field H (magnetomotive force per unit length)	Oersted	$\frac{10^3}{4\pi}$	Ampere turns/meter (At/m)

†Unit system abbreviations: CGS (centimeter-gram-second), MKSA (meter-kilogram-second-ampere), and SI (International System).

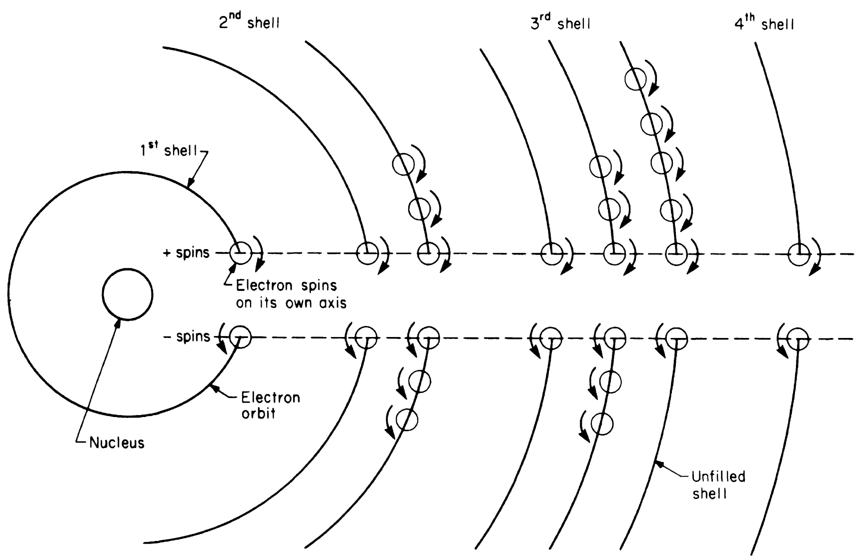

Figure 8.1.1 Schematic diagram of an iron atom.

steps or *jumps* that are related to imperfections or inclusions in the crystalline structure of the material.

The particles used in magnetic tape coating are so small that Bloch walls do not form. They behave as single-domain particles that are spontaneously magnetized to saturation. Irreversible magnetization is achieved only through irreversible rotation of the individual particle magnetizations [4, 5].

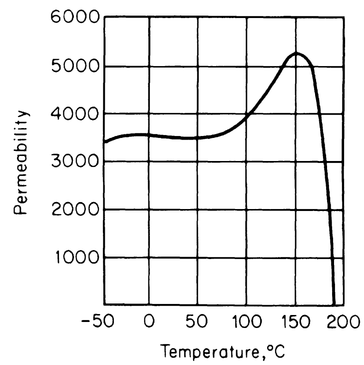

Figure 8.1.2 Effect of temperature on the permeability of typical ferrite.

8.1.2a Curie Point

The Curie point is the temperature at which the thermal agitation energy overcomes the exchange forces. The spontaneous magnetization disappears and the material is rendered nonmagnetic. This process is reversible; when the temperature is lowered below the Curie point, the spontaneous magnetization returns and the material is again magnetic. Figure 8.1.2 shows the effect of temperature on the permeability of a typical ferrite.

8.1.2b Magnetic Induction

When a current I is connected to a solenoid coil of N turns, a magnetic field H is created that has direction as well as strength, and is defined by

$$H = \frac{0.4\pi N I}{l} \tag{8.1.1}$$

Where:
H = magnetic field in oersteds
l = length of the solenoid in centimeters
I = current in amperes

As a result of the field H, flux lines are produced in the surrounding space (see Figure 8.1.3). The flux lines form closed loops that flow from one end of the solenoid coil, into the air, and reenter the coil at the opposite end. The measure of the intensity or the concentration of the flux lines per unit area is called the *flux density*, or the *induction B*.

Figure 8.1.3*a* shows that with no magnetic material present in the solenoid coil the flux density B is relatively low and is equal to the applied field H. When a piece of magnetic material is placed in the solenoid coil, the flux density is increased (Figure 8.1.3*b*). This results from the magnetic moments of the electron spins aligning themselves with the applied field H, causing the magnetic material to become a magnet [1, 6]. The sum of the magnetic moments per unit volume is the magnetization M. The magnetization of a material creates magnetic fields. Inside the

