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DEMAGNETIZATION IN PERMANENT MAGNET MOTORS

Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science in Engineering.

by

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The author is indebted to Delco Products Division for the use of their facilities and to Mr. William Fritz for the lengthy discussions the writer had with him. A word of thanks must go to Miss Diane Broadstone who, very patiently, typed this thesis.

ABSTRACT

The design of high production, fractional horsepower, permanent magnet motors is discussed, and a technique for dealing with demagnetization aspects is developed.

The magnets under consideration are the ceramic type which are relatively new and inexpensive. These magnets could be made in large quantities at different times without the loss of repeatability in characteristics.

This kind of motors is becoming highly competetive in the automotive field and the home appliances benefiting from the great advances in the art of solid state devices for power conversion to D.C.

There is a lack of design technique for the permanent magnet motor due to its recent entery into the market. The general design techniques peculiar to this type of motors are discussed, and in particular, a new graphical method for dealing with the demagnetization problem is developed in explicit details. It is shown that demagnetization can be predicted, and experimental data is presented to support the theoretical solutions.

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INTRODUCTION

Motors having permanent magnets as their fields are referred to in this thesis as permanent magnet motors. The permanent magnet motors discussed here are the high volume (Millions), fractional horsepower (less than .5 horsepower), inexpensive (less than $10.00) type motors. Naturally, these motors have broad tolerances and inexpensive components, but still, they are reliable and easily meet their life expectency.

Since we are dealing with permanent magnets, we shall define few symbols and terminologies, using the CGS System, before we proceed any further.

ϕ: Total flux in maxwells

B: Magnetic induction or flux density in gauss

Br: Magnetic induction left in a magnet after the magnetizing field is reduced to zero; See Figure 1.

H: Magnetizing force in Oersteds

Hc: Coercive Force (Oersteds) which is the magnetizing (or demagnetizing) force required to bring the induction to zero; See Figure 1.

Hci: Intrinsic Coercive Force; See Figure 2.

Permeability: The ratio of the normal induction to the corresponding magnetizing force.

Ha: Demagnetizing force in Oersteds due to the armature ampere turns.

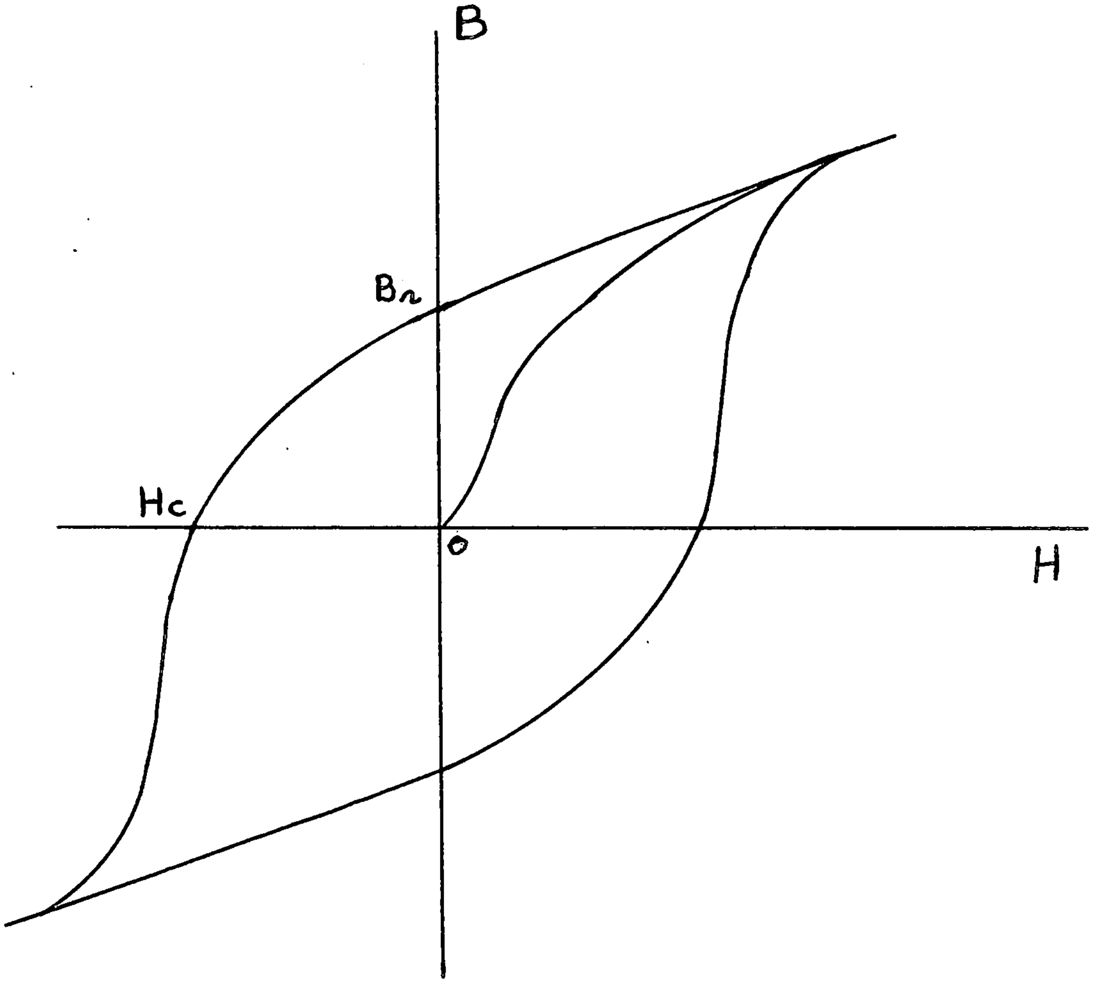

FIGURE 1, HYSTERESIS LOUP

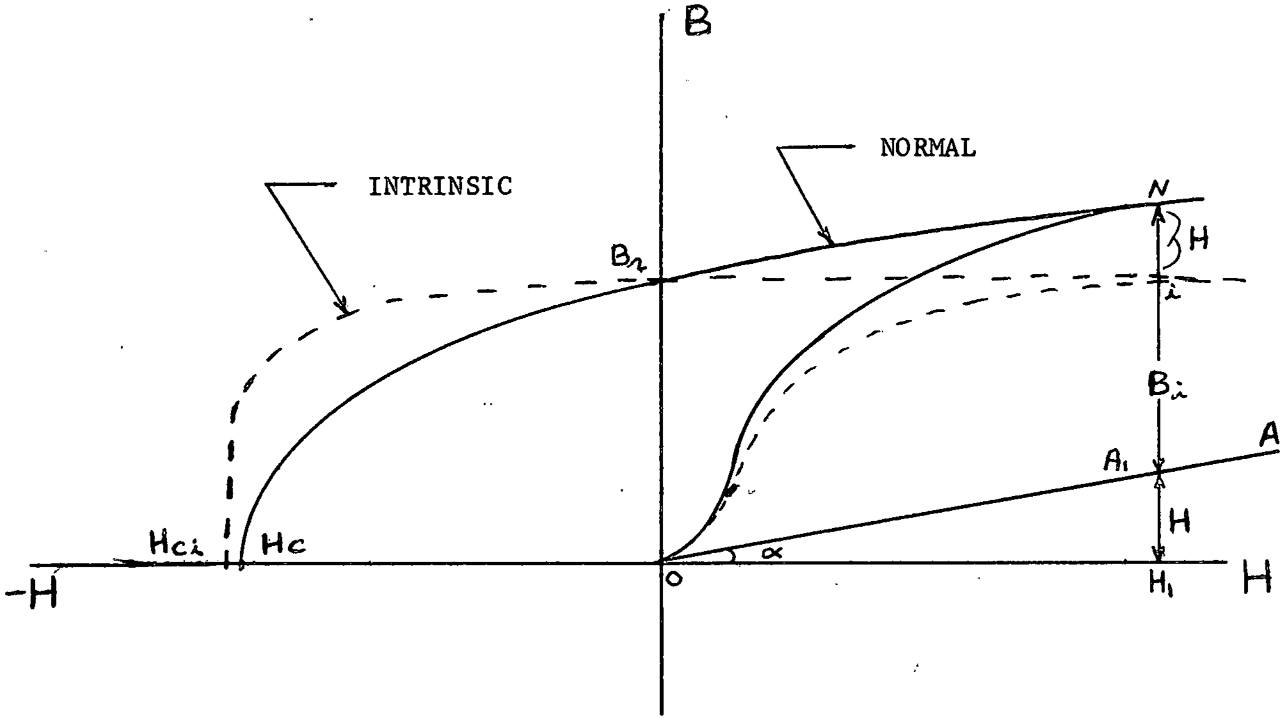

FIGURE 2, NORMAL AND INTRINSIC CURVES

Incremental Permeability: $\mu\Delta$, the ratio of the cyclic change in magnetic induction to the corresponding cyclic change in magnetizing force when the mean induction differes from zero. $\mu\Delta = \frac{\Delta B}{\Delta H}$

Demagnetizing Curve: The second quadrant of the hysteresis loop is referred to as the demagnetization curve; See Figures 1 and 2.

