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Electrical
Manufacturing

Magnetizing and Demagnetizing Permanent Magnets

The high coercive force of today's magnetic materials not only makes possible improved permanent magnets, but also creates problems in magnetizing these materials. For many applications a magnet can be magnetized only after it has been assembled in the magnetic circuit of the end product. The mechanics of magnetization have a decided design influence. Here are some practical techniques.

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Permanent Magnet Properties

Permanent magnet material	Induction, gauss B_{max}	Magnetizing force, oersteds H_{max}	Coercive force, oersteds H_c	Intrinsic coercive force, oersteds H_{ci}	Approximate reversible permeability μ_r
36% cobalt steel	15,000	1,000	240	—	12
Alnico 2	12,500	2,000	560	—	6
Alnico 5	16,000	2,000	600	—	3.5
Alnico 6	15,700	3,000	750	775	5.0
Alnico 7	14,700	5,000	1,000	1,050	3.5
Cunife	8,400	2,500	550	—	3
Cunico	8,000	3,000	660	700	2
Cobalt platinum	22,900	15,000	4,200	5,000	1.2
Barium ferrite	4,000	10,000	1,500	2,900	1.2
Silmanal	20,800	20,000	550	5,000	1

Magnetizing and Demagnetizing Permanent Magnets

The high coercive force of today's magnetic materials not only makes possible improved permanent magnets, but also creates problems in magnetizing these materials. For many applications a magnet can be magnetized only after it has been assembled in the magnetic circuit of the end product. The mechanics of magnetization have a decided design influence. Here are some practical techniques.

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CHANGING THE STATE OF magnetization is an important factor in using modern permanent magnet materials. Magnetization and demagnetization of today's ever-higher coercive-force materials call for equipment and techniques that are a great departure from the early methods of touch and shock. Progress in permanent magnets has generally been toward increased coercive force requiring high field strength equipment for magnetization and demagnetization.

Generally, problems of magnetization must be solved by the user of permanent magnets. Although a permanent-magnet manufacturer magnetizes in order to establish standards and to check quality, a very high percentage of his output is shipped in a demagnetized condition, because:

1. Most permanent magnets must be magnetized after assembly in the magnetic circuit of the device or equipment in which they are used.
2. Shipping costs of magnetized magnets are high because a fully magnetized magnet must be protected from the influence of adjacent magnets by keepering or separation.

