



## Tape Wound Toroidal Core Design Manual



## **Tape Wound Core Design Manual**

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# INTRODUCTION TO THE TAPE WOUND CORE

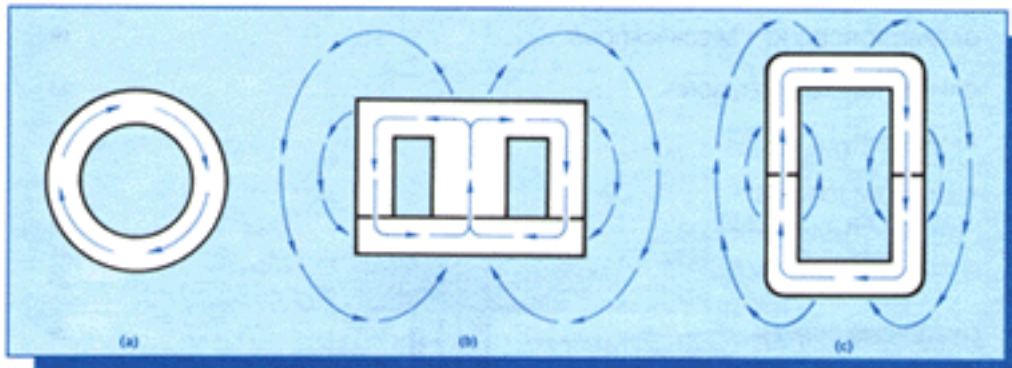
The tape wound core approaches the perfect magnetic circuit configuration. A review of the physical and magnetic characteristics of the toroidal shape reveals many features which contribute to this near-perfect circuit.

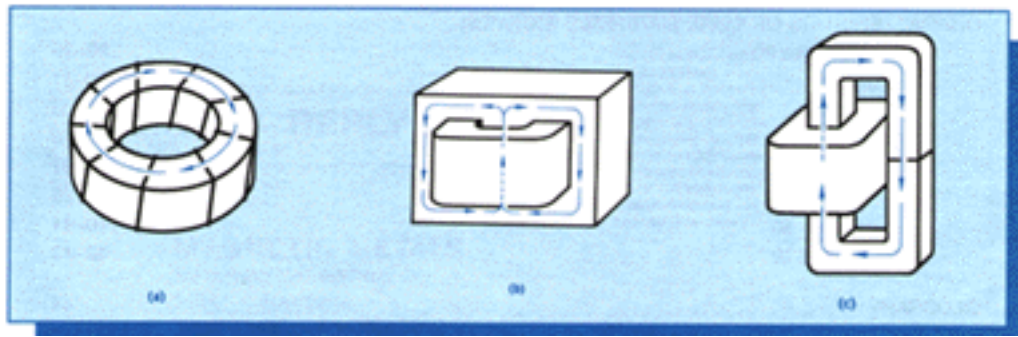
The effective air gap in the magnetic path is so small that it can be considered non-existent. This minimizes losses, fringing, leakage, distortion, and decreases the magnetizing force necessary to produce a given flux within the material. Figure 1 illustrates the leakage flux phenomenon in comparison to conventional "E" laminations and "cut cores."

In a toroidal core and coil assembly, the entire magnetic path is contained within the electrical winding, further minimizing leakage flux and increasing winding-to-winding coupling. Figure 2 illustrates this effect in comparison to the lamination and the cut core.

The tape wound core configuration also provides a good degree of self-shielding from external magnetic fields. The single, uniform, magnetic path causes any entering magnetic field to split into two and induce equal but opposite voltages in the two halves of a uniformly distributed winding. Thus, there tends to be no voltage apparently induced in the total winding. This effect can be achieved somewhat in a cut core, by splitting the windings into two halves, with one half on each leg. However, the areas in which this technique can be applied is minimal, because of the cost consideration.

Tape wound cores generate a small flux in the axial direction. This leakage flux can be contained by ring laminations assembled to the top and bottom of the core.





This manual gives complete ordering information and specifications for Magnetic Metals' comprehensive line of Tape Wound Cores. It describes the different materials, thicknesses, cases, coatings for Tape Wound Cores and presents typical hysteresis loops, CCFR control curves and core loss curves.

The unique advantages of the Tape Wound Core configuration in magnetic circuitry permits the most efficient application of high permeability magnetic alloys.

This manual is a reference source for engineers involved in the application, specification and/or purchase of these cores.

Originally published in early 1968, this updated edition of Magnetic Metals' Tape Wound Core Design Manual reflects today's technology in basic magnetic alloys, core casing, core testing and applications. It is intended to fill the design needs of both the more experienced engineer and the engineer new to Tape Wound Cores, their construction and application.

Also available - for quick reference - is a Tape Wound Core Design Chart which gives the designer instant access to the most commonly used design formulae, core dimensions and constants.