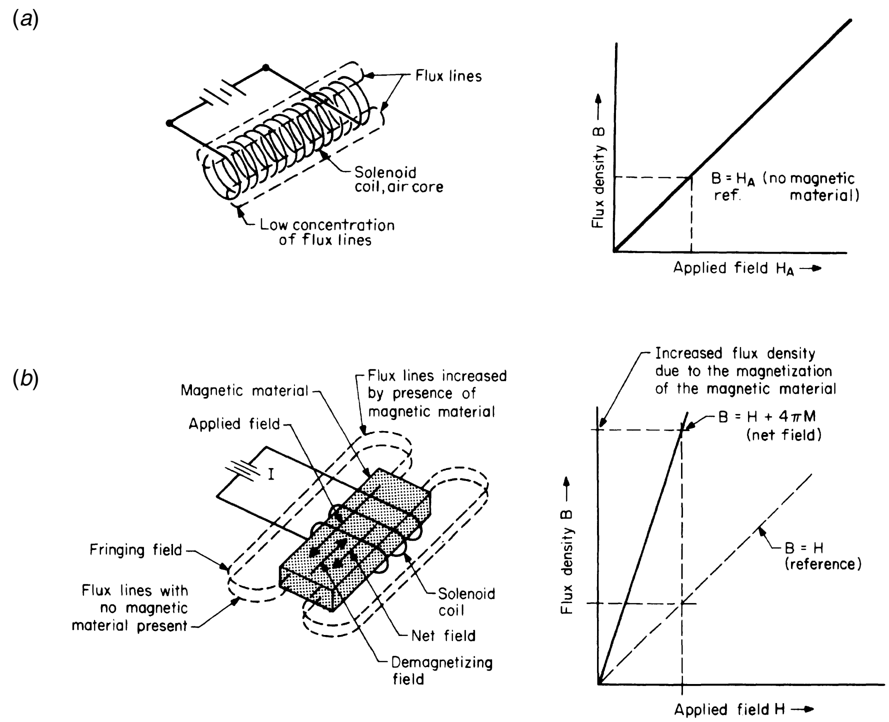

Figure 8.1.3 Properties of flux increase: (*a*) air core, (*b*) magnetic core material.

material these fields are called *demagnetization fields* because they oppose the magnetization. Outside the material, they are called *stray* or *fringing fields*. The net field acting on the material is the vectorial sum of the demagnetization field and the applied field. The flux density is the net field plus the magnetization M, that is

$$B = H + 4\pi M \tag{8.1.2}$$

where H = net field, and M and B are in gauss.

Initial Magnetization *B-H* Curve

The relationship of the induced flux density B and the net field H of soft magnetic material is typically described by the initial B-H magnetization curves and the B-H hysteresis loop.

Figure 8.1.4*a* shows the initial magnetization curve of a typical soft magnetic material. This curve is obtained by starting with a toroid ring in the demagnetized state and plotting the flux density B against the field H. The demagnetization field in a toroid ring is zero; the net field is

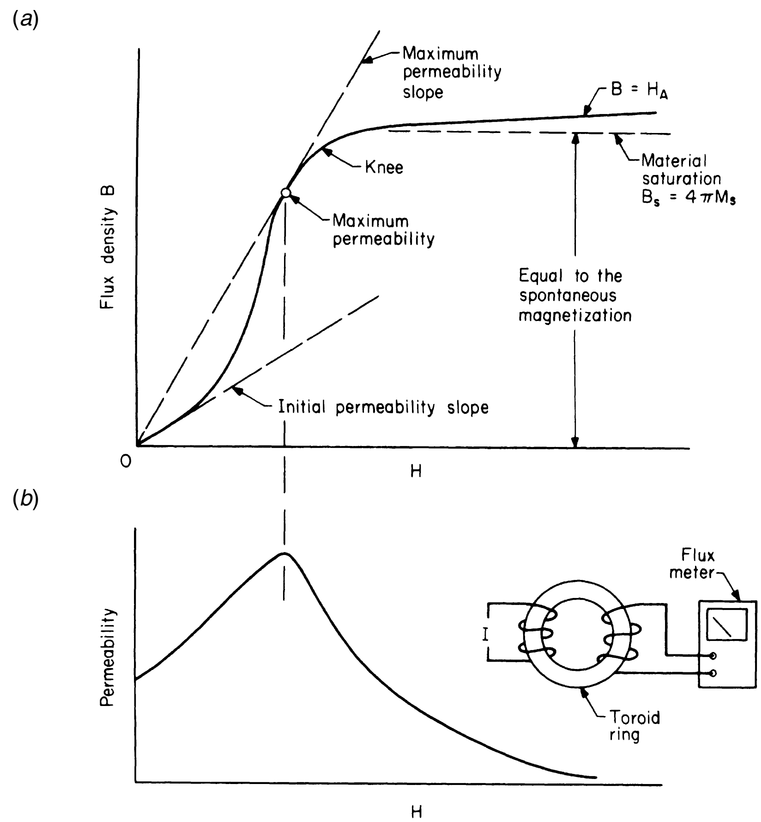

Figure 8.1.4 Permeability effects: (*a*) initial *B-H* curve, (*b*) permeability versus *H* field.

therefore equal to the applied field. The slope of the initial magnetization curve is the permeability μ, defined by

$$\mu = \frac{B}{H} \tag{8.1.3}$$

In CGS units, the permeability is a dimensionless ratio and represents the increase in flux density relative to air caused by the presence of the magnetic material. The permeability can also be defined in terms of the magnetization *M* as

$$\mu = 1 + \frac{4\pi M}{H} \tag{8.1.4}$$

Starting at the origin, the curve has a finite slope which is the initial permeability. As the field H is increased, the slope becomes steeper; this is the maximum *permeability region*. The value of the maximum permeability is determined with a straight line of the steepest slope that passes through the origin and also contacts the magnetization curve. Finally, as H is further increased, a point is reached on the initial B-H curve where the magnetization approaches a finite limit indicated by the dotted line. At this point, the magnetization of the material does not increase with further increases in the field, This is the saturation flux density B, which is equal to the spontaneous magnetization of the magnetic material. After the material has reached saturation, the slope of the B-H curve changes and the flux density B continues to rise indefinitely at the rate of $B = H_A$ as if the magnetic material were not present. Figure 8.1.4*b* shows a plot of the permeability as a function of the field.