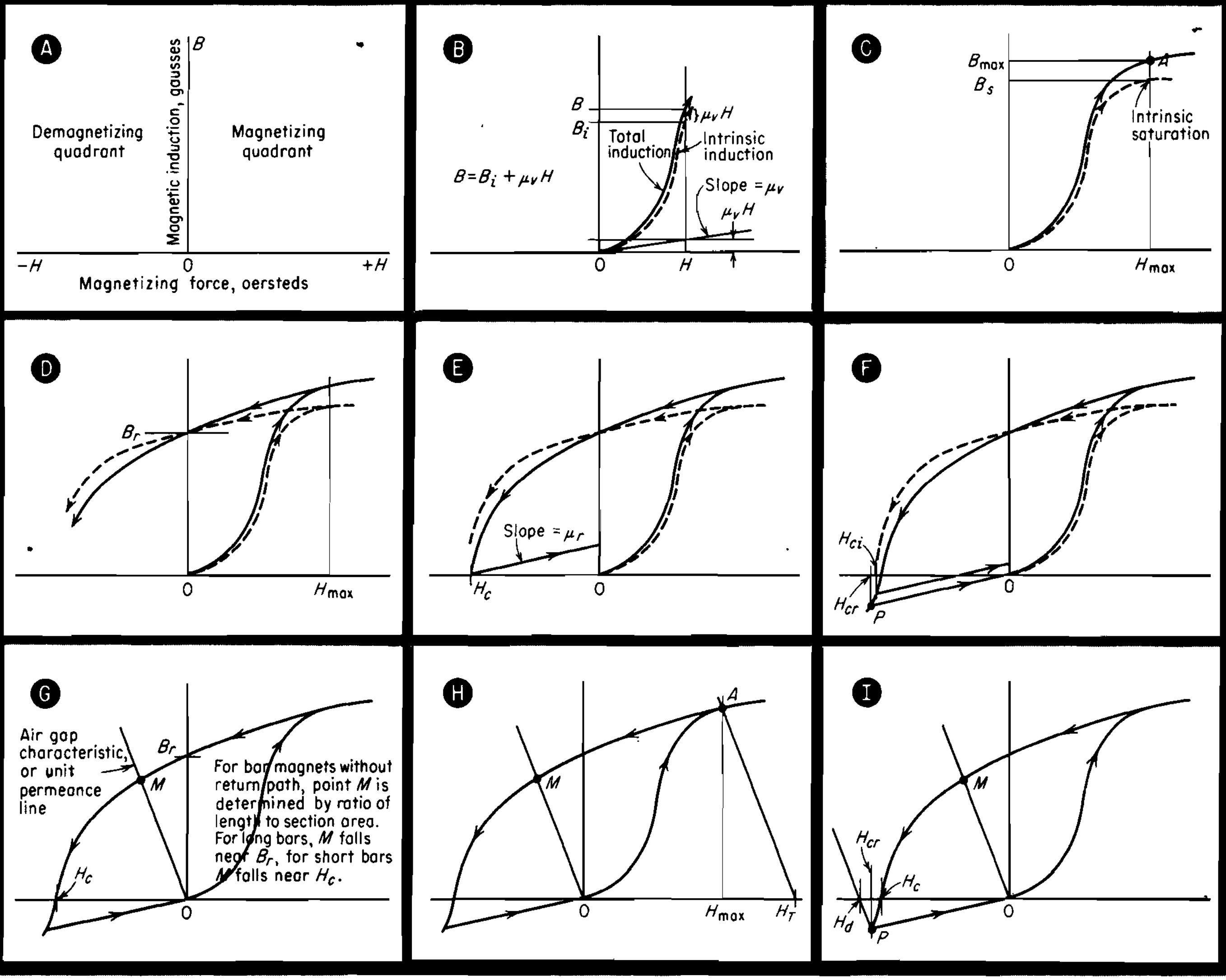


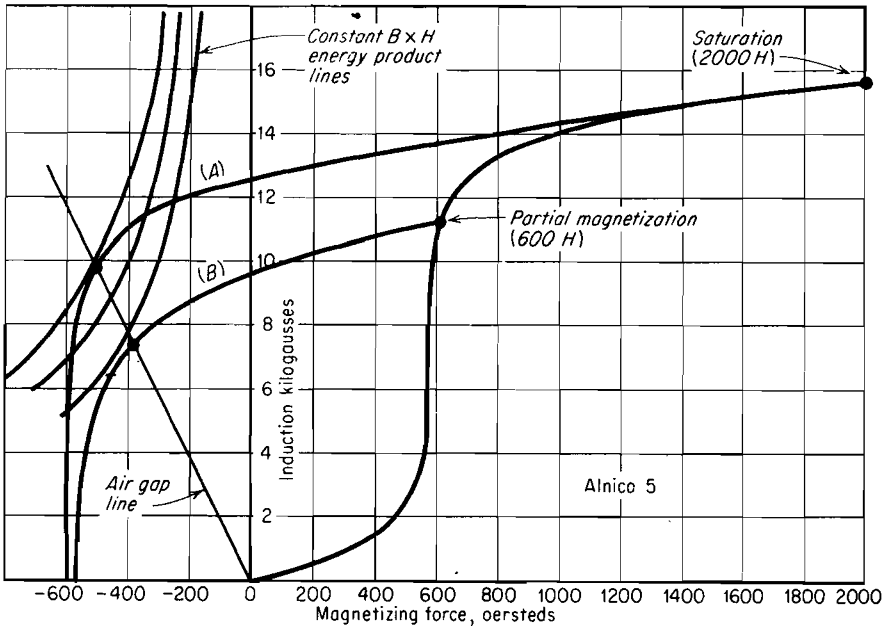
Fig. 1—(A) The properties of permanent magnets can be defined graphically by a plot of magnetizing force H in oersteds *vs* total magnetic induction B in gausses. (B) Total induction is a function of both H and its effect on the magnetic material (intrinsic induction) and can be expressed as $B = B_i + \mu_v H$. where B_i = intrinsic induction and μ_v = space permeability. Since μ_v = unity for space, it follows that $B = B_i + H$ for positive (magnetizing) forces, and $B = B_i - H$ for negative (demagnetizing) force. (C) As an increasing magnetizing force is applied to unmagnetized magnetic material, both B and B_i increase until saturation at H_{max} when B_i levels off at B_s. Further increase in H will raise B above B_{max}, but intrinsic induction will stay constant at B_s. (D) When saturating force H_{max} is removed, both B and B_i drop back to a residual induction level B_r determined by the magnetic orientation of the material. Then as increasingly negative potential is applied, B will decrease along a demagnetizing curve, lagged by B_i. (E) The negative force required to reduce B to zero is defined as the coercive force (H_c). Upon removal of H_c the magnetic material still exhibits some induction and will recoil along a minor hysteresis loop; slope is determined by reversible permeability (μ_r). (F) Even a negative potential H_{ci} (intrinsic coercive force) sufficient to drop B_i to zero still leaves some induction. Completely demagnetizing the material requires a still greater force H_{cr} (relaxation coercive force) which can be several times H_c depending on material. (G) For a given magnetic circuit the demagnetizing effect of the air gap locates magnet's operating point (M) on the demagnetization curve. Slope of line OM depends on the geometry of the magnet and completeness of the magnetic circuit. (H) For any magnet configuration, a unit permeance line drawn at any point on the hysteresis loop expresses the ratio of B to H as seen by a unit volume of the permanent magnet. Thus, a parallel line through A intersects at H_t, the total force required for saturation and counteracting the air gap. (I) Similarly, a parallel line through P defines H_d as the negative force required for complete demagnetization with an air gap. For large air gaps or low length-to-cross-section ratios, H_d and H_t can be considerable unless the slope of OM is raised by keepers or return paths.

3. Demagnetized magnets are far easier to assemble with steel parts and will not pick up magnetic particles.

The successful assembly of many devices such as meters and loud speakers make a completely demagnetized magnet a necessity.

Magnet Characteristics. For convenience, a permanet magnet can be thought of as a grouping of elementary magnetic volumes—each exhibiting a magnetic force. These forces are unorganized in a demagetized magnet and cancel each other so the permanent magnet exhibits no external field energy. Subjecting this permanent magnet to an external field aligns the elementary magnet volumes in a given direction and the permanent magnet then exhibits an external magnetic field energy. This is the magnetization process. Demagnetization is the subjecting of the permanent magnet to external forces which unlock or destroy the alignment, and allow the elementary magnetic volumes to return to a randomly oriented condition that exhibits no field energy.