Intrinsic Demagnetization Curve: As figure 2 shows, line OA would be obtained without the presence of a magnet. This line is linear with a slope of unity (the B and H coordinates are drawn to different scales in figure 2). In the presence of a magnet, the solid line curve is obtained (normal curve). At H_1, $B = B_N$ instead of just B_{A1}, and this is due to the intrinsic magnetization which is the spontaneous magnetization characterizing permanent magnets. Therefore, $B_N = Bi + H$ where Bi is due to the intrinsic magnetization, and $H = B_{A1}$ (Unity Slope). To draw the intrinsic curve if the normal curve is given only, at every given H subtract the value of H from the corresponding B. The intrinsic curve is used in determining demagnetization.

During the research on which this thesis is based, magnets used were made by Allen Bradley Company (MO5-C and MO6-C Magnets). Other magnets were made by Stackpole Carbon Company (A-19 Magnets). Magnets made by Indina General Company (Indox III) also were tested.

Demagnetization in a permanent magnet motor could be a very serious problem facing the designer of such a machine.

This thesis deals with the problem assuming that the magnets used are the ceramic type (Antiferromagnetic Materials).

In practical usage of permanent magnets, it is desirable that a high level of flux (or flux density, Br) remains after the external field is removed when magnets are magnetized. Also, it is desirable that the magnet would have a high degree of resistance to becoming demagnetized by the opposing magnetic fields generated within the device of which the magnet is a part. Ferromagnetic materials, like Alnico, usually have a very high Br, but their resistance to demagnetization is very low (low Hc). This demagnetization problem limited the use of permanent magnets until few years ago when new techniques were developed to make permanent magnets from antiferromagnetic materials (Ceramic Magnets). Ceramic magnets are developed with higher Br and higher Hc every year, and their industrial usage is increasing at a very high rate. Magnets having Br $>$ 4000 Gauss and Hc $>$ 4000 Oersted are realized in the laboratories and soon will be available commercially.

The difference between ferromagnetism and antiferromagnetism is found in the fashion in which the spin magnetic moments of neighboring atoms are aligned.(1) In ferromagnetism, the spin magnetic moments of neighboring atoms are kept parallel to each other by the exchange interaction. In antiferromagnetism the spin magnetic moments of neighboring atoms are antiparallel. This antiparallel coupling is usually accomplished with the help of a negative oxygen ion. The negative oxygen ion is sandwiched between two positive ions (the two elementary magnets).

If the two positive ions have the same magnetic moment, the net strength of magnetization is zero giving rise to the name antiferromagnetism. However, if the compounds are made in such a way that some of the neighboring ions are different, and consequently, have different strength magnetic moments, a certain net magnetization will occur. These compounds are called FERRIMAGNETIC, and they are usually referred to as FERRITES. The ceramic magnets mentioned above are these same Ferrimagnetic Compounds or Ferrites. These compounds are

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(1) "Modern Physics" by R. L. Sproull, J. Wiley and Sons, New York, 1966, Chapter 9.

usually lead ferrites, barium ferrites, strontium ferrites, or other compounds.

Ceramic magnets have high Hc because ferrites have precipitated impurities, strains, small crystals, and other imperfections all of which contribute to impeding the movements of the domain boundaries.(2)

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(2) For a very extensive coverage of the subject of magnetism, see "Ferromagnetism" by R. M. Bozorth, D. Van Nostrand, 1951, Chapter 10.

ADVANTAGES AND LIMITATIONS OF PERMANENT MAGNET MOTORS

The permanent magnet motor is competitive with the wound field motor. Let us compare these two classes of machines.

D. C. Motors are basically three types - series, shunt, and compound. The inexpensive type of permanent magnet motor under consideration has only the characteristics of a shunt type motor; therefore, a total replacement of wound-field motors by permanent magnet motors could not be accomplished without some sacrifices in the performance characteristics of the motor, or increasing the cost of the motor by resorting to aiding series windings.

Another limitation that the permanent magnet motor faces is the fact that the demagnetization problem could become very serious at low temperatures. It is easier to change domain boundaries in a magnet at low temperatures; therefore, it is easier to demagnetize a magnet at such temperatures.

The performance of a permanent magnet motor changes with temperature more drastically than does the performance of a similar wound-field motor.

As far as motor control is concerned, the control of a permanent magnet motor is more limited than a wound field-motor because, in a permanent magnet motor, only the armature current is under control.

However, the permanent magnet motor has enough advantages to make it more desirable than the conventional wound-field motor in many applications. Consider these several examples.

The permanent magnet motor has a linear speed-torque characteristics because the flux in the poles is almost constant for all values of armature current. Consider this general expression.(3)

$$N = \frac{E_\ell}{K\Phi} - \frac{R_\alpha \; T}{1355\, K^2 \Phi_p^2} \qquad (1)$$

Where: E_ℓ = Line Voltage

K = Constant

Φ_p = Flux Per Pole

R = Armature Resistance

T = Torque

N = Motor Speed

From relation (1) above, it is seen that N is linearly dependent on T.

Another example: Since no current is required for the field of a permanent magnet motor, it runs cooler and more efficiently than the wound field motor which develops Joule

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(3) Magnetic Materials Producers Association, final report, December 9, 1964, P. 16, pamphlet written by Basil Wenworth

Losses in the field resistance. Other advantages accrue in that the permanent magnet motor usually weighs less, is of smaller size, and costs less than a wound-field motor. Further, miniaturization (on the order of .25 in^3) has become increasingly important, and the permanent magnet motor is easier to miniaturize than the wound-field motor.

As a final example, the commutation in a permanent magnet motor is better than that of a wound-field motor because of the low incremental permeability of the permanent magnet which is in series with the air-gap. (4) This tends to reduce the reactance voltage.

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(4) Magnetic Materials Producers Association, final report, December 9, 1964, P. 16, pamphlet written by Basil Wenworth

PERMANENT MAGNET MOTOR DESIGN

Permanent magnet motor design differs from the conventional motor design in at least two important ways. One dissimilarity will be discussed in this section, the second one will be discussed in the next section.

The two important dissimilarites are the demagnetization problem encountered in permanent magnet motors, and the calculations for the total flux available per pole. Now, we shall discuss in brief how a designer may calculate for the total flux per pole.

There are many ways one may follow in the flux calculations for a permanent magnet motor. Almost every manufacturer of permanent magnets has written simple procedures to follow when calculating the flux per pole. These simple procedures are very good approximations; however, we shall mention a more complicated method which can yield very accurate results.

Figure 3 shows a cross-section of a permanent magnet motor. The same figure illustrates how the magnet flux is distributed in the motor.