8.1.2c Hysteresis Loop

If the H field is decreased after the initial magnetization curve reaches the saturated state, it is found that the induction does not follow the same initial curve back to the origin but traces a curve called the *hysteresis loop*, shown by Figure 8.1.5. As the magnetization is gradually decreased from the saturation point C, it follows along the lines CD and reaches a finite value B_r (the *remanence*), which is the flux density remaining after removal of the applied field. In order to reduce the remanence to zero, a negative field—the coercive force H_c—must be applied. The curve from D to E is the demagnetization curve. As H is further increased in the negative direction, the magnetization will proceed from E to F, and the material will eventually become saturated in the opposite direction. If at this point the field is again reversed to the positive direction, the magnetization will trace the line F, G, C and the hysteresis loop is completed.

Hysteresis Losses

The area of the hysteresis loop is the energy necessary to magnetize a magnetic substance. This energy is expended as heat. The loop area is a measure of the heat energy expended per cycle, per unit volume, and is called the *hysteresis loss*

$$W_h = \frac{A}{4\pi} \quad \text{ergs/(cm}^3 \cdot \text{ cycle)} \tag{8.1.5}$$

A practical expression for power loss P in watts is given by

$$P = \frac{f\,a\,l}{4\pi} \times A \times 10^{-7} \tag{8.1.6}$$

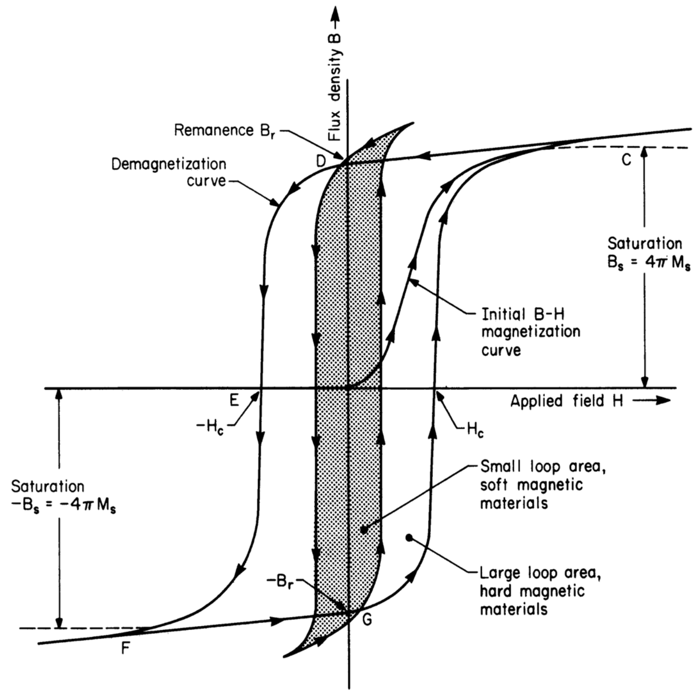

Figure 8.1.5 *B-H* loops for hard and soft materials.

Where:
A = area of the loop, gauss-oersteds
f = frequency, Hz
a = cross-sectional area of core, cm^2
l = magnetic path length, cm

Figure 8.1.5 shows a comparison between the hysteresis loops for hard and soft magnetic materials. As indicated by the difference in the areas of the loops, more energy is required to magnetize the hard magnetic materials.

Initial *M-H* Curve and *M-H* Hysteresis Loop

The initial *M-H* curve and *M-H* hysteresis loops are plots of the magnetization *M* versus the net field *H* and are typically used to describe the intrinsic properties of hard magnetic materials such as those used in recording media. An initial *M-H* curve is shown in Figure 8.1.6. The slope of the *M-R* curve is the *susceptibility x* and is defined by

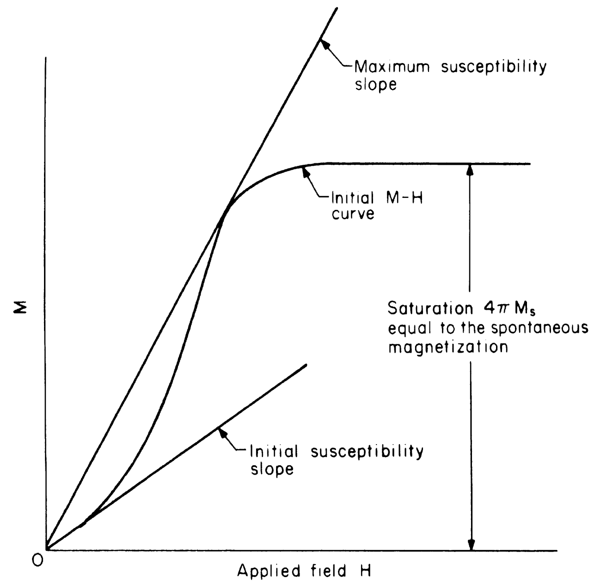

Figure 8.1.6 Initial *M-H* curve.

$$x = \frac{M}{H} \quad (8.1.7)$$

The permeability may be related to the susceptibility by

$$\mu = 1 + 4\pi x \quad (8.1.8)$$

When the saturation magnetization M_s is reached, the *M-H* curve approaches a finite limit and does not increase indefinitely as in the case of the *B-H* curve.