The problems of magnetization and demagnetization



Partial Magnetization

Fig. 2—Intersection of the demagnetization curve (B) of a partially magnetized magnet with its air-gap line falls on a much lower available energy contour than does curve (A) for the same magnet initially magnetized to saturation.

can be illustrated by using the hysteresis loop of a permenent magnet to visualize the influence of the unit magnetic properties. Figure 1 demonstrates the generation of the magnetization and demagnetization portions of a hysteresis loop; (A) through (F) define inherent properties of a permanent magnet material, and (G), (H), (I) show the effect of the physical shape of the magnet and its circuit on the process of magnetization and demagnetization. The values of B_{max}, H_{max}, H_c H_{ci} and μ_r for commonly used permanent magnet materials are listed in the table. These listed properties must be modified by the air-gap characteristic influence to determine the full magnetization and demagnetization forces required.

Incomplete magnetization has many adverse influences on the effective use of a permanent magnet's inherent properties. Figure 2 compares alnico 5 demagnetization curves (A) for fully saturated material and (B) for the same material only partially magnetized. The available external energy is greatly reduced with partial magnetization. Since the magnet volume required to establish a given amount of field energy in an external air gap is inversely proportional to energy product ($B \times H$), it follows that partial magnetization is extremely costly. Further, a magnet's ability to withstand demagnetizing influence is reduced since the full coercive force can not be realized.

Shaping and Timing. In addition to the material properties and the air gap effect, the shape of the applied field and time duration of the magnetizing force may influence the completeness of magnetization. Modern permanent magnets are low in permeability. Their presence in a field will not to any great degree shape the field. Consequently, the magnetizing structure or fixture must produce a field pattern that at least approximates the shape of the magnet.

Current-carrying conductors and soft steel may be arranged to produce about any degree of field curvature required. Subjecting a magnet to a field strength in excess of that needed to saturate is not objectionable, provided the equipment produces essentially the same shape field as the magnet. Field strengths higher than required may actually leave a magnet magnetized at an angle to the desired axis, when the field shape is quite dissimilar from that of the magnet. The end effect would be that of partial magnetization.

Regarding the time to magnetize, induction is essentially instantaneous. However, inductance and induced eddy currents can influence the rate of current build up in a magnetizer. In heavily inductive electromagnets, the current may require one or two seconds to attain maximum value. Once maximum current is reached there is no necessity to hold the current since induction occurs immediately.

Magnetizing Equipment

Conventional Magnetizers. Electromagnets are convenient for magnetizing the more common shapes of permanent magnets such as rods, bars, rings and some U-shaped magnets and assemblies. The conventional electromagnet magnetizer of Fig. 3 has pole pieces which can be changed to shape the field. One pole is movable with respect to the other to provide the family of curves shown in Fig. 4 for various air gaps. Magnetizers of this type are usually operated from a full-wave rectifier and are designed for intermittent operation.

Principal design considerations for an electromagnet to magnetize a particular magnet are:

1. Core section must be adequate to carry the saturation flux.

2. Ampere-turns must be sufficient to produce the total potential required by the magnet length, the magnetizer yoke and any air gaps present.

Due to leakage and losses, the core of the electromagnet should be about four times the area of the magnet to insure adequate flux level in the permanent magnet. Also the flux should be directed according to the shape of the permanent magnet. Figure 5 shows good and bad practice for a variety of situations. When magnetizing very large magnets, enough potential should be used that a small air gap can be placed between magnet and mag-

Electromagnet Magnetizer

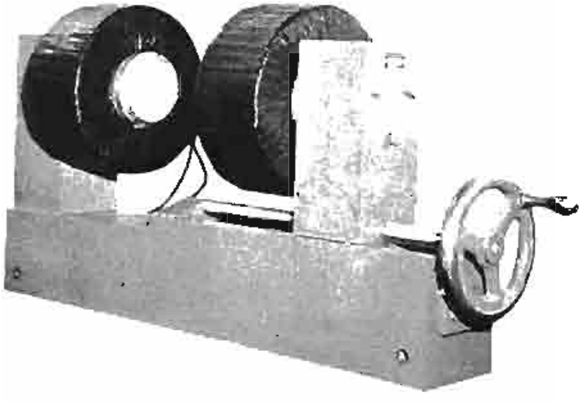


Fig. 3—Conventional electromagnet magnetizer with variable air gap; operates from 125 volts d-c. Pole pieces can be changed to shape the field to suit common magnet shapes.