For specific engineering assistance or further information on any Tape Wound Core or application discussed in this manual, call Magnetic Metals Company (714) 828-4625 in Anaheim, CA. In Camden, N. J. (856) 964-7842.

## TAPE WOUND CORE CONSTRUCTION

Tape wound cores are fabricated on specially designed machines which wind insulated tape onto a mandrel under controlled tension to provide an extremely uniform cross-section.

The wound cores are then annealed in a hydrogen or other atmospheres. This develops the required magnetic characteristics previously determined by careful raw material selection and process control.

Annealed cores are sensitive to mechanical strain in varying degrees depending upon the alloy. These strains cause changes in the magnetic characteristics of the material which may severely alter the performance of the finished core. To prevent these changes from taking place, the annealed tape cores are housed within cases which protect them from the strains of electrical winding and other external disturbances. (see Figure 3.)

The cases are fabricated of various materials depending upon the intended application: Plastics, such as phenolic, nylon, glass reinforced nylon and metals, like aluminum are used.

A damping medium fills the space between the core and the case to minimize the motion of the core within the case, thus reducing the possibility of change in electrical characteristics under shock and vibration.

The non-metallic cases (glass-filled nylon, phenolic, nylon) are the most widely used. The glass filled nylon case has proven superior to the phenolic case because of its greater strength. Aluminum cases provide greater environmental protection and this quality can be further enhanced by the application of an epoxy finish over the case.

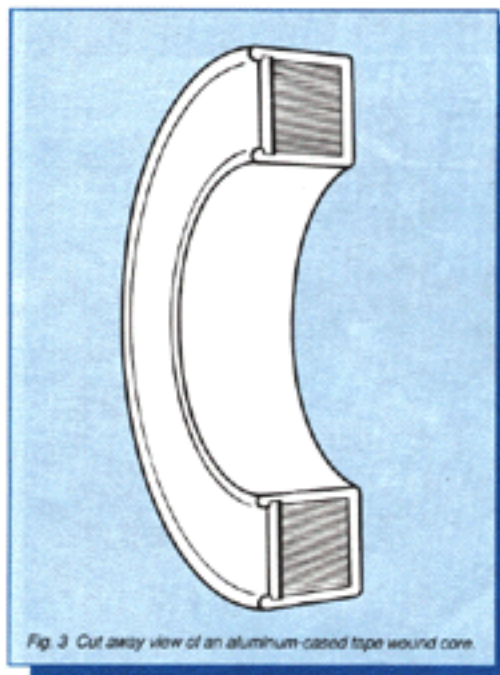


Fig. 3 Cut away view of an aluminum-cased tape wound core.

# MATERIALS FOR TAPE WOUND CORES

The magnetic materials used for tape wound cores can be classified in two broad categories: (1) "Square Loop" or (2) "Round Loop". This classification is made to the relative shape of the B-H loop.

## 1. Square loop versions tend to have:

1. Higher maximum flux capabilities ( $B_m$ )
2. Wider loops (greater  $H_c$  loop width at zero flux)
3. Higher squareness ratios ( $B_r/B_m$ ) - ratio of residual flux density to maximum flux density
4. Higher core losses

## 2. Round loop versions tend to have:

1. Lower  $B_m$
2. Narrower loops
3. Lower squareness ratios
4. Higher initial permeability
5. Lower core losses

The specific characteristics of each available material are detailed on the following pages. A composite of the square B-H loops is shown in Figure 12 while Figure 13 (see page 26) shows a composite of the round B-H loops. Preliminary design considerations plus the comparison curves and charts will enable the designer to select the optimum material for his application, and then use the detailed characteristics for final design.

## Square Loop Materials

See Table II, Page 9, for comparison of specific characteristics.

**Super Square 80 - 80 % Ni/Fe/Mo**, Super Square 80 offers the designer a magnetic material of unusual uniformity. In comparison to Square 80 (or any of its equivalents) Super Square 80 offers higher maximum flux density, higher gain and a higher squareness ration with only a very slight increase in coercive force. One noteworthy feature of this material is the remarkable uniformity of the cores produced. These cores have half the spread of typical magnetic electrical characteristics normally encountered with Square 80. This material is made to provide a high degree of thermal stability for certain magnetic characteristics like  $B_m/B_r$ ,  $H$ ,  $\delta H$ . When thermal stability is a requirement, complete specifications should be reviewed with Magnetic Metals' engineering department.

**Square 80 - 80 % Ni/Fe/Mo-**is a low coercive force material with similar characteristics to supermalloy. It offers good squareness and high gain. Core losses are quite low. Applications include low power, high efficiency inverter transformers, low level and high frequency magnetic amplifiers, magnetic modulators and pulse transformers.

**Square 50 - 50 % Ni/Fe/ alloy, (grain oriented).** It offers the highest squareness ratio (lowest saturated reactance) and very high gain. This material has  $B_m$  while cores losses are low enough to consider its use in higher frequency applications than the silicon steels. Applications include bi-stable switching devices, inverter transformers, high performance power magnetic amplifiers, linear current transformers, timing devices, driver transformers, and wherever an extremely square loop material, manufactured to close tolerance, is required.