If, at the saturation point of the initial *M-H* curve, the applied field is made to follow the same sequence as previously outlined for the *B-H* loop, an *M-H* hysteresis loop will be traced (see Figure 8.1.7).

The ratio of the rernanent magnetization M_r to the saturation magnetization M_s is called the *squareness ratio* and is an important parameter in evaluating the magnetic orientation of the particles in magnetic tape. The squareness ratio is 1.0 for perfectly oriented particles. More practical values for oriented particles range from 0.7 to 0.9. Randomly oriented particles are approximately 0.5.

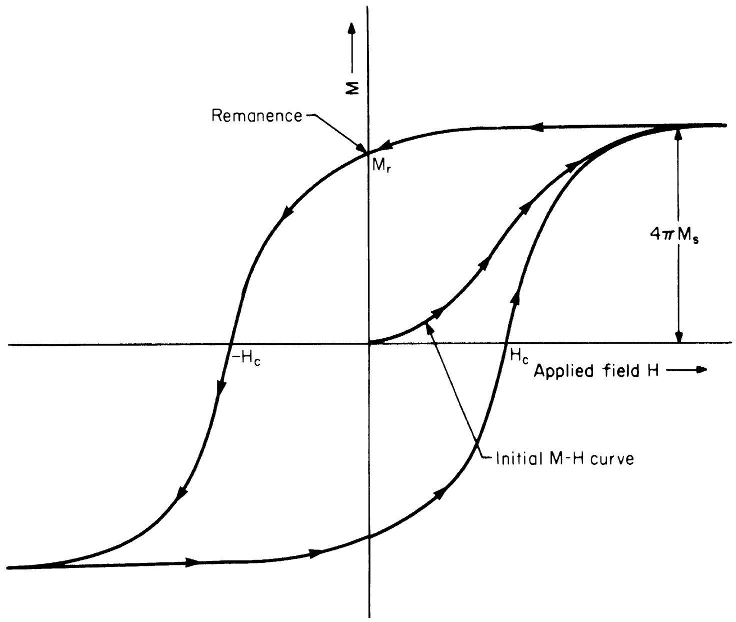

Figure 8.1.7 *M-H* hysteresis loop.

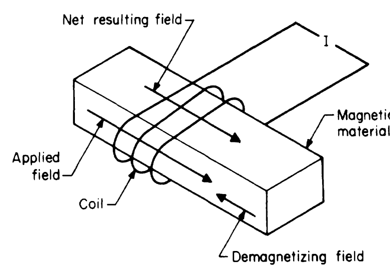

Figure 8.1.8 Demagnetization field.

8.1.2d Demagnetization

If a short bar of magnetic material is magnetized by an applied field H, poles are created at each end. These poles in turn create a magnetic field in the opposite direction to the applied field. This opposition field is called the *demagnetizations field* H_d (see Figure 8.1.8). The net field H acting on the bar is

$$H = H_A - H_d \tag{8.1.9}$$

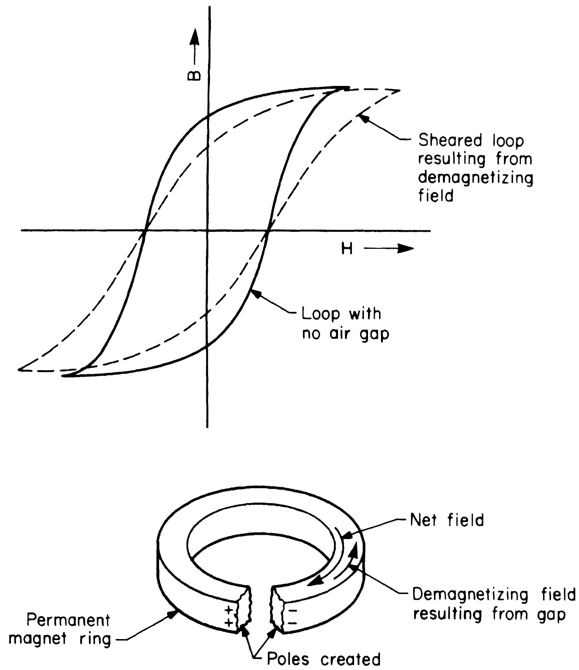

Figure 8.1.9 Sheared hysteresis loop.

The demagnetizing field H_d is dependent on the shape of the magnetic object and the magnetization M [1, 3].

The demagnetization field is zero in a ring core with no air gap. However, when an air gap is cut, creating poles at the gap-confronting surfaces, the resulting demagnetization field shears the hysteresis loop from the original position. This effect is shown by Figure 8.1.9.

To bring a magnetic substance to a demagnetized state, a field that is equal to the coercive force H_c must be applied. However, upon removal of this field, the residual flux density will rise to a value B_1, as illustrated by Figure 8.1.10. It is possible to reduce this residual flux density to zero by increasing demagnetization field to a value greater than H_c and then decreasing it to zero as shown by the dashed lines. This technique requires knowledge of the magnetic history of the material.