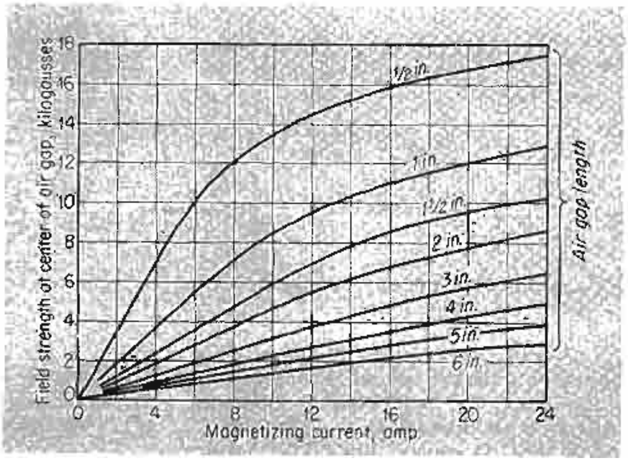
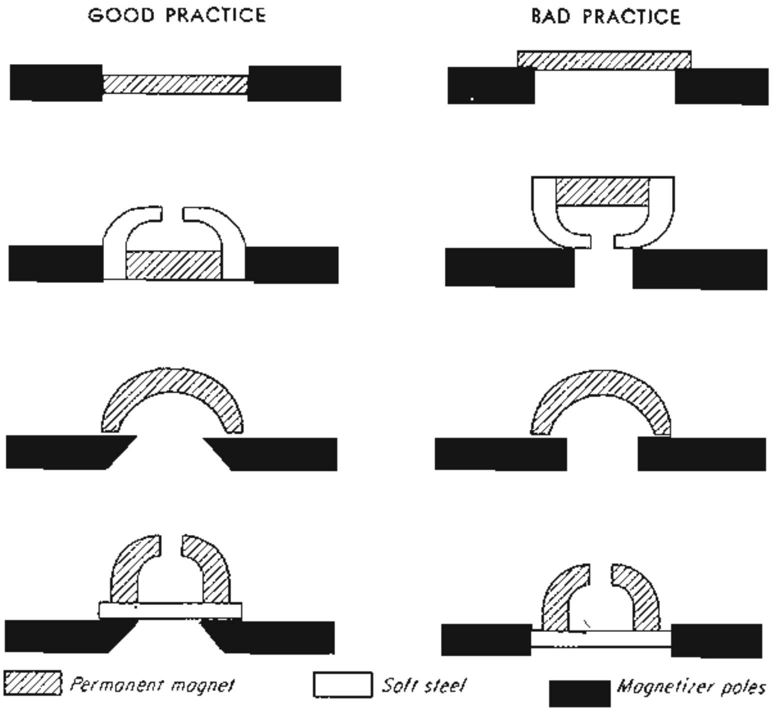


Fig. 4—Air-gap field strength vs magnetizing current curves for various gap lengths demonstrate the degree of control possible with an electromagnet magnetizer.

Fig. 5 (below)—Practical pointers on magnetization of common permanent magnet shapes.



COMMENTS

Flux should be passed directly through magnet proper . . .

. . . not through "soft" steel poles designed to carry only operating flux (approx 50 per cent of saturation flux).

Tapered electromagnet pole pieces direct flux upward to approximate a semicircular field.

Magnetizing field must be sufficient to saturate both the magnet and any parallel "soft" steel paths.

netizer poles to facilitate removing the magnet. In multipole permanent magnet configurations, such as rotors for motors and generators, all poles must be magnetized simultaneously. A matching multi-pole electromagnetic system is required to achieve a symmetrically magnetized magnet.

Impulse Magnetizers. Since the time interval required is extremely short, magnetizing can be achieved by a current impulse, provided its magnitude is sufficient to deliver the peak H required.

The development of materials with high coercive force and high available energy has led to relatively intricate agnet configurations. The length of magnet limbs has decreased and circular shapes and parallel circuits are common. Many of the newer shaped permanent magnet arrangements cannot be magnetized by placing them in contact with conventional electromagnets. Instead they are magnetized by the flux field around a conductor carrying a high current impulse. Some shapes can only accommodate a single conductor threading through the window of the magnetic circuit. Others must be wound with several turns of heavy wire. In fact, many magnet designs are materially influenced by how the magnetizing conductor or conductors can be arranged.

Impulse magnetization has become more popular not only for these newer shapes, but also for nearly all types

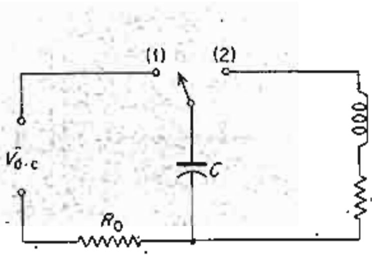


Fig. 6—Basic circuit: (1) Capacitor C is charged to voltage V at rate determined by R_0. (2) Capacitor is switched to discharge a current pulse through magnetizing coil L. As long as R is greater than $2\sqrt{L/C}$, pulse will be unidirectional without oscillation.

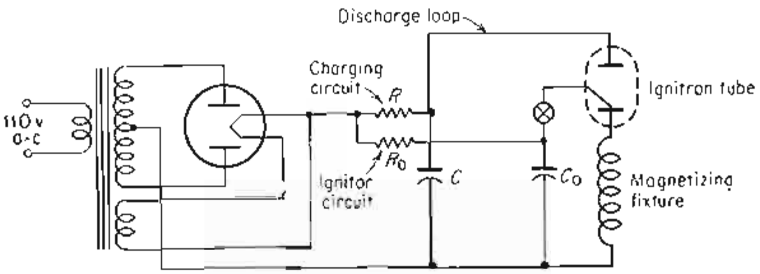


Fig. 7—Practical impulse circuit for peak currents up to 10,000 amp. Circuit constants are such that when C is fully charged, voltage across C_0 will fire the ignitron tube to conduct unidirectional magnetizing current pulse.