Figure 4 shows a simple magnetic circuit simulating the magnetic circuit around an armature slot. This circuit consists of a permanent magnet (M), two iron paths (R_1 and R_2), an air-gap (Ag), and a current carrying conductor (I). For

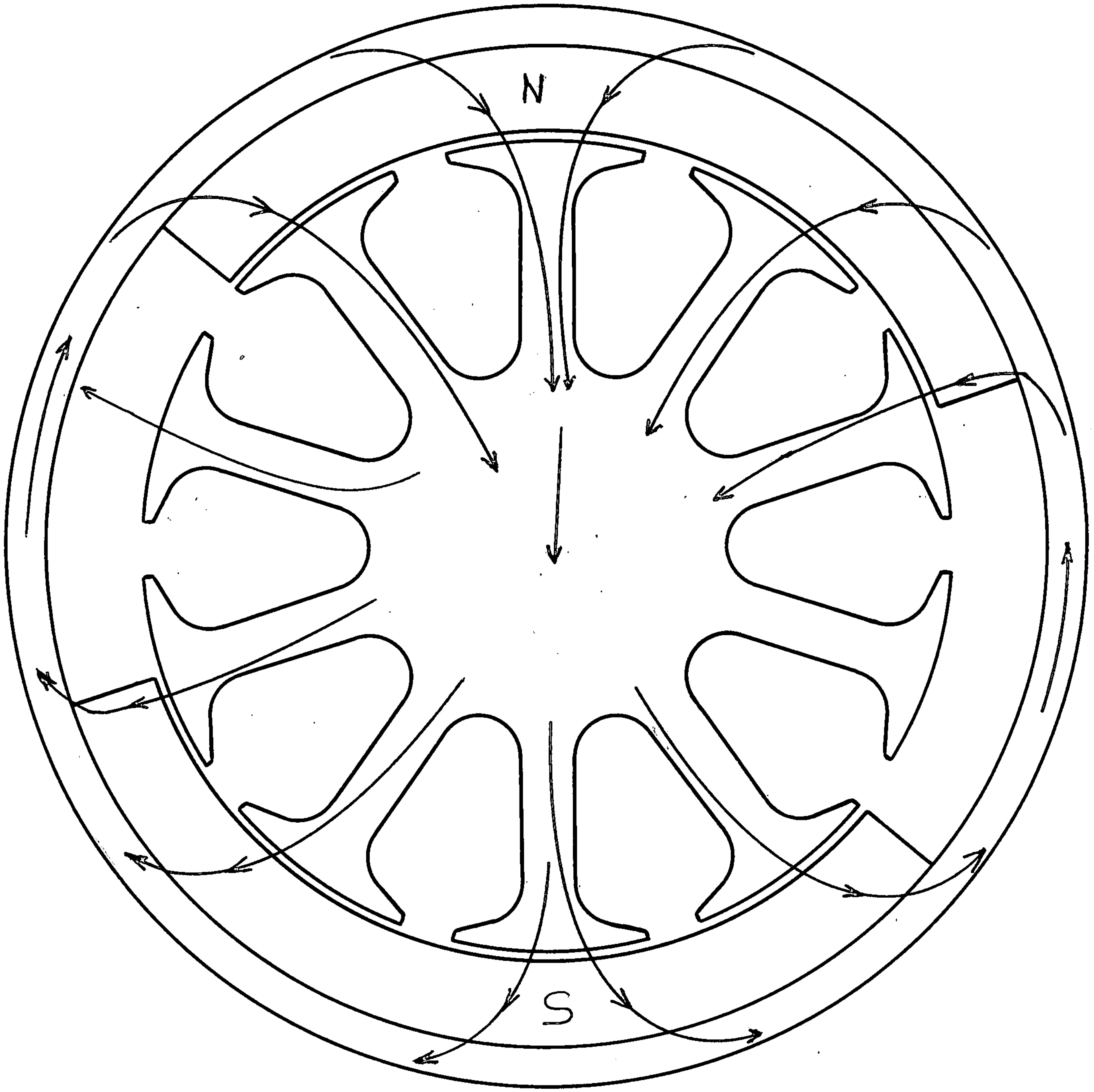

FIGURE 3, A CROSS SECTION OF A PERMANENT MAGNET MOTOR

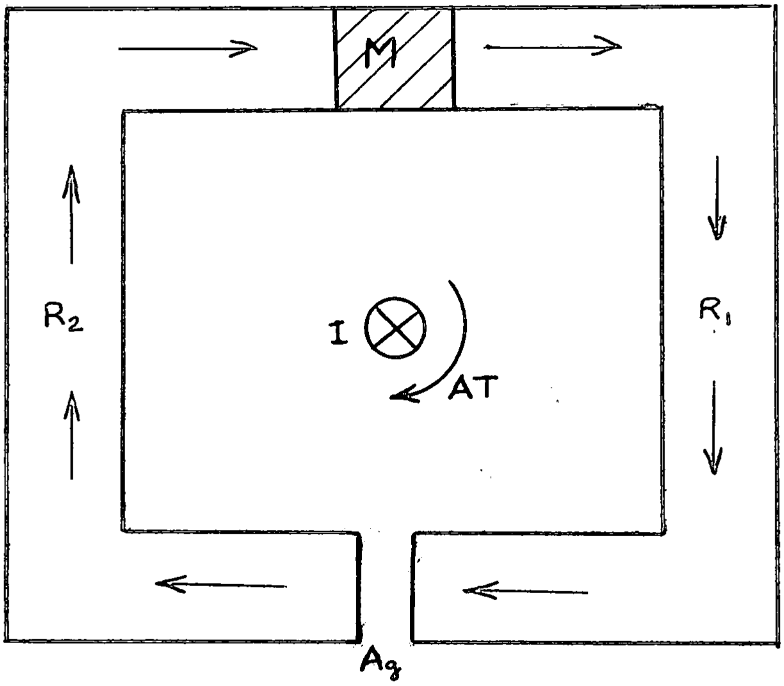

FIGURE 4, A MAGNETIC CIRCUIT

this circuit, an equation could be written as follows:

$$R_1 \phi + Ag \phi + R_2 \phi + M \phi = ATA + ATF$$

Where: R_1 = Iron Reluctance

R_2 = Iron Reluctance

Ag = Air-Gap Reluctance

M = Magnet Reluctance

ATA = Armature Ampere Turns

ATF = Field Ampere Turns

ϕ = Flux

If such an equation is written for every loop around every slot in figure 3, and all the equations then solved simultaneously for a given number of armature ampere turns and magnet flux, a quantitative distribution of flux could be obtained. Of course, once that is done, the total flux per pole could be easily summed up and made available for the performance calculations.

This is a time consuming method, and it is best suited for computer applications. However, its accuracy may justify its use even without the aide of a computer if a computer is not available.

The importance of this method lies in the fact that the flux density distribution in the motor is given, and the designer can avoid excessively high densities of flux by changing the flux paths where the high densities occur.

DEMAGNETIZATION IN A PERMANENT MAGNET MOTOR

The flux density in a permanent magnet does not stay constant under all conditions. The loss in flux could be either reversible or permanent. For example, a magnet could be demagnetized by mechanically shocking it, by heating it, or by subjecting it to an external demagnetizing field.

The loss of flux due to mechanical shock is permanent. Alnico Magnets are demagnetized easily by means of mechanical shock, but the writer had tried in vain to demagnetize a ceramic magnet via mechanical shock. In every trial, the magnet broke into several pieces before significant demagnetization was noticed. One large manufacturer (5) of ceramic magnets was contacted concerning this test, and he confirmed the findings of the writer.

If the total flux of a permanent magnet is measured at room temperature, and then another measurement is taken after the temperature of the magnet has been increased to a value below the Curie Point. The second measurement would indicate a reduction in flux. If the permanent magnet is cooled.

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(5) Stackpole Carbon Company, St. Marys, Pennsylvania, Mr. H. White

back to room-temperature again, the flux level would increase back to the original level without any permanent loss.(6) However, if the permanent magnet were heated to or above the Curie Point, the loss in flux would be permanent, and the magnet would be completely demagnetized.

In a permanent magnet motor, the armature ampere-turns have a demagnetizing effect on the magnet. The effect could be either a reversible loss in flux or a permanent one. In figure 5 a cross section of a two-pole permanent magnet motor is shown. In this ten-slot armature motor, notice that the armature ampereturns are not opposing the magnet flux everywhere in the motor, only in teeth 2, 6, and 7. Actually, very little flux, the leakage flux only, passes through tooth #6; therefore, it could be neglected. There are three teeth under each pole, but most of the demagnetizing effect takes place in only one of the three teeth. This offending tooth is under the trailing edge of the magnet. If the motor is uni-directional in rotation, only the trailing edge of the magnet is demagnetized to a certain level. The level of demagnetization depends on the area of the critical tooth, the magnitude of the ampere-turns in the armature, and the properties and dimensions of the permanent magnet.