**Microsil - 3 % Si/Fe - Oriented Silicon Iron Alloy.** This material is generally used for high power, relatively low frequency applications in high performance power transformers, saturable reactors, inverter transformers, magnetic amplifiers (power), current transformers, output transformers, etc. This is the least expensive of the square loop materials and has high maximum flux. The Squareness ratio is lower than for Square 50. The core losses are higher while gain is significantly lower.

**Supermendur - 49 % Co/49 % Fe/V.** This is the highest flux density material available in tape wound cores. Applications include power transformers, power magnetic amplifiers, inverters, and wherever size and weight are a major design consideration.

## **Round Loop Materials**

See Table II, Page 9, for comparison of specific characteristics.

**Supermalloy - 80 % Ni/Fe/Mo.** This is an 80% nickel-iron alloy processed for exceptionally high initial permeability. Applications include very low level signal transformers, low level magnetic preamplifiers, high value inductors which have no superimposed direct currents and precision current transformers.

**SuperPerm 80 - 80 % Ni/Fe/Mo.** This is similar to Supermalloy, but it is processed for pulse and high frequency performance. Applications include very low level signal transformers, low level and high frequency magnetic preamplifiers, and high value inductors at high frequency.

**SuperPerm 49 - 50 % Ni/Fe/ Alloy.** This material has characteristics that fall between Silicon Steel and 80% Ni/Fe/Mo. It provides the designer with high initial permeability as well as a high maximum flux. Applications include current transformers, proportioning reactors, high quality and wide frequency response transformers and medium power magnetic amplifiers.

# ORDERING INFORMATION

## How To Order Tape Wound Cores

Magnetic Metals' Tape Wound Cores should be ordered by part number.

The part number of the tape wound core describes the core size, case type, material and material thickness.

**EXAMPLE:** The part number 11-P-4602 designates a core with a 1" I.D. X 1.5" O.D. X .375" strip width (height), made from .002" thick Square 50 material in a plastic case.

11-Size code

P-Case code

46-Material code

02-Tape thickness code

### Core Size

Tape wound core sizes and physical characteristics - designated by a two, three or four digit number - are tabulated on pages 11 through 13, Table VII.

### Case / Coating Codes

Available case and coating types are designated by a letter (Example: A = Aluminum) and are listed in Table I, Page 9. Epoxy coatings are designated by the code "E", "D", and "M". Due to shrinking stresses of Epoxy coating, uncased cores using the "D" coating are guaranteed only to meet the core loss limits for Microsil material. Microsil cores required to meet guaranteed CCFR (Constant Current Flux Reset) limits and/or matching should be ordered with the "M" coating or case. "D" coating is not recommended for uncased nickel cores.

### Gapped Cores

See special section, page 19 on how to order and specify gapped cores.

### Pulse Cores

Cores for pulse applications are processed and tested differently. Add suffix "P" to standard core number. See page 8 for information.

### Material Code

Magnetic Metals has assigned code number to the various types of materials used the manufacture of Tape Wound Cores. For example, the 80% nickel/iron alloy processed for maximum initial permeability - known as Permalloy, HyMu 80, etc. - has been assigned the material code number "80".

On pages 5 and 6, the materials are described in more detail.

Table II, page 9, presents Magnetic Metals' material designations, and provides the code numbers to be used when ordering.

### **Tape Thickness Code**

Materials used in the manufacture of Tape Wound Cores are supplied in thicknesses from .0005" through .012" for nickle alloys. Silicon alloys (Microsil) are available from .001 through .012.

Table IV, Page 10, indicates the available thicknesses and the ordering code.

### **Pulse or High Frequency Applications**

Magnetic Metals has developed a special process whereby tape wound core pulse or high frequency performance is optimized. To ensure that cores intended for pulse applications are manufactured under this process, the suffix "P" should be added to the standard core number, i.e., 11P4601-P. Cores specially processed for pulse applications will not necessarily meet the low frequency CCFR limits published in this catalog.