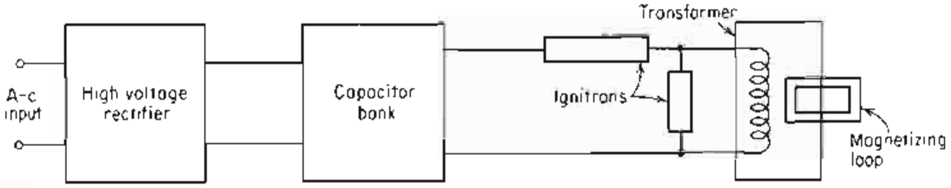


Fig. 8—Current impulses above 10,000 amp can be obtained by adding a step-down transformer. A second ignitron shunts the transformer primary; its firing is timed to prevent reversal of secondary current when impulse flux decays.

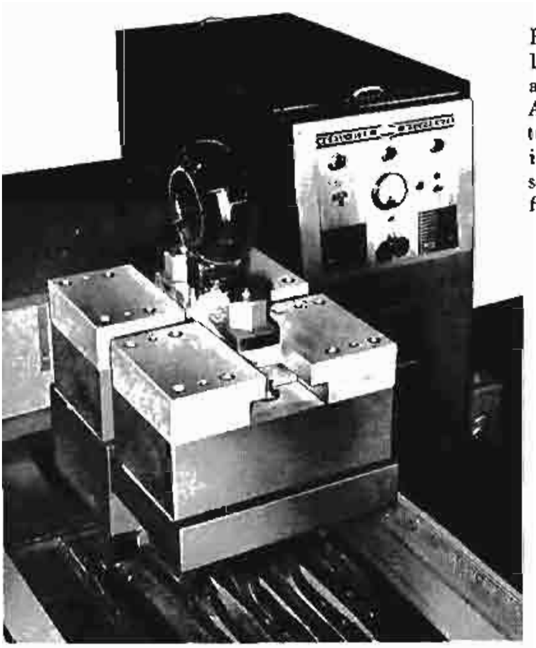


Fig. 9—Large cross-section magnet mounted in its magnetizing fixture atop magnetizing transformer. Control cabinet houses rectifier and switching equipment. Capacitor bank is a separate structure (not shown).

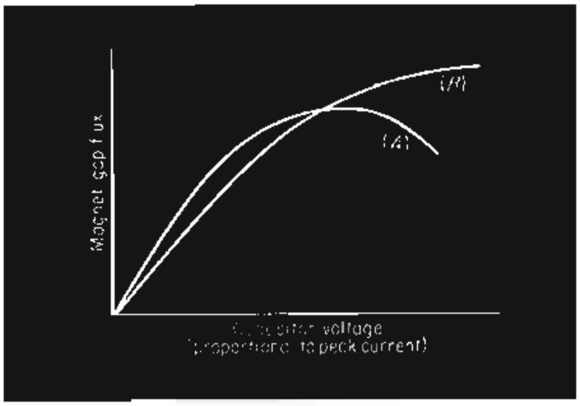


Fig. 10—Eddy current influence: (A) for increasingly high current impulses, counter-flux of induced eddy currents can actually decrease the net magnetizing flux unless (B) the current impulse lasts long enough for the eddy currents to decay faster than the pulse itself.

of permanent magnets, because equipment to produce extremely high instantaneous currents requires relatively low investment and will operate directly from 60-cycle a-c power supplies.

One convenient system is shown in Fig. 6. Here a capacitor is first charged from d-c source and then switched to discharge through the magnetizing circuit. The charging rate can be a relatively long period, making this system ideal for limited-capacity power supplies. Further the time of discharge is of the order of 0.01 sec so there is negligible heating of the magnetizing conductor.

A properly designed impulse system can develop instantaneous peak power several hundred times the maximum demand from the line during charging, and no heavy current is involved in switching. Large values of capacitance can be obtained by paralleling electrolytic capacitors of the type widely used for power-supply filters. Figure 7 shows the circuit of a refined impulse magnetizing unit combining a rectifier to provide d-c charging current with an ignitron tube for switching.

The current required for impulse magnetization around a single conductor can be estimated as:

$$I = 5Hr$$

Where I = peak current in amperes

H = required field strength to saturate in oersteds

r = maximum radius of the magnet configuration in inches (distance from conductor center to outside of magnet).

The peak currents which available switching tubes can handle are limited to the order of 10,000 amp. In many impulse magnetizing applications several hundred thousand peak amps may be required. Here a step-down transformer can be used to raise the current level in the magnetizing loop as shown in Fig. 8. As the capacitor is discharged into the transformer, the primary current is unidirectional, and the core flux is at a high level. But the flux decay at the end of the current pulse would reverse the secondary current and demagnetize the magnet were it not for a second ignition tube shunting the primary winding. As the primary voltage starts to reverse, the shunt tube fires and in effect continues the primary current long enough for the secondary current to decay exponentially and unidirectionally. Firing of the shunting ignition is controlled by a thyratron fired by the capacitor bank. Figure 9 shows a magnetizing fixture and magnet mounted on a magnetizing transformer.

Eddy Currents. Magnetic induction by impulse in magnets of large cross section (such as in Fig. 9) can be delayed by induced eddy currents. If the pulse is of short duration compared to the time constant of the eddy current paths, more than one impulse may be necessary to raise induction in the magnet interior to saturation. Or the time duration of the pulse must be lengthened.