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(6) Parker and Studders "Permanent Magnets and Their Application", John Wiley and Sons 1962, P. 343

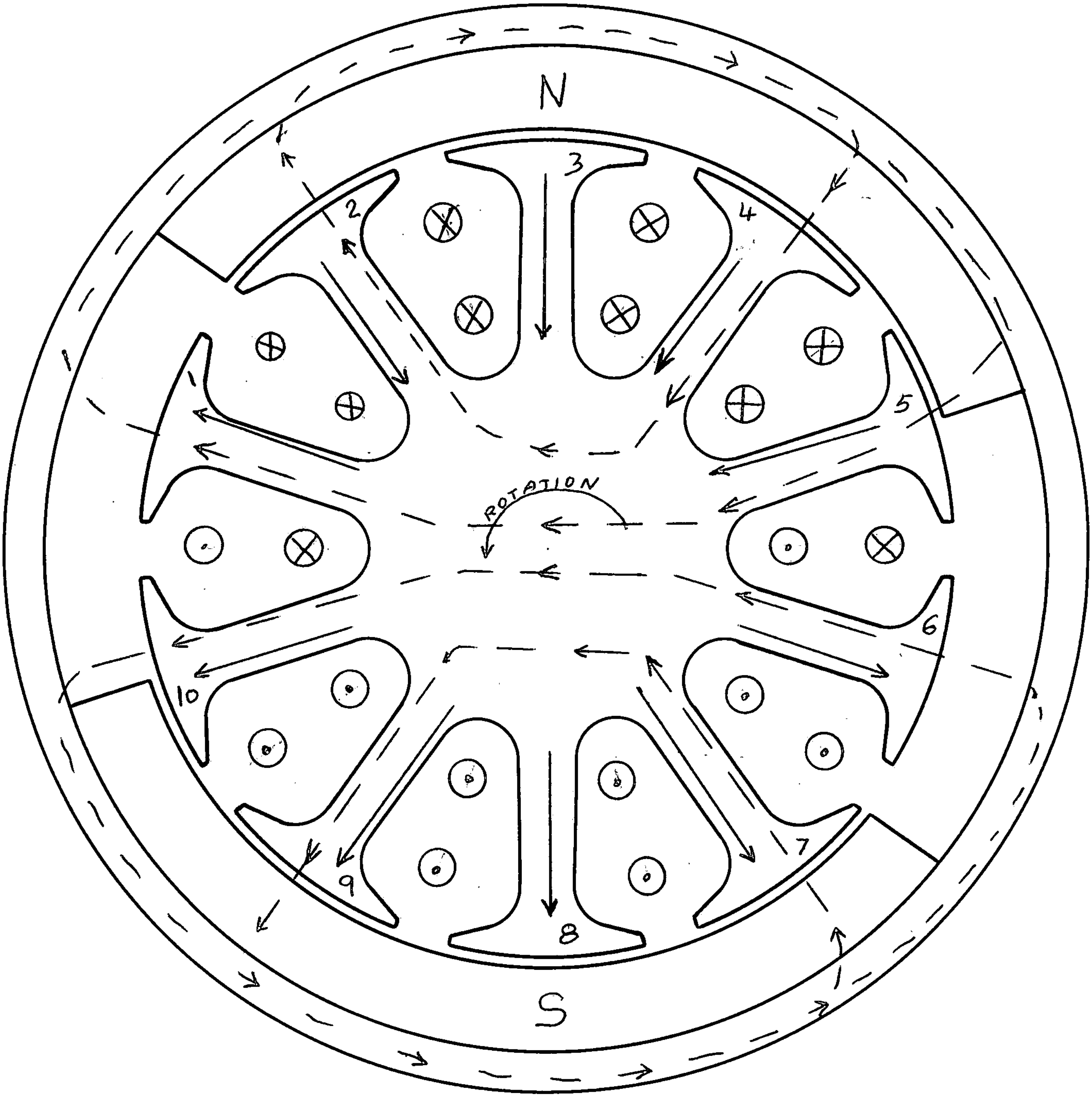

FIGURE 5, FLUX DISTRIBUTION IN A TWO POLE PERMANENT MAGNET MOTOR

____ ____ FLUX DUE TO MAGNET

---- ---- FLUX DUE TO ARMATURE AMPERE TURNS

Figure 5 shows one offending tooth out of three only because we have a ten-slot armature. If the number of slots increases, we can distinguish a larger ratio of critical teeth. If the number of slots is very large, we can see that half the magnet arc is subjected to varying degrees of demagnetization intensity as figure 6 shows.

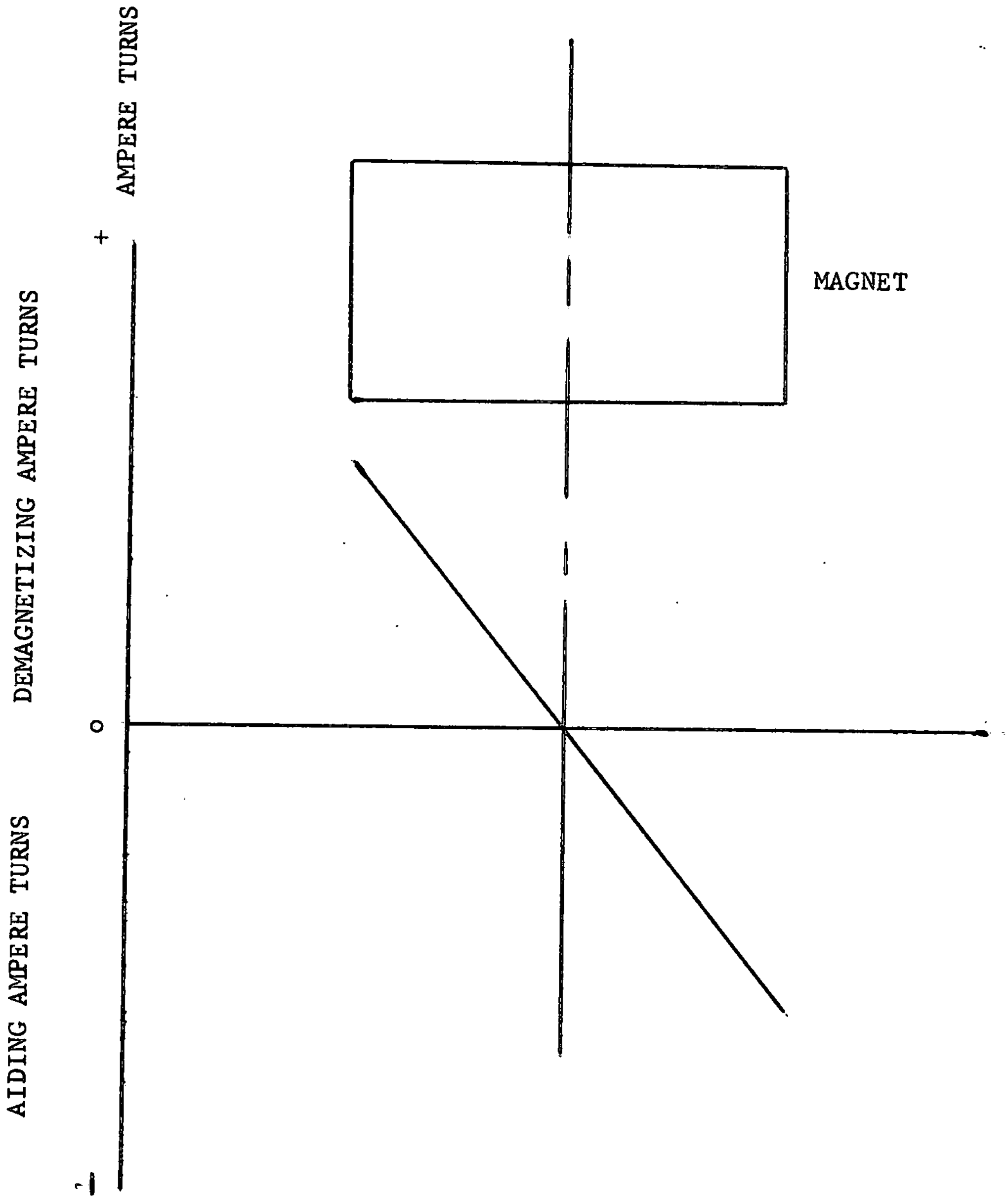

FIGURE 6, ARMATURE AMPERE TURNS DISTRIBUTION UNDER ONE POLE

GRAPHICAL SOLUTIONS

The problem of calculating and predicting demagnetization in a permanent magnet motor requires mostly graphical solutions. Knowing the properties of the magnet, the Pci Line and Ha, one could predict the demagnetization which may take place in a given magnet. First, we shall explain the terms Pci and Ha. Then we shall show how a graphical solution could be obtained. Refer to figure 7. Tan α , or the slope of the line oa is called the permeance coefficient Pc. From figure 4, the following equations could be written neglecting the iron paths:

$Hm\ Lm = Hg\ Lg$

Where: m = Magnet

L = Length

g = Air-Gap

Since $Hg = Bg$; we can write:

$$Hm\ Lm = Bg\ Lg \tag{2}$$

Also Since $\emptyset m = \emptyset g$

$$Bm\ Am = Bg\ Ag \tag{3}$$

If we divide (3) by (2)

$$\frac{Bm\ Am}{Hm\ Lm} = \frac{Bg\ Ag}{Lg\ Bg}$$

$$\frac{Bm}{Hm} = \text{Tan}\ \alpha = \frac{Ag\ Lm}{Lg\ Am} \tag{4}$$

The line whose slope is tan α is called the permeance

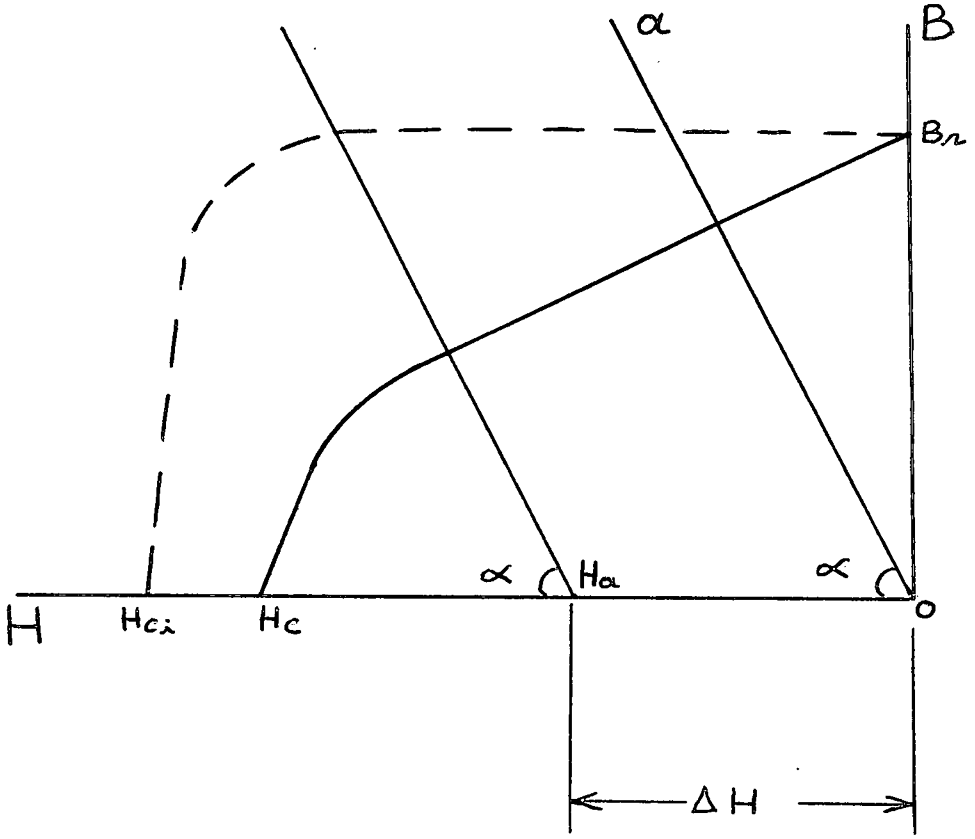

FIGURE 7, THE DEMAGNETIZATION CURVE AND THE ANGLE α. TAN $\alpha = \frac{Bm}{Hm}$

coefficient line Pc, and it is drawn from the origin to the normal demagnetization curve. Knowing the definition of the intrinsic demagnetization curve, a new load line called the intrinsic permeance coefficient line Pci could be constructed.

$$Pci = \frac{Bm + Hm}{Hm} = Pc + 1 \quad (4\text{-a})$$

So far, we assumed I = o amperes in figure 4. If $I > o$, the following will be true:

$$Hm\ Lm = Bg\ Lg + .4\pi NI$$

Where N = Number of Turns

I = Current

$$\therefore \quad Hm = \frac{Bg\ Lg + .4\pi NI}{Lm}$$

Since from (3) $Bg = \frac{Bm\ Am}{Ag}$

$$Hm = \frac{Bm\ Am\ Lg}{Ag\ Lm} + \frac{.4\pi NI}{Lm} \qquad (5)$$

From figure 7 and equation (4)

$$\frac{Bm}{Hm-Ha} = \frac{Ag\ Lm}{Am\ Lg}$$ (7)

$$\underline{Hm-Ha} = \frac{Bm\ Am\ Lg}{Ag\ Lm}$$

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(7) J. Ireland, Indiana General Corporation, a non cataloged pamphlet.

Therefore

$$Ha = Hm - \frac{Bm\ Am\ Lg}{Ag\ Lm}$$

$$\text{or } Hm = \frac{Bm\ Am\ Lg}{Ag\ Lm} + Ha \qquad (6)$$

If we compare (6) to (5), we find the following is true:

$$Ha = \frac{.4\pi NI}{Lm} \text{ Oersteds} \qquad (7)$$

If we were dealing with other than ceramic magnets where the incremental permeability ($\mu\Delta$) is not unity, equation (7) would become:

$$Ha = \frac{.4\pi NI}{Lm/\mu\Delta}$$

PROCEDURES FOR THE GRAPHICAL SOLUTION

Now, we are able to demonstrate the graphical method of predicting demagnetization. Refering to figure 8, we construct line OO' which is the permeance coefficient line Pci. This line intersects the intrinsic curve at point A. From A, we draw a line to A' perpendicular to the H axis, OA' = Pc. From A', we draw a line perpendicular to the B axis $A'B_{r1}$. The point B_{r1} represents the flux density at which the motor is operating. Having calculated for Ha, we move an equal distance on the H axis and draw a line Ha H' because we have moved on the curve by the amount Ha via energizing the motor. Ha H' has the same slope as OO'. This new line intersects the intrinsic curve at point C. From C, we draw a line CD parallel to the upper portion of the intrinsic curve. This line represents a portion of the new intrinsic curve caused by introducing an air-gap in the circuit and a demagnetizing force Ha. Then we draw a line DD' parallel to the B axis. We go back to point C and draw a line CC' parallel to the B axis and intersecting the normal curve at C'. Of course, CC' = Hc'. From C', we draw a line C'E parallel to the upper portion of the normal curve. This line represents a portion of the new normal curve caused by introducing an air-gap in the circuit and demagnetizing force Ha. DD' and