## TABLES: CASE TYPES, MATERIAL CODES

| TABLE I - CASE TYPES                                   |                      |                                   |                                                                 |                                 |                        |
|--------------------------------------------------------|----------------------|-----------------------------------|-----------------------------------------------------------------|---------------------------------|------------------------|
| Case / Coating Type                                    | Case / Coating Codes | Maximum Coating Build-up (Inches) | Temperature Range For Continuous Operation (in Degrees Celsius) | Max. Temp. (in Degrees Celcius) | Breakdown Test Voltage |
| Aluminum                                               | A                    | -                                 | -55 to +170                                                     | 200                             | -                      |
| Aluminum with Epoxy Coat                               | E                    | (See Table VI.)                   | -55 to +155                                                     | 170                             | 1000                   |
| Plastic                                                | P                    | (1)                               | -55 to +155                                                     | 155                             | -                      |
| Sealed Plastic                                         | S                    | (2)                               | -55 to +105                                                     | 130                             | -                      |
| Uncased / Epoxy Coat (Fluidized Bed for Microsil Only) | D                    | (3)<br>(See Table VI.)            | -55 to +155                                                     | 170                             | 1000                   |
| Uncased Epoxy Paint (For Microsil Only)                | M                    | (3) .005                          | -                                                               | 170                             | 500                    |
| Uncased, Unimpregnated                                 | U                    | (3)                               | -                                                               | -                               | -                      |
| Uncased, Impregnated                                   | G                    | (3)                               | -                                                               | -                               | -                      |
| Edge Cover, Light Epoxy Dip                            | N                    | (3)                               | -                                                               | -                               | -                      |
| Special Case Specified by Customer                     | H                    | -                                 | -                                                               | -                               | -                      |
| End Cap                                                | C                    | -                                 | -55 to +155                                                     | 150                             | 1000                   |

Notes: (1) Cases will be either Nylon (glass reinforced) or phenolic as available. (2) Non-reinforced Nylon. (3) Recommended for Microsil cores only. See page 4.

| TABLE II - MATERIAL DESIGNATIONS |                         |                              |                                   |
|----------------------------------|-------------------------|------------------------------|-----------------------------------|
| Material Code                    | Material Descriptipn ** | Magnetic Metals Designations | Trade Names of Similar Materials* |

|            |                                                                                                              |                 |                                                                                                          |
|------------|--------------------------------------------------------------------------------------------------------------|-----------------|----------------------------------------------------------------------------------------------------------|
| <b>46</b>  | Grain oriented 50% Nickel/Iron alloy processed for maximum B-H loop squareness                               | Square 50       | Hy-Ra "49" <sup>1</sup><br>Orthonol <sup>2</sup> ,<br>Deltamax <sup>3</sup> , Hipernik<br>v <sup>6</sup> |
| <b>81</b>  | 80% Nickel/Iron/Molybdenum alloy processed for B-H loop squareness                                           | Square 80       | Square Permalloy Hy-Ra "80"                                                                              |
| <b>87</b>  | Special 80% Nickel/Iron/Molybdenum alloy processed for maximum B-H loop squareness                           | Super Square 80 | Exclusive to<br>Mangetic Metals<br>Company                                                               |
| <b>107</b> | High flux density Vanadium/Cobalt/Iron alloy processed for maximum B-H loop squareness                       | Supermendur     | Supermendur <sup>4</sup>                                                                                 |
| <b>33</b>  | Grain oriented Silicon/Iron alloy                                                                            | Microsil        | Silectron Z <sup>4</sup> Oreintal<br>T-S <sup>5</sup> Hipersil                                           |
| <b>34</b>  | Selected higher flux G. O.S.                                                                                 | Microsil        |                                                                                                          |
| <b>86</b>  | Special 80% Nickel/Iron/Molybdenum alloy processed for highest initial permability and lowest H <sub>0</sub> | Supermalloy     | Supermalloy <sup>4</sup> Hymu<br>"800" <sup>1</sup>                                                      |
| <b>80</b>  | 80% Nickel/Iron/Molybdenum alloy processed for pulse and high frequency performance                          | SuperPerm80     | 4-79 Permalloy <sup>1</sup> ,<br>Hymu "80" <sup>1</sup> , Mu-Metal <sup>3</sup> , Hypernom <sup>6</sup>  |
| <b>49</b>  | Non-oriented 50% Nickel/Iron alloy processed for high initial permeability                                   | SuperPerm 49    | High Permeability<br>"49" <sup>1</sup> , 48-Ni <sup>5</sup> , 4750 <sup>3</sup>                          |

\*Trade Names of: 1:-The Carpenter Steel Co. 2-Magnetics Div., Spang Industries, Inc. 3-Allegheny Ludium Steel Corp. 4-Aronld Engineering Co. 5-Armo Steel Co. 6-Westinghouse

\*\*Compositions shown are approximated. For exact materials' compositon, See Table III.