Figure 10 illustrates the influence of eddy currents in terms of capacitor voltage (proportional to peak current) and air-gap flux for a C-shaped magnet around a single conductor. For increasingly high magnetizing currents, the eddy current flux will oppose and effectively lessen the net magnetizing flux—unless the impulse time is long enough to permit the eddy current to decay faster than the current pulse. This can be accomplished by increasing the capacitance or the effective inductance. The capacitor voltage and transformer turns ratio are the convenient variables to control the impulse for a given magnet structure.

Half-Cycle Magnetizer. Unidirectional high current impulses can be provided by a half-wave rectifier connected between a magnetizing fixture and an a-c source. This basic arrangement, shown in Fig. 11, uses a thyratron-controlled ignitron tube to pass a half-cycle of current to the magnetizer. The firing point controls the amount of current and magnetizing force, Fig. 12.

This equipment may be used without the use of a transformer for currents up to the capacity of available ignitrons. Above this level, current multiplication by means of a transformer is necessary. To prohibit current reversal in the secondary, a premagnetizing circuit supplies pulsating d-c current to the primary of opposite polarity to the main pulse to saturate the transformer core. Since the core in this equipment is usually designed to operate at about 50 per cent of normal core densities, the main pulse will cause a maximum flux change from 100 per cent to zero flux level or less, depending on the firing point as shown by the curves of Fig. 12. Consequently, only unidirectional secondary current will flow.

Half-Cycle Impulse Magnetizer

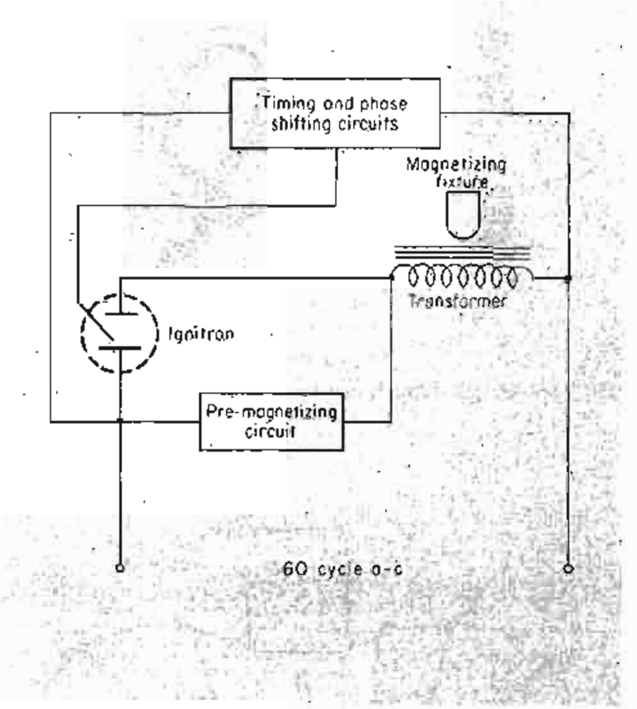


Fig. 11—Half-cycle magnetizer circuit passes half-cycle current impulses whose amplitude and duration is controlled by the firing of a thyratron in the ignitor circuit. For currents above 10,000 amp a transformer is used. To prevent flux reversal, a pre-magnetizing circuit saturates the transformer with d-c pulses of opposite polarity to the main pulse.

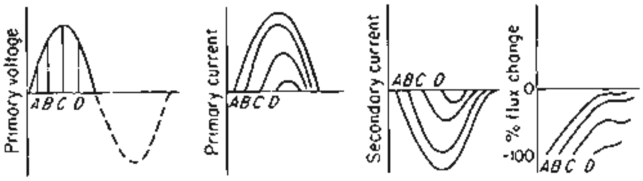
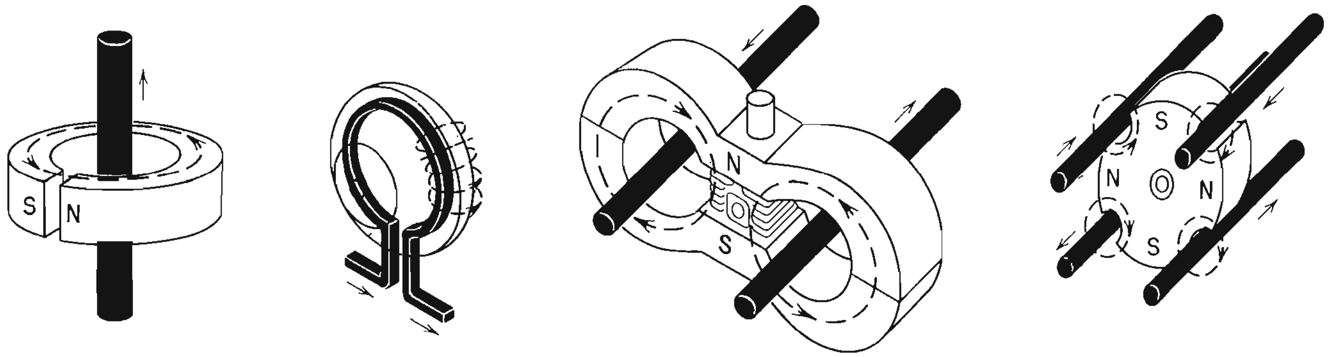


Fig. 12—Voltage, current and flux change for various firing points of a half-cycle magnetizer with transformer.