A more effective method to completely demagnetize a magnetic material is demagnetization by reversals. In this method, the material is first saturated by an ac field, then cycled through a series of diminishing field reversals as shown by Figure 8.1.11. The magnetic material will be left in a demagnetize state when zero field is reached regardless its magnetic history. This technique is used to bulk erase magnetic tape and other recording media, by exposing it to a strong ac field and then slowly removing the magnetic media from the field.

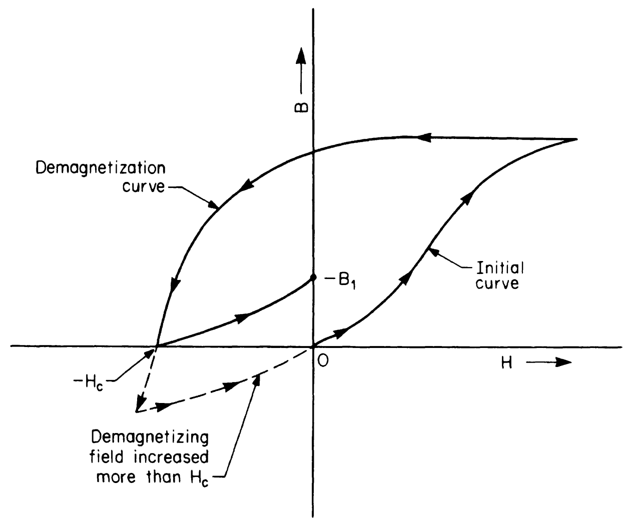

Figure 8.1.10 Demagnetization curve.

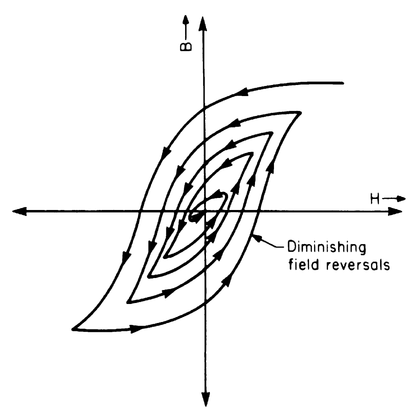

Figure 8.1.11 Demagnetization by reversals.

8.1.3 References

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Chapter

8.2

Video Recording Fundamentals

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8.2.1 Introduction

The basic elements of a magnetic tape recorder are illustrated in Figure 8.2.1. A magnetic tape is moved in the direction indicated by a tape-drive device or *transport.* The magnetic coating of the tape contacts the magnetic heads in a prescribed sequence, starting with the erase head and ending with the reproduce head.

The erase head demagnetizes the tape coating by exposing the magnetic particles to a high-frequency field that is several times greater in strength than the coercivity of the particles. As the tape is drawn past the erase head, the erasing field gradually decays, leaving the magnetic coating in a demagnetized state.

The tape then moves into contact with the record head, which consists of a ring-shaped core made of a relatively high-permeability material, and having a nonmagnetic gap. A magnetic field fringes from the gap, varying in accordance with the magnitude of the current signal flowing in the head coil. With low-level signals the field is small, and some magnetic particles in the tape coating will be forced into alignment with the field. As the signal field is increased, a larger number of particles will become oriented in the direction of the recording field. As the tape is moved past the record gap, the magnetic coating acquires a net surface magnetization having both magnitude and direction. This magnetization is a function of the recording field at the instant the tape leaves the *recording zone,* a small region in the vicinity of the trailing edge of the gap.

The magnetization of the fundamental recording system just described is not necessarily linear with respect to the head current. Linear magnetization can be achieved by adding a high-frequency ac bias current to the signal current. Audio recorders use such a scheme to linearize the tape and reduce the distortion. In video recorders, the signal information in the form of a frequency-modulated carrier is recorded directly, without ac bias.

8.2.2 Fundamental Principles

When the tape approaches the nonmagnetic gap of the reproduce head, the flux $d\Phi/dt$ from the magnetized particles is forced to travel through the high-permeability core to link the signal windings and produce an output voltage. The output voltage is proportional to $d\Phi/dt$, the rate of

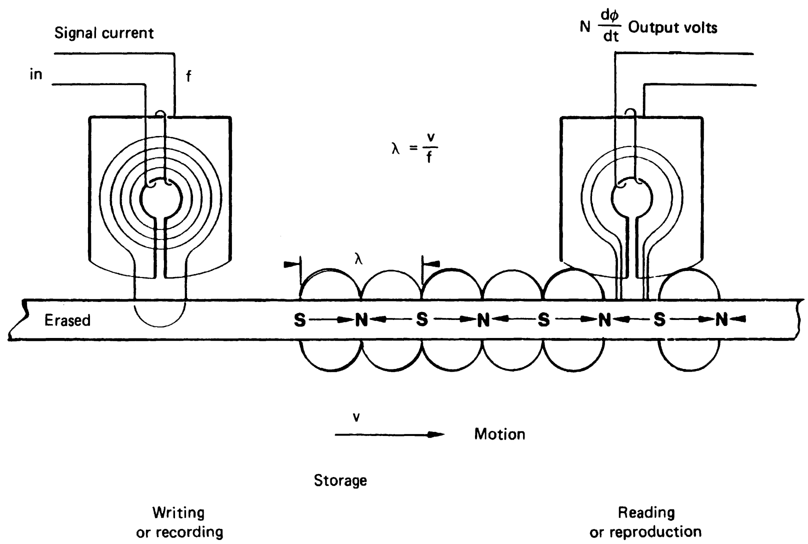

Figure 8.2.1 Fundamental recording and reproduction process.

change of the inducted flux, and therefore will rise at the rate of 6 dB per octave until a wavelength is reached where the gap and spacing losses begin to reduce the head output.