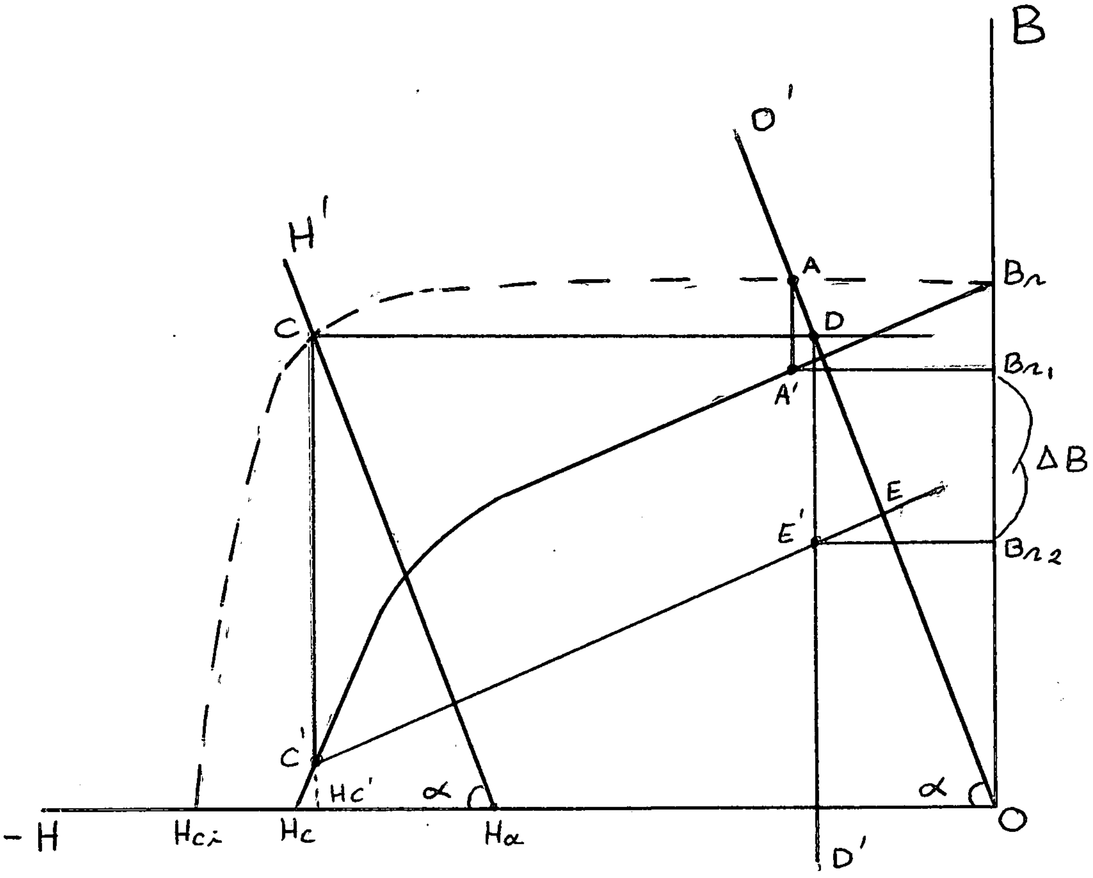


FIGURE 8, DEMAGNETIZATION CURVE SHOWING

DEMAGNETIZATION OF AMOUNT ΔB

C'E intersect at E'. From E', we draw a line $E'B_{r2}$ perpendicular to the B axis. B_{r2} represents the flux density at which the motor is operating after introducing an air-gap in the circuit and a demagnetizing force Ha.

$B_{r1} - B_{r2} = B$ = The permanent demagnetization of the magnet, under the critical tooth, after de-energizing the motor.

Notice how no demagnetization will take place if the line Ha H' intersects the intrinsic curve before the knee as in figure 9.

If the motor is subjected to the same demagnetizing force Ha again, no further demagnetization will occur because we would be operating above the knee of the new curve. If the Ha is increased, of course a new demagnetization will take place. Also, the motor will be demagnetized further if the same Ha is repeated in the opposit direction of rotation; that is, if the motor was demagnetized in the CW rotation first and the CCW rotation second or vice versa.

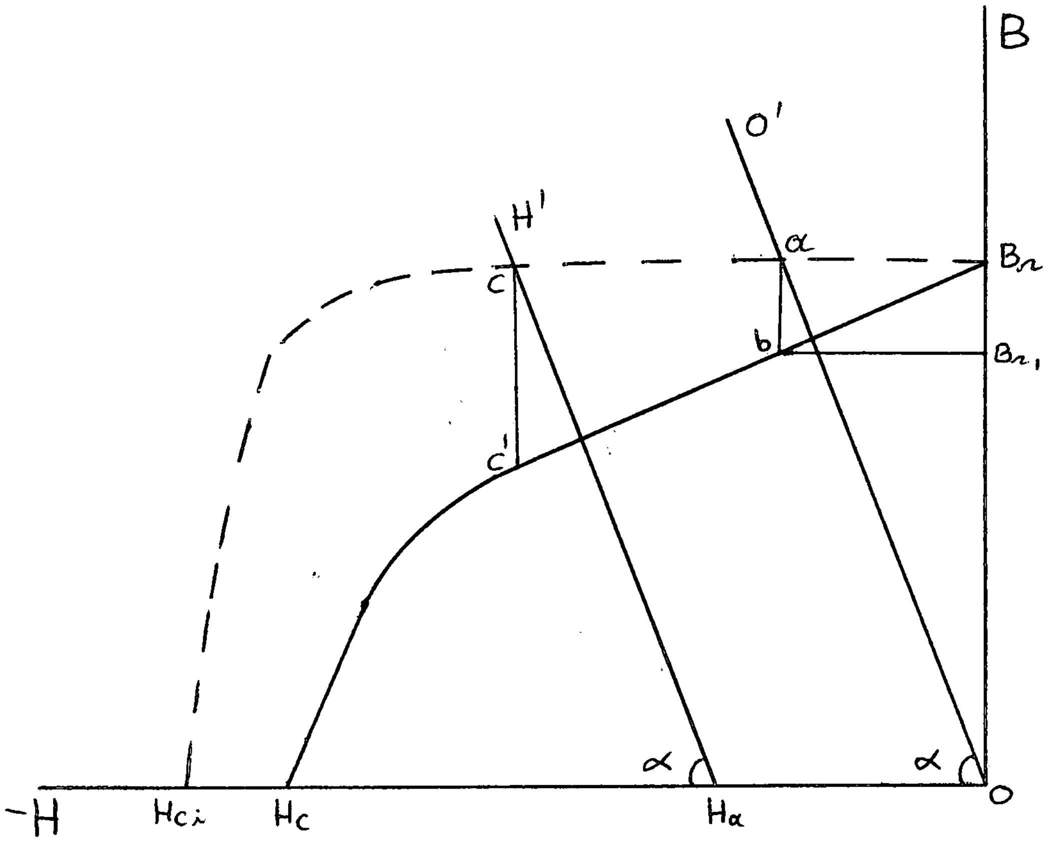


FIGURE 9, DEMAGNETIZATION CURVE SHOWING NO DEMAGNETIZATION

(Ha HAS NO PERMANENT DEMAGNETIZATION EFFECT)

SOLVING AN ACTUAL PROBLEM

In a two-pole permanent magnet motor (see the following photographs), we have:

1 - Lap winding, two parallel paths

2 - The maximum stall current at -40°F is 115 amperes.

3 - $L_m = .95$ Cm

4 - $L_g = .076$ Cm

5 - $N = 11$ turns / coil, two coils / slot

6 - $A_g \approx A_m$

7 - The total area of the magnet = 29.1 CM^2

8 - The area under the critical tooth = 5.8 CM^2

$$P_{ci} = P_c + 1 = \frac{L_m}{L_g}\frac{A_g}{A_m} + 1 \approx \frac{L_m}{L_g} + 1 = \frac{.95}{.076} + 1$$

$$= 12.5 + 1 = 13.5$$

$$\therefore \tan \alpha = 13.5$$

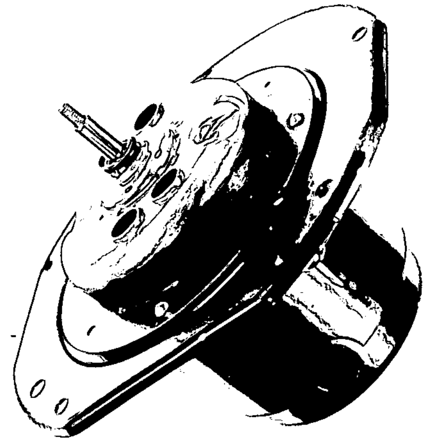
Now, we calculate for Ha.

$$H_a = \frac{.4\pi NI}{L_m}$$

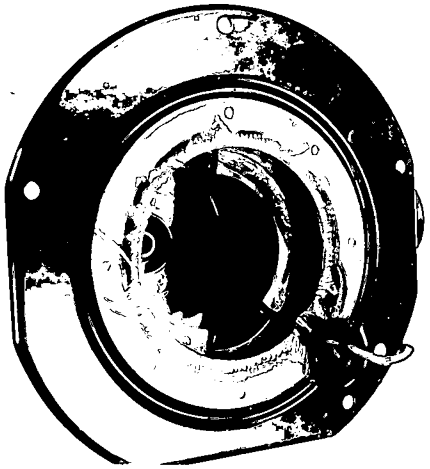
$$= \frac{.4\pi \times 11 \times 115 \times 2}{.95 \times 2} = 1675 \text{ oersteds}$$

If we go to figure 10 and follow the same procedures outlined in the previous section, we find:

The operating flux density before demagnetization is 3000 gausses.