The half-cycle magnetizing circuit is versatile and widely used both with a transformer and as a direct-control device. Typical magnet configurations with conductors arranged for magnetization by either capacitor or half-cycle impulse equipment are shown in Fig. 13. Figure 14 illustrates an arrangement to magnetize several hundred pounds of alnico at once by using several turns and relatively low current instead of the tremendous current required with a single conductor.

The half-cycle circuit offers the inherent advantages of impulse magnetizing in that conductor heating is negligible and line burden is low compared to the instantaneous peak power produced. However, when compared to capacitor impulse equipment the demand and effect on source regulation is much more severe. In large capacitor equipment the energy may be accumulated at a low demand rate for several seconds, while in the half-cycle circuit the total energy is taken from the source in a half-cycle interval. So half-cycle equipment for high-current applications is often located near a plant power distribution substation so that line reactance is not encountered and other equipment is not adversely affected.

Conductor Arrangements for Impulse Magnetization



"C" shape

Radial magnetization of bowl configuration

"E" shape magnetron field magnets

4-pole generator rotor

Fig. 13—Straight-through conductor arrangements for typical magnet shapes—suitable for capacitor-discharge or half-cycle units.

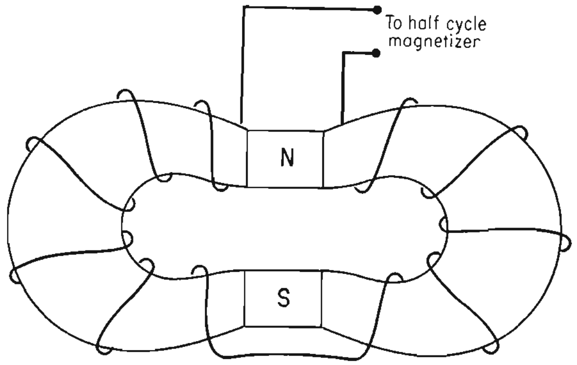


Fig. 14—Half-cycle magnetizing loop for a 700-lb, alnico 5 magnetron assembly. To reduce peak current requirements and improve flux distribution, several turns of wire are used instead of a straight-through conductor.

Generally, the pulse duration with the half-cycle equipment is long enough to minimize the influence of eddy currents on flux penetration.

Demagnetizing Equipment

Demagnetization is a less frequently faced problem than magnetization. However, complete demagnetization is considerably harder to achieve and constitutes a very real problem for the manufacturer and the user of permanent magnet materials.

As brought out in (F) Fig. 1, by subjecting a magnet to its relaxation coercive force H_{cr} it can be completely demagnetized. However, this requires an accurate knowledge of the slope of the minor hysteresis loop and the exact location of point *P*. For this reason demagnetization by applying a precise amount of reverse field is seldom used.

In practice, permanent magnets are usually demagnetized by applying an alternating magnetic potention and slowly reducing its magnitude to zero, as sketched in Fig. 15. As the applied potential is reduced in amplitude, the magnet follows an ever-decreasing hysteresis loop until the magnetizing force and the magnetic inductor both reach zero. However, the rate of decay is significant. Figure 16 shows that if the applied peak potential is reduced too rapidly, the symmetry of the resulting interior hysteresis loops with respect to the origin is destroyed and the magnet will retain an appreciable amount of induction—either positive or negative depending on the polarity of the applied potential when the first reduction is made.

This method of demagnetization requires first, the initial magnitude of peak *H* must be nearly as great as the minimum value of $H_{\max}$ required to saturate, and second, that *H* must be reduced by relatively small amounts to zero. For highly directional permanent magnet materials with extremely non-linear magnetization characteristics, this is a very important consideration.

A practical method for achieving this effect is to pass the magnet through an a-c solenoid having the required peak *H* at its center. Figure 17 shows a production belt demagnetizer operating on this principle. As the magnet leaves the solenoid it passes through a continuously decreasing alternating field.

An alternate way is to leave the magnet fixed in position with respect to the coil and decrease the current slowly with respect to the frequency. Still another is to discharge a capacitor into an inductance to produce a damped oscillation, Fig. 6. By proper choice of *R*, *L* and *C*, the frequency, peak current and rate of decay can be controlled.

An interesting circuit for decaying current with time over a period of a few cycles uses two thyratron tubes connected back to back, Fig. 18. Pulses are fed to the grids to overcome the fixed bias and allow each tube to conduct for part of each half cycle. A phase-shifting circuit delays each successive pulse so that each tube fires later in each subsequent half cycle and conducts a lower peak current for a briefer period.

In demagnetizing with alternating current, it is often difficult to obtain the peak *H* requirement, especially where the magnets are of low length-to-section ratio. As suggested at (G), (H), (I) in Fig. 1, the peak potential required can be reduced if the self-demagnetizing influence of the magnets shape is minimized by increasing the slope of the air-gap line. This can be achieved by using a demagnetizing fixture shaped to provide return paths of soft steel that create the effect of a long magnet whose operating point is close to B_r.