# TABLES: ALLOYS, THICKNESS CODES, TOLERANCES, COATING THICKNESS

| TABLE III - COMPOSITION OF ALLOYS (NOMINAL) |                          |                                         |                                       |
|---------------------------------------------|--------------------------|-----------------------------------------|---------------------------------------|
| Oriented Silicon Iron                       | 50 % Nickel / Iron alloy | Molybdenum Permalloy                    | Supermendur                           |
| Iron-97%<br>Silicon-3%                      | Nickel-50%<br>Iron-50%   | Nickel-80%<br>Iron-16%<br>Molybdenum-5% | Cobalt-49%<br>Iron-49%<br>Vanadium-2% |

| TABLE IV-TAPE THICKNESS CODES |      |
|-------------------------------|------|
| Tape Thickness                | Code |
| .0005"                        | 005  |
| .001"                         | 01   |
| .002"                         | 02   |
| .004"                         | 04   |
| .006"                         | 06   |
| .012"                         | 12   |

| TABLE V - TOLERANCE ON TAPE WOUND CORE AND CASES |           |              |        |             |           |        |
|--------------------------------------------------|-----------|--------------|--------|-------------|-----------|--------|
| Core                                             | Tolerance |              |        |             | Tolerance |        |
| ID or OD                                         | Core ID   | Core OD      | Case   | Core Height | Core      | Case   |
| Up to 1.50"                                      | +.016"    | -.016" +.032 | +.005" | Up to 1.00" | +.016"    | +.010" |
| 1.51" to 2.50"                                   | +.016"    | +.032"       | +.008" |             | -.000"    | -.005" |
| 2.51" to 3.50"                                   | +.032"    | +.032"       | +.012" | Over 1.00"  | +.032"    | +.020  |
| Over 3.50"                                       | +.032"    | +.062"       | +.015" |             | -.000"    | -.005" |

We should note that core ID, OD and height tolerances are for UNCASSED cores.

| TABLE VI - MAXIMUM COATING THICKNESS |                 |                     |
|--------------------------------------|-----------------|---------------------|
| Case Type                            | ID or OD        | Thickness Per Side* |
| Aluminum /Epoxy (E type)             | Up to .999"     | .015"               |
|                                      | 1.000 and Over  | .015"               |
| Uncased /Epoxy (D type)              | Up to .50"      | .010-.030"          |
|                                      | .50" up to 1.0" | .020"-.040"         |
|                                      | 1.0" up to 1.5" | .030."-.060"        |
|                                      | 1.5"            | .040"-.070"         |

\*Where core buildup  $(OD-ID/2)$  is greater than strip width, use the larger coating thickness.