8.2.2a Recording Signal Parameters

The physical distance that one cycle of the recorded signal occupies along the tape is called the *wavelength,* which is directly proportional to the relative velocity between the head and the tape, and inversely proportional to the frequency of' the recorded signal. It may be expressed as

$$\lambda = \frac{v}{f} \tag{8.2.1}$$

Where:
λ = wavelength, in
v = velocity, in/s
f = frequency, Hz

The *linear packing density* is the number of flux reversals per unit length along the recording medium. Because there are two flux reversals, or bits, per cycle, the linear packing density may be expressed as

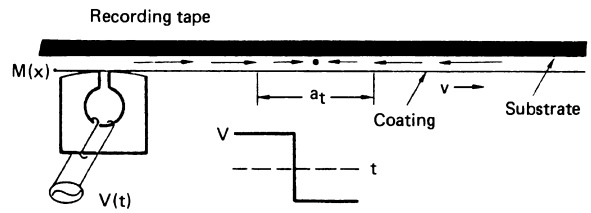

Figure 8.2.2 Resultant magnetization from a step change in head voltage.

$$\frac{\text{bits}}{\text{in}} = 2\left(\frac{2}{\lambda}\right) = \frac{2}{\lambda} \tag{8.2.2}$$

The *area packing density* is the number of bits per unit area and is, therefore, equal to the number of recorded tracks per inch times the linear packing density, or

$$\frac{\text{bits}}{\text{in}^2} = \left(\frac{2}{\lambda}\right)\frac{\text{tracks}}{\text{in}} \tag{8.2.3}$$

When the magnetization is oriented in the direction of relative motion between the head and tape, the process is referred to as *longitudinal recording*. If the magnetization is aligned perpendicular to the surface of the tape, it is called *vertical* or *perpendicular* recording.

Transverse recording exists when the magnetization is oriented at right angles to the direction of relative head-to-tape motion. From these definitions, longitudinal magnetization patterns are produced by both rotary- and stationary-head recorders.

8.2.2b The Recording Process

The recording process consists of applying a temporally changing signal voltage to a record head as the tape is drawn by the head. The magnetic field that results from the energized head records a magnetization pattern that spatially approximates the voltage waveform. In *saturation* or *direct recording*, the signal consists of polarity changes with modulated *transition times* or zero crossings. Strict linear replication of this signal is not required because the information to be recovered depends only on a knowledge of when the polarity transitions occur. Examples are digital recording, where the transitions are synchronized with a bit time interval and occur at bit positions depending upon the coded pattern, and FM video recording, where a modulated sine wave is applied so that the transitions occur not regularly but according to the signal information contained in the modulation.

The essential process in direct recording, therefore, is the writing of a transition or polarity change of magnetization. In Figure 8.2.2, the resulting magnetization from a step change in head voltage is shown. In saturation recording, the spatial variation of magnetization will not be a perfect replica of the time variation of signal voltage. Even if the head field change is perfectly abrupt, the magnetization will gradually change from one polarity to another. In Figure 8.2.2,

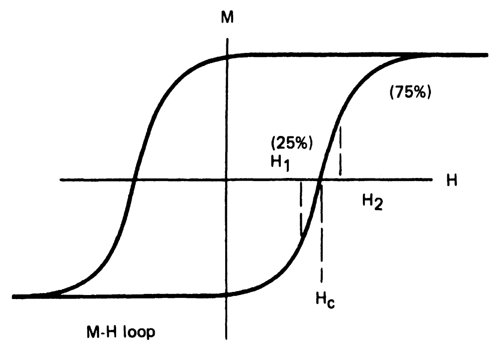

Figure 8.2.3 *M-H* hysteresis loop for a typical tape.

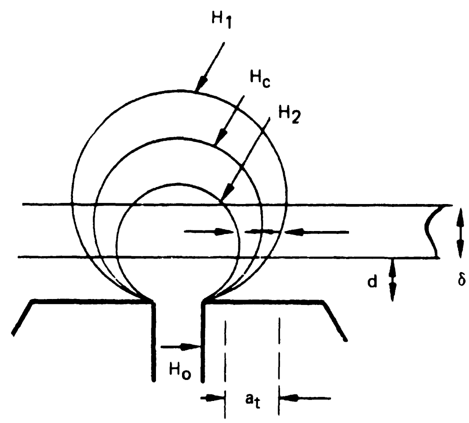

Figure 8.2.4 Head-field contours showing recording zone in tape.