Eddy Currents. The influence of induced eddy currents must be considered in magnets of appreciable cross section. The opposition of induced eddy currents to the field of the external demagnetizer is maximum in the center of the magnet section and diminishes rapidly toward the edges. In large magnets the eddy currents actually may prohibit demagnetization in the center portion. The depth of penetration (D) of an alternating flux in a ferromagnetic material is given by the following expression:

$$D = K\sqrt{e/\mu f}$$

$e =$ resistivity
$\mu =$ permeability
$f =$ frequency
$K =$ constant

Modern permanent magnet materials (alnico family) are of low permeability and relatively high resistivity which results in good penetration, generally speaking. In practice, 60-cycle alternating current is used successfully in demagnetizing all but the largest magnets. For extremely large castings lower frequencies of 5-10 cycles are sometimes used. In many instances incomplete demagnetization attributed to eddy current influence is actually the result of the effective H being too low and the consequent lack of symmetry about the origin.

With permanent magnets having values of H_c approaching B_r, the extreme values of H_{ci} and H_{cr} encountered make conventional demagnetizing difficult. Many of these materials have low Curie temperatures above which magnetization disappears. Exposure to their Curie temperature of Barium ferrite (460 C) and cobalt platinum (480 C) allows complete demagnetization without changing the internal structure of the material; ie, they can be remagnetized to obtain their full magnetic properties. ○○○

Alternating Field Demagnetization

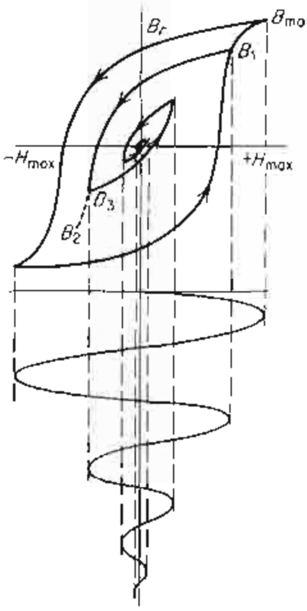


FIG. 15

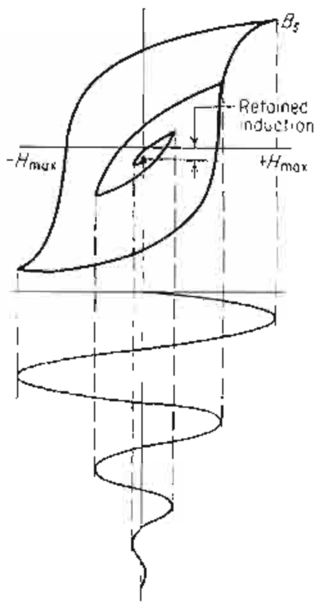


FIG. 16

Fig. 15—Exposing a magnet to a gradually reduced alternating flux field, initially of magnitude H_{max}, will remove any external traces of magnetic induction.

Fig. 16—But if the amplitude of the alternating field is reduced too quickly, the symmetry of the hysteresis loop about the origin may be destroyed and the magnet will retain some induction.

Typical Demagnetizers

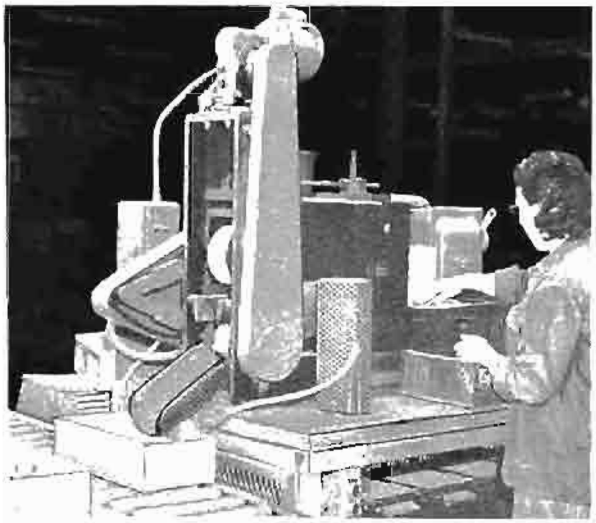


Fig. 17 -The effect of a gradually reduced alternating field can be achieved by belt-conveying the magnets through an a-c solenoid whose field at the center is H_{max}.

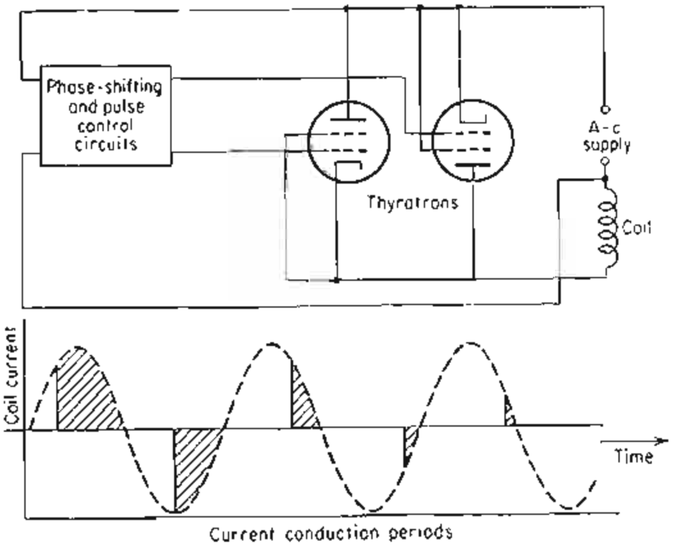


Fig. 18—Back-to-back thyratrons demagnetize by impulses with a phase-shifting circuit to delay firing on each successive half cycle to decrease the amplitude and duration of each successive pulse.

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