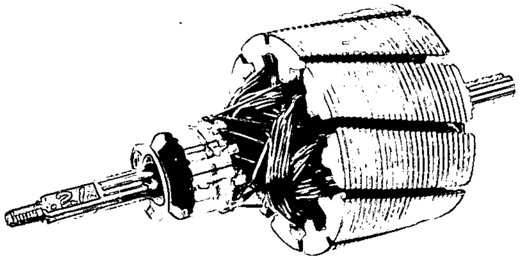


PHOTOGRAPH #1 MOTOR



PHOTOGRAPH #2 CASE AND

THE TWO MAGNET SEGMENTS



PHOTOGRAPH #3 ARMATURE

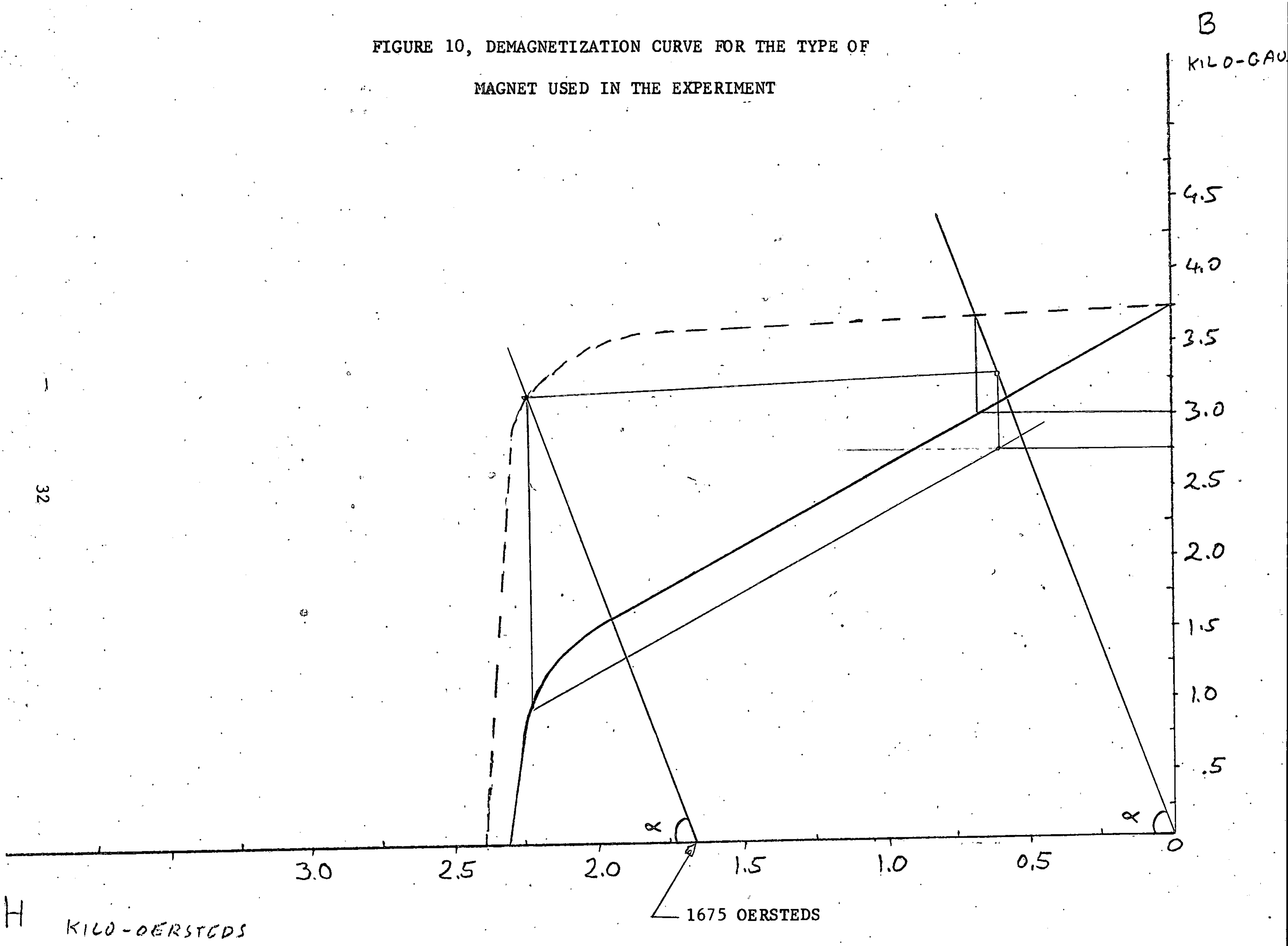


FIGURE 10, DEMAGNETIZATION CURVE FOR THE TYPE OF MAGNET USED IN THE EXPERIMENT

The operating flux after demagnetization is 2750 gausses.

Total flux before demagnetization = 29.1 X 3000 =
87300 maxwells

Flux loss due to demagnetization = 250 X 5.8 = 1450
maxwells

$$\% \text{ loss in flux} = \frac{1450 \times 100}{87300} = 1.66\%$$

Two motors were driven at a constant speed of 3600 RPM reading the generated voltage with a high impedance digital voltmeter. Then the same motors were stalled in a chamber where the temperature was -40°F. After the temperature of the two motors returned back to room-temperature again, the above generated voltage test was repeated.

Generated voltage before demagnetization = 9.78 volts

Generated voltage after = 9.63 volts

$$\% \text{ loss} = \frac{(9.78 - 9.63)\ (100)}{9.78} = 1.53\%$$

Having in mind that the demagnetization curve of figure 10 represents the average for the type of magnet used in the test not the exact magnet used, the correlation between calculated data and measured data is very good.

Since demagnetization was not significant, the motor was not redesigned. Had the demagnetization been excessive, the magnet radial length would have been increased, or the power out-put of the motor would have been decreased.

THE EFFECT OF DEMAGNETIZATION ON PERFORMANCE

The torque developed in a given motor depends on the total flux in the motor. Also, the current and the speed are a function of the flux.

Let us restate equation (1):

$$N = \frac{E\ell}{K\phi} - \frac{RaT}{1355K^2\phi^2} \qquad (1)$$

Also $T = K_t\ Ia\ \phi$ (8) $\qquad$ (8)

Where: N = Motor Speed

$E\ell$ = Line Voltage

K = Constant

ϕ = Total Flux

Ra = Armature Resistance

T = Torque

Kt = Another Constant

Ia = Armature Current

It is obvious from equation (1) above that the speed increases if the flux decreases ($T = 0$). Equation (8) indicates that a loss in flux results in a decrease in the torque unless the current increases. Therefore, a loss in

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(8) Electrical Engineering Volume I, C. L. Dawes, McGraw Hill Company, 1952, P. 485.

flux will result in an increase in the speed of a motor at no load and in a decrease in torque.