this is indicated by a gradual change in vector lengths; the notation a_t denotes an estimate of the distance along tape over which the magnetization reverses. The nonzero distance between polarity changes of magnetization is due to the finite-loop slope at the coercivity, combined with the gradual decrease of the head field away from gap center. This process is illustrated in Figures 8.2.3 and 8.2.4. In Figure 8.2.3 the *M-H* remanence loop is shown for a well-oriented tape sample. The magnetization M is the remanence magnetization that results from the application of a field H, which is subsequently removed. If the tape is saturated in one direction, for example, $-M$, and a positive field is applied, then the magnetization will start to switch toward the positive direction when the field is close to the remanent coercivity H_c^r. Because the slope of this *M-H* loop is not infinitely steep for fields near H_c^r, the switching will take place gradually. H_1 denotes the field that switches 25 percent of the particles to leave the magnetization at $-M/2$; H_c^r is, in fact, the 50 percent reversing field that leaves $M = 0$. H_2 denotes the 75 percent switching field that leaves the magnetization halfway to positive saturation ($+M/2$). During recording, a finite transition width will occur, depending on how H_1 and H_2 are spatially separated. In Figure 8.2.4, three contours of recording field are plotted for the three fields H_1, H_c^r, and H_2. In plots of head fields, larger fields are closer to the surface of the head and toward the gap center. Thus, along the midplane of the tape the field magnitudes H_2, H_c^r, H_1 are in decreasing order away from the

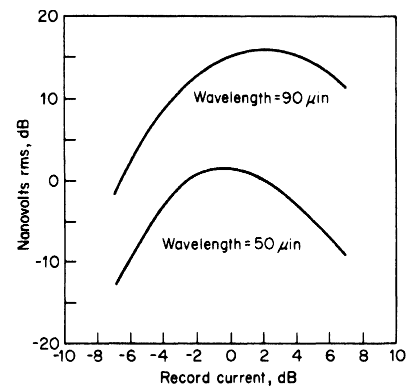

Figure 8.2.5 Reproduce voltage versus record current for typical video tape.

gap centerline. Therefore, if the tape is initially magnetized negatively, a positively energized head (H_0) will switch the magnetization according to Figure 8.2.3 following the spatial change of the fields. This yields a finite transition width a_t. The transition width can be narrowed by using tape with a steeper loop gradient, making H_1 closer to H_2 in magnitude (a narrower spread in switching fields) and decreasing the head-to-tape spacing, which moves H_1 and H_2 closer together spatially (a larger head field gradient) as indicated in Figure 8.2.4. In addition, spatial changes in magnetization cause demagnetization fields in the tape that further broaden the transition. This demagnetization broadening can be reduced by increasing the tape coercivity.

In saturation recording, the signal current is held fixed for all wavelengths. The current level is set to optimize the short-wavelength output, and complete saturation of the tape does not occur. In Figure 8.2.5 reproduce voltage versus input current is shown for two different wavelengths in square-wave recording for video tape (Ampex 196). If true saturation were to occur, the curves would increase initially with current as the tape is recorded, and then level, representing a magnetization saturated to full remanence and recorded fully through the tape thickness of 200 μin (5 μm*)*. However, at short wavelengths these curves are peaked, and the current that yields the maximum output represents recording only a very small distance into the tape. For video recording on a type C format machine optimized at 10 MHz ($\lambda \approx$ 100 μin), this is a record depth of approximately 50 μin. A mechanism for optimization of this parameter can be seen by considering the change in transition with record current. As the current is raised, the point of recording shifts continuously downstream from the gap center. The transition width depends upon the head-field gradient at the recording point. This field derivative, $H_2 - H_1$, divided by the separation between them, increases with distance along the head surface, as shown in Figure 8.2.4, reaching a maximum near the gap edge and thereafter decreasing. Because the reproduce voltage increases with decreasing transition width, a maximum voltage will occur as the current is increased. This peaking becomes more pronounced as the wavelength is reduced.

A form of linearity known as *linear superposition* is found in saturation recording. For constant-current recording (strictly, *constant-field amplitude*) the reproduce voltage from a complicated pattern can be shown to closely resemble the linear superposition of isolated transition voltage pulses, according to the timing and polarity change of the series of transitions. The lack of complete linear superposition is believed due to demagnetization fields. This accompanies large head-to-medium separations, as in rigid-disc applications, where the increase in the demagnetization fields can cause significant nonlinearities.

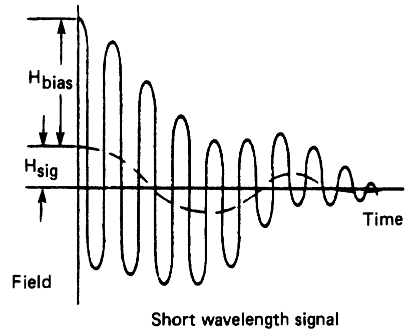

Figure 8.2.6 Signal-field history for ac-bias recording.

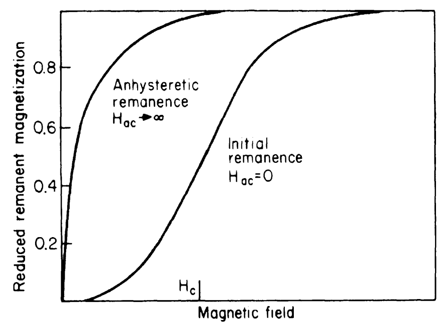

Figure 8.2.7 Comparison of sensitivities of ac-bias and direct recording.