TABLE VII - CORE DIMENSIONS

| CORE SIZE | CORE DIMENSIONS IN |       |      | CASE DIMENSIONS IN |                    |       |                    |       |                    | NET CORE AREA CM <sup>2</sup> |             |                  |       | MEAN PATH LENGTH IN CM |       |       | CASE WINDOW AREA IN <sup>2</sup> |        | RATIO ID/OD | GR. CORE WEIGHT SQUARE 50* Pounds Grams | PRODUCT Wa X Ca IN <sup>4</sup> |
|-----------|--------------------|-------|------|--------------------|--------------------|-------|--------------------|-------|--------------------|-------------------------------|-------------|------------------|-------|------------------------|-------|-------|----------------------------------|--------|-------------|-----------------------------------------|---------------------------------|
|           | ID                 | OD    | HT   | ID                 |                    | OD    |                    | HT    |                    | .001 SF=.75                   | .002 SF=.85 | .004 .006 SF=.90 | Metal |                        |       |       | Plastic or End Caps              |        |             |                                         |                                 |
|           |                    |       |      | Metal              | Plastic or End Cap | Metal | Plastic or End Cap | Metal | Plastic or End Cap |                               |             |                  |       |                        |       |       |                                  |        |             |                                         |                                 |
| 433       | .375               | .438  | .125 | .310               | .310               | .513  | .513               | .197  | .212               | .01905                        | .0216       | .0229            | 1.277 | 3.24                   | .0755 | .076  | .856                             | .00149 | .680        | .000297                                 |                                 |
| 343       | .500               | .563  | .125 | .435               | .435               | .637  | .637               | .197  | .212               | .01905                        | .0216       | .0229            | 1.670 | 4.24                   | .1486 | .149  | .888                             | .00219 | .992        | .000767                                 |                                 |
| 356       | .562               | .625  | .125 | .498               | .498               | .700  | .700               | .197  | .212               | .01905                        | .0216       | .0229            | 1.865 | 4.74                   | .1948 | .194  | .899                             | .00219 | .992        | .000767                                 |                                 |
| 482       | .625               | .688  | .125 | .560               | .560               | .762  | .762               | .197  | .212               | .01905                        | .0216       | .0229            | 2.062 | 5.24                   | .246  | .246  | .908                             | .00242 | 1.098       | .000970                                 |                                 |
| 431       | .687               | .750  | .125 | .622               | .622               | .825  | .825               | .197  | .212               | .01905                        | .0216       | .0229            | 2.257 | 5.73                   | .304  | .304  | .916                             | .00265 | 1.202       | .001197                                 |                                 |
| 38        | .375               | .500  | .125 | .312               | .312               | .563  | .575               | .197  | .200               | .0378                         | .0428       | .0454            | 1.374 | 3.49                   | .0765 | .076  | .750                             | .00320 | 1.452       | .000597                                 |                                 |
| 106       | .438               | .563  | .125 | .373               | .375               | .638  | .630               | .197  | .205               | .0378                         | .0428       | .0454            | 1.572 | 3.99                   | .1093 | .110  | .778                             | .00366 | 1.661       | .000854                                 |                                 |
| 47        | .500               | .625  | .125 | .437               | .435               | .688  | .700               | .197  | .200               | .0378                         | .0428       | .0454            | 1.767 | 4.49                   | .1500 | .149  | .800                             | .00411 | 1.866       | .001172                                 |                                 |
| 74        | .625               | .750  | .125 | .560               | .570               | .825  | .820               | .197  | .195               | .0378                         | .0428       | .0454            | 2.160 | 5.49                   | .246  | .255  | .833                             | .00503 | 2.28        | .001924                                 |                                 |
| 90        | .750               | .875  | .125 | .685               | .665               | .950  | .945               | .197  | .195               | .0378                         | .0428       | .0454            | 2.553 | 6.48                   | .369  | .347  | .857                             | .00594 | 2.70        | .00288                                  |                                 |
| 366       | .875               | 1.000 | .125 | .810               | .790               | 1.075 | 1.095              | .197  | .212               | .0378                         | .0428       | .0454            | 2.945 | 7.48                   | .515  | .490  | .875                             | .00686 | 3.11        | .00403                                  |                                 |
| 153       | 1.000              | 1.125 | .125 | .935               | .915               | 1.200 | 1.220              | .197  | .210               | .0378                         | .0428       | .0454            | 3.338 | 8.48                   | .687  | .658  | .889                             | .00777 | 3.53        | .00536                                  |                                 |
| 2         | .500               | .750  | .125 | .435               | .435               | .825  | .825               | .197  | .200               | .0756                         | .0857       | .0907            | 1.963 | 4.99                   | .1486 | .149  | .667                             | .00914 | 4.15        | .00232                                  |                                 |
| 144       | .625               | .875  | .125 | .560               | .560               | .950  | .950               | .197  | .200               | .0756                         | .0857       | .0907            | 2.356 | 5.98                   | .246  | .246  | .714                             | .01097 | 4.98        | .00385                                  |                                 |
| 5         | .650               | .900  | .125 | .585               | .575               | .975  | .985               | .197  | .200               | .0756                         | .0857       | .0907            | 2.435 | 6.18                   | .269  | .260  | .722                             | .01134 | 5.14        | .00420                                  |                                 |
| 148       | .750               | 1.000 | .125 | .685               | .685               | 1.075 | 1.075              | .197  | .200               | .0756                         | .0857       | .0907            | 2.749 | 6.98                   | .369  | .369  | .750                             | .01280 | 5.81        | .00576                                  |                                 |
| 483       | .875               | 1.125 | .125 | .810               | .790               | 1.200 | 1.220              | .197  | .212               | .0756                         | .0857       | .0907            | 3.142 | 7.98                   | .515  | .490  | .778                             | .01463 | 6.64        | .00805                                  |                                 |
| 9         | 1.000              | 1.250 | .125 | .915               | .920               | 1.340 | 1.342              | .197  | .200               | .0756                         | .0857       | .0907            | 3.534 | 8.98                   | .658  | .665  | .800                             | .01646 | 7.46        | .01027                                  |                                 |