Figure 11 shows the change in performance due to a decrease in available flux. Notice that the speed-torque curve rotates from position S_1 T_1 to S_2 T_2. For a given load between zero and T_o the speed increases. Between To and the stall point, the speed decreases with a decrease in flux. The explanation could be found in the following equation:

$$N = K_2 \frac{E_\ell - Ia\ Ra}{\phi} \quad (9) \qquad (9)$$

Where: K = Constant

E_ℓ = Line Voltage

Ia = Armature Current

Ra = Armature Resistance

ϕ = Total Flux

N = Motor Speed

At point To, figure 11 shows no change in RPM. This is because the numerator in the right side of the equation (9) changed by the same amount as ϕ did. To the right of T_o, the change in the denominator (ϕ) was less than the change

---

(9) $E = \phi N K_1$

$E = E_\ell - Ia\ Ra \qquad E_\ell - Ia\ Ra = \phi N K_1$

and $N = K_2 \frac{E_\ell - Ia\ Ra}{\phi}$

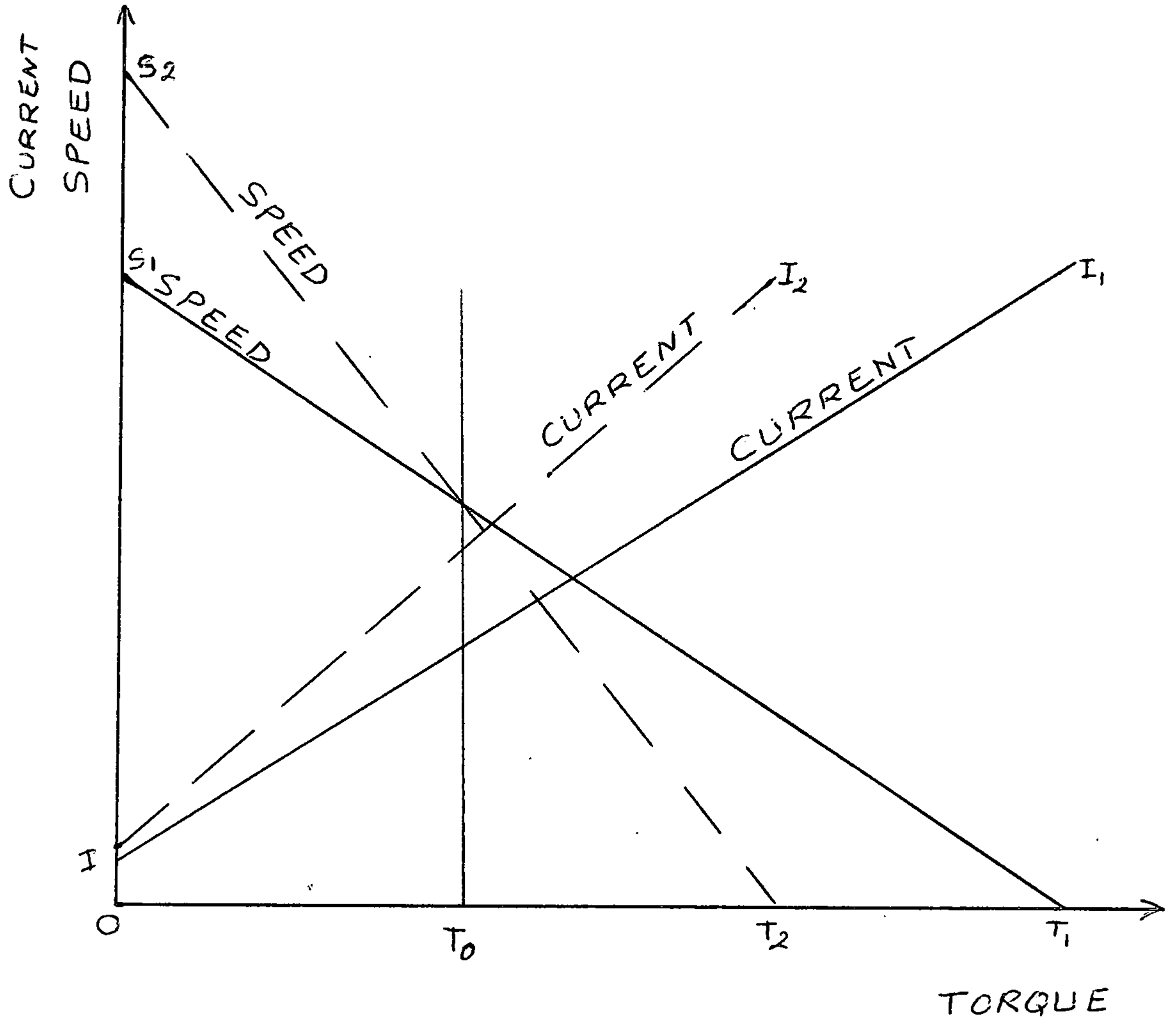

FIGURE 11, EFFECT OF DEMAGNETIZATION ON MOTOR PERFORMANCE

____BEFORE DEMAGNETIZATION

----AFTER DEMAGNETIZATION

in the numerator; therefore, the speed decreased. To the left of T_0 the decrease in ϕ was more than the decrease in the numerator; consequently, the speed increased. Equation (8) predicted a decrease in the torque if ϕ decreased. This is shown in figure 11 by noticing that stall torque T_1 decreased to T_2. Since the stall current is a function of armature resistance only, it did not change with ϕ. Notice in figure 11 that $I_1 = I_2$ and this resulted in shifting the current-torque curve from the II_1 to the II_2 positions resulting in higher current at all loads when the flux decreased.

So far, we discussed the effect of demagnetization on the static loads (constant torque points). If the motor load is a dynamic load (fan load), the demagnetization has a slightly different effect. The current increases as in the case of a static load, but the speed does not change as much as in the case of a static load.

Demagnetization results in higher operating temperatures due to higher currents; therefore, it should be avoided as much as possible. If the increase in the radial length of the magnet is not practical or desirable, a four-pole motor design may solve the demagnetization problem. Thus, the higher the number of poles the less the effect of the armature ampere-turns per pole and the less the demagnetization.

If the trailing edge of the magnet is tapered as in figure 12, the air-gap under the critical tooth increases. The increase in the air-gap shifts the intrinsic permeance coefficient line Pci increasing the value of tan α , see figure 12, as shown below:

$$\mathrm{Tan}\,\alpha \approx \frac{Lm}{Lg}$$

This may give the impression that the demagnetization would decrease. However, such a move would also decrease the active ATF of the magnet.

ATF = K X Hc X Lm

Where: ATF = Magnet MMF

K = Constant

Hc = Magnet Coercive Force

Lm = Magnet Length

This, plus the fact that, in most cases, such a configuration increases the cost of the magnet, this design is not an effective one for reducing demagnetization.

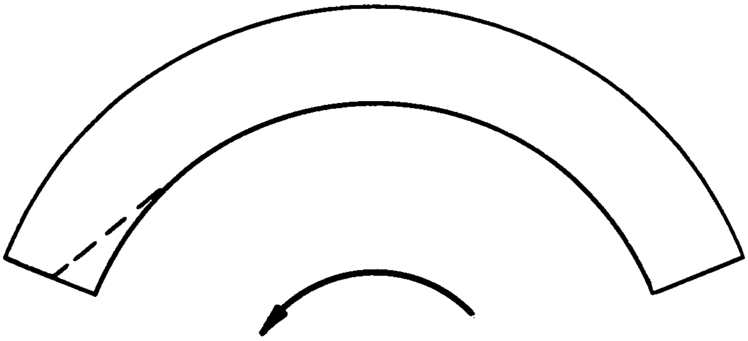

FIGURE 12, ONE MAGNET SEGMENT

---- TAPERING THE TRAILING EDGE

TO INCREASE THE AIR-GAP

SUMMARY AND CONCLUSIONS

Presently, more engineers are designing more permanent magnet motors for more applications than ever, especially in the Automotive Field and Light Home Appliances.

The magnets of a permanent magnet motor could demagnetize especially when stalled at low temperature because of the opposing ampere-turns set up by the armature windings.

This loss of flux results in higher operating currents and higher motor temperatures which could be damaging to the winding and other components. Also, the loss of flux will result in less available torque and change in the speed. If the motor is running a fan for example, the change in speed could result in a noisy operation or insufficient volume of moving air depending whether the change was an increase or a decrease in the speed.

To safeguard against demagnetization, a designer could use the demagnetization curve with its intrinsic and normal curves to predict, to a good degree of accuracy, the amount of demagnetization if any. As previously seen, the solution is a graphical one. It is straight forward and agrees well with the laboratory findings.

If the designer finds out that the demagnetization will be excessive, he could change the motor design to reduce the amount of demagnetization. We saw that the demagnetizing force Ha was:

$$Ha = \frac{.4\pi NI}{Lm}$$

Where: NI = Armature Ampere-Turns

Lm = Radial Length of Magnet

To reduce the amount of demagnetization, obviously, NI has to be reduced, or Lm has to be increased. Usually NI could not be reduced because that means a change in the characteristics of the motor. Increasing Lm means an increase in the overall diameter of the motor. If this is practically acceptable, the increase in Lm is an easy solution to the problem of demagnetization. Otherwise, increasing the number of poles will reduce the amount of demagnetization because demagnetization takes place at the trailing edge of the magnet only. Therefore, the demagnetizing effect will be divided among more trailing edges if the number of poles is increased.