8.2.2c Bias Recording

In some applications, predominantly audio recording, strict linearity is required between the reproduced voltage and the input signal. This may be achieved by superimposing a high-frequency, large-amplitude bias current on the signal (Figure 8.2.6). The physical process is called *anhysteresis* [1]. The bias field supplies the energy to switch the particles while the resulting remanent magnetization is a balance between the signal field and the interparticle magnetization interactions. In Figure 8.2.7 a comparison is shown between the magnetic sensitivity of ac bias recording and direct recording. Alternating-current bias or anhysteresis results in an extremely linear characteristic with a sensitivity an order of magnitude greater than that for unbiased recording. In typical audio applications, the bias current is somewhat greater than that of the signal in direct recording. The signal current is approximately an order of magnitude less than the bias current and is set to maintain the harmonic distortion below 1 to 2 percent. For complete anhysteresis there should be many field reversals as the tape passes the recording point where the bias field equals the tape coercivitv. This is achieved if the bias wavelength is substantially less than the record-gap length. In fact, to avoid reproducing the bias signal itself, the bias wavelength is usually less than the reproduce-gap length.

As in direct recording, a current optimization occurs, but in bias recording it is with respect to the bias current. In Figure 8.2.8, reproduce voltage is shown versus bias at short and long wavelengths. At long wavelengths, the optimum bias occurs approximately when the bias field has recorded through to the back of the medium. This is often taken to be the usable bias current

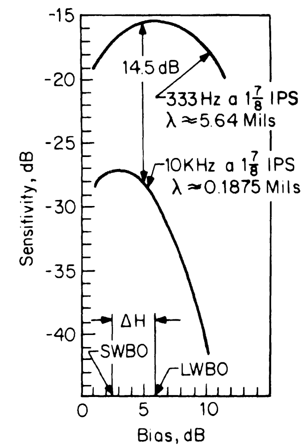

Figure 8.2.8 Low-level output sensitivity versus bias for long and short audio wavelengths.

since close to this optimization a minimum in the distortion occurs. For shorter-wavelength machines, the bias is chosen as a compromise between *short-wavelength bias optimization* (SWBO) and *long-wavelength bias optimization* (LWBO).

8.2.2d Particle Orientation

The previous discussion applies generally to all types of recording tape; the most common is that composed of uniaxial elliptical particles oriented *longitudinally* in the direction of head-tape motion. However, *isotropic* tape does exist and is composed of particles of cubic (threefold) symmetry that exhibit high remanence in all directions. In addition, it is conceptually possible to *vertically* orient the grains to result in a tape isotropic in the plane, but capable of recording signals perpendicular to the surface. These last two would be advantageous for transverse recording since the difficult process of orienting elliptical particles along the tape cross direction could be avoided.

During the tape-coating process, elliptical particles will naturally orient along the tape-coating direction. A field applied during coating improves the orientation even further. It is quite difficult to orient these particles vertically because the hydroscopic coating forces overwhelm the magnetic force from a vertical-orienting field. Success has, however, been achieved with systems that *inherently* yield vertical orientation. As an example, barium-ferrite platelets can be coated to yield perpendicular media since the magnetization anisotropy axis is perpendicular to the plane of the particles. Other vertical medium can be made by sputtering CoCr on either a tape or substrate.

8.2.2e Erasure

The writing of new information on previously recorded media requires that the previous information be completely removed. Erasure requirements, in terms of the previous-signal to new-signal ratio, vary from –30 dB for digital systems to as much as –90 dB for professional analog audio. Analog video recorders require about –60 dB.

Erasure is the ac-bias or anhysteretic process with zero-signal field. If a reel of tape is placed in a large ac field that is slowly reduced so that many field cycles occur when the field is near the coercivity, then complete erasure is easily obtained, In addition, the largest amplitude of the ac-erasing field must be sufficient to reverse at least 99.9 percent of the particles (for –60 dB), and in practice that field is about three times the coercivity.

Most tape recorders utilize erase heads to remove old information before recording new data. Similar to bias recording, the requirement of the erase frequency is that the wavelength be much less than the erase-head gap to provide sufficient reversals of the particles. However, one important problem occurs with an erase head. As the erase current increases, the erasure level does not continuously increase as more of the *M-H*-loop tail is switched. There is an erasure plateau of about –40 dB for erase-gap lengths of 1 to 2 mils (0.0254 to 0.0508 mm) and tape thicknesses of 200 to 400 μin (5.08 to 10.16 μm). This leveling is believed to be due to the phenomenon of rerecording [2]. As the tape passes the erase head, the field from the portion yet to be erased (entering the gap region) acts as a signal for the bias-erase field to record a residual signal at the recording zone on the far side of the gap. This effect is seen only at long wavelengths where the field is high. The problem is eliminated with double erasure by using a double-gap erase head. The erasure level can be decreased by decreasing the ratio of the tape thickness (or recording depth) to erase-gap length; this reduces the rerecording field.

8.2.3 References

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2. McKnight, John G.: "Erasure of Magnetic Tape," *J. Audio Eng. Soc.*, Audio Engineering Society, New York, N.Y., vol. 11, no.3, pp. 223–232, 1963.

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