| 64        | .500               | .750  | .250 | .435               | .420               | .825  | .840               | .327  | .330               | .1512                         | .1714       | .1815            | 1.963 | 4.99                   | .1486 | .139  | .667                             | .01829 | 8.29        | .00464                                  |                                 |
| 67        | .625               | .875  | .250 | .570               | .570               | .945  | .945               | .327  | .340               | .1512                         | .1714       | .1815            | 2.356 | 5.98                   | .255  | .255  | .714                             | .0219  | 9.95        | .00797                                  |                                 |
| 79        | .750               | 1.000 | .250 | .665               | .670               | 1.085 | 1.093              | .327  | .330               | .1512                         | .1714       | .1815            | 2.749 | 6.98                   | .347  | .353  | .750                             | .0256  | 11.61       | .01085                                  |                                 |
| 30        | 1.000              | 1.250 | .250 | .915               | .920               | 1.340 | 1.343              | .327  | .330               | .1512                         | .1714       | .1815            | 3.534 | 8.98                   | .658  | .665  | .800                             | .0329  | 14.93       | .0205                                   |                                 |
| 159       | 1.125              | 1.375 | .250 | 1.060              | 1.040              | 1.450 | 1.470              | .327  | .342               | .1512                         | .1714       | .1815            | 3.927 | 9.97                   | .882  | .849  | .818                             | .0366  | 16.59       | .0276                                   |                                 |
| 53        | 1.250              | 1.500 | .250 | 1.170              | 1.170              | 1.570 | 1.570              | .327  | .320               | .1512                         | .1714       | .1815            | 4.320 | 10.97                  | 1.075 | 1.075 | .833                             | .0402  | 18.25       | .0336                                   |                                 |
| 37        | .625               | 1.000 | .188 | .570               | .570               | 1.085 | 1.085              | .265  | .272               | .1706                         | .1933       | .205             | 2.553 | 6.48                   | .255  | .255  | .625                             | .0268  | 12.16       | .00899                                  |                                 |
| 7         | .750               | 1.125 | .188 | .665               | .670               | 1.215 | 1.217              | .265  | .265               | .1706                         | .1933       | .205             | 2.945 | 7.48                   | .347  | .353  | .667                             | .0309  | 14.03       | .01224                                  |                                 |
| 485       | 1.125              | 1.500 | .188 | 1.060              | 1.040              | 1.575 | 1.595              | .265  | .280               | .1706                         | .1933       | .205             | 4.123 | 10.47                  | .882  | .850  | .750                             | .0433  | 19.65       | .0311                                   |                                 |
| 489       | 1.625              | 2.000 | .188 | 1.545              | 1.525              | 2.090 | 2.110              | .265  | .280               | .1706                         | .1933       | .205             | 5.694 | 14.46                  | 1.875 | 1.827 | .813                             | .0598  | 27.13       | .0661                                   |                                 |
| 3         | .625               | 1.000 | .250 | .570               | .550               | 1.085 | 1.085              | .327  | .330               | .227                          | .257        | .272             | 2.553 | 6.48                   | .255  | .238  | .625                             | .0357  | 16.17       | .01196                                  |                                 |
| 61        | .750               | 1.125 | .250 | .665               | .665               | 1.215 | 1.215              | .327  | .340               | .227                          | .257        | .272             | 2.945 | 7.48                   | .347  | .347  | .667                             | .0411  | 18.66       | .01628                                  |                                 |
| 380       | .875               | 1.250 | .250 | .810               | .790               | 1.325 | 1.345              | .327  | .340               | .227                          | .257        | .272             | 3.338 | 8.48                   | .515  | .490  | .700                             | .0466  | 21.15       | .0242                                   |                                 |
| 10        | 1.000              | 1.375 | .250 | .925               | .920               | 1.455 | 1.468              | .327  | .330               | .227                          | .257        | .272             | 3.731 | 9.48                   | .672  | .665  | .727                             | .0521  | 23.64       | .0315                                   |                                 |
| 16        | 1.625              | 2.000 | .250 | 1.525              | 1.525              | 2.110 | 2.110              | .327  | .330               | .227                          | .257        | .272             | 5.694 | 14.46                  | 1.827 | 1.827 | .813                             | .0795  | 36.08       | .0856                                   |                                 |
| 27        | .750               | 1.000 | .375 | .665               | .670               | 1.085 | 1.093              | .452  | .465               | .227                          | .257        | .272             | 2.749 | 6.98                   | .347  | .353  | .750                             | .0384  | 17.42       | .01628                                  |                                 |
| 146       | .625               | 1.125 | .250 | .560               | .540               | 1.200 | 1.220              | .327  | .340               | .302                          | .343        | .363             | 2.749 | 6.98                   | .246  | .229  | .556                             | .0512  | 23.22       | .01529                                  |                                 |
| 382       | .750               | 1.250 | .250 | .685               | .670               | 1.325 | 1.343              | .327  | .330               | .302                          | .343        | .363             | 3.142 | 7.98                   | .369  | .353  | .600                             | .0585  | 26.54       | .0230                                   |                                 |
| 39        | 1.000              | 1.500 | .250 | .925               | .920               | 1.570 | 1.592              | .327  | .330               | .302                          | .343        | .363             | 3.927 | 9.97                   | .672  | .665  | .667                             | .0731  | 33.18       | .0420                                   |                                 |
| 13        | 1.250              | 1.750 | .250 | 1.170              | 1.170              | 1.820 | 1.822              | .327  | .340               | .320                          | .343        | .363             | 4.712 | 11.97                  | 1.075 | 1.075 | .714                             | .0878  | 39.81       | .0672                                   |                                 |
| 32        | .625               | 1.000 | .375 | .570               | .570               | 1.085 | 1.085              | .452  | .445               | .340                          | .386        | .408             | 2.553 | 6.48                   | .255  | .255  | .625                             | .0535  | 24.26       | .01794                                  |                                 |
| 41        | .750               | 1.125 | .375 | .665               | .675               | 1.215 | 1.210              | .452  | .465               | .340                          | .386        | .408             | 2.945 | 7.48                   | .347  | .358  | .667                             | .0617  | 27.99       | .0244                                   |                                 |

\*For gross core weights of other materials, see table XII

For other sizes, refer to factory.

| TABLE VII - CORE DIMENSIONS (Cont.) |                    |       |       |                    |                    |       |                    |       |                    |                               |             |                  |        |                        |       |       |                                  |       |             |                                         |                                 |
|-------------------------------------|--------------------|-------|-------|--------------------|--------------------|-------|--------------------|-------|--------------------|-------------------------------|-------------|------------------|--------|------------------------|-------|-------|----------------------------------|-------|-------------|-----------------------------------------|---------------------------------|
| CORE SIZE                           | CORE DIMENSIONS IN |       |       | CASE DIMENSIONS IN |                    |       |                    |       |                    | NET CORE AREA CM <sup>2</sup> |             |                  |        | MEAN PATH LENGTH IN CM |       |       | CASE WINDOW AREA IN <sup>2</sup> |       | RATIO ID/OD | GR. CORE WEIGHT SQUARE 50* Pounds Grams | PRODUCT Wa X Ca IN <sup>4</sup> |
|                                     | ID                 | OD    | HT    | ID                 |                    | OD    |                    | HT    |                    | .001 SF=.75                   | .002 SF=.85 | .004 .006 SF=.90 | Metal  |                        |       |       | Plastic or End Caps              |       |             |                                         |                                 |
|                                     |                    |       |       | Metal              | Plastic or End Cap | Metal | Plastic or End Cap | Metal | Plastic or End Cap |                               |             |                  |        |                        |       |       |                                  |       |             |                                         |                                 |
| 28                                  | .875               | 1.250 | .375  | .800               | .795               | 1.340 | 1.343              | .452  | .465               | .340                          | .386        | .408             | 3.338  | 8.48                   | .503  | .496  | .700                             | .0699 | 31.72       | .0353                                   |                                 |
| 44                                  | 1.000              | 1.375 | .375  | .925               | .925               | 1.455 | 1.455              | .452  | .445               | .340                          | .386        | .408             | 3.731  | 9.48                   | .672  | .672  | .727                             | .0782 | 35.46       | .0473                                   |                                 |
| 12                                  | 1.125              | 1.500 | .375  | 1.050              | 1.050              | 1.570 | 1.570              | .452  | .445               | .340                          | .386        | .408             | 4.123  | 10.47                  | .866  | .866  | .750                             | .0864 | 39.19       | .0609                                   |                                 |
| 486                                 | 1.375              | 1.750 | .375  | 1.295              | 1.275              | 1.840 | 1.860              | .452  | .467               | .340                          | .386        | .408             | 4.909  | 12.47                  | 1.317 | 1.277 | .786                             | .1029 | 46.65       | .0926                                   |                                 |
| 6                                   | .650               | 1.150 | .375  | .585               | .585               | 1.240 | 1.240              | .452  | .455               | .454                          | .514        | .544             | 2.827  | 7.18                   | .269  | .269  | .565                             | .0790 | 35.83       | .0252                                   |                                 |
| 52                                  | .750               | 1.250 | .375  | .665               | .665               | 1.340 | 1.335              | .452  | .455               | .454                          | .514        | .544             | 3.142  | 7.98                   | .347  | .347  | .600                             | .0878 | 39.81       | .0326                                   |                                 |
| 484                                 | .875               | 1.375 | .375  | .810               | .790               | 1.450 | 1.470              | .452  | .467               | .454                          | .514        | .544             | 3.534  | 8.98                   | .515  | .490  | .636                             | .0987 | 44.79       | .0483                                   |                                 |
| 11                                  | 1.000              | 1.500 | .375  | .925               | .920               | 1.570 | 1.593              | .452  | .465               | .454                          | .514        | .544             | 3.927  | 9.97                   | .672  | .665  | .667                             | .1097 | 49.76       | .0630                                   |                                 |
| 87                                  | 1.250              | 1.750 | .375  | 1.170              | 1.170              | 1.820 | 1.822              | .452  | .445               | .454                          | .514        | .544             | 4.712  | 11.97                  | 1.075 | 1.075 | .714                             | .1317 | 59.72       | .1008                                   |                                 |
| 42                                  | 1.500              | 2.000 | .375  | 1.400              | 1.400              | 2.110 | 2.110              | .452  | .455               | .454                          | .514        | .544             | 5.498  | 13.96                  | 1.539 | 1.539 | .750                             | .1536 | 69.67       | .1443                                   |                                 |
| 362                                 | .750               | 1.250 | .500  | .685               | .665               | 1.350 | 1.345              | .607  | .630               | .605                          | .685        | .726             | 3.142  | 7.98                   | .369  | .347  | .600                             | .1170 | 53.08       | .0461                                   |                                 |
| 62                                  | 1.000              | 1.500 | .500  | .925               | .920               | 1.570 | 1.593              | .607  | .610               | .605                          | .685        | .726             | 3.927  | 9.97                   | .672  | .665  | .667                             | .1463 | 66.35       | .0840                                   |                                 |
| 29                                  | 1.250              | 1.750 | .500  | 1.170              | 1.160              | 1.820 | 1.850              | .607  | .610               | .605                          | .685        | .726             | 4.712  | 11.97                  | 1.075 | 1.057 | .692                             | .1755 | 79.62       | .1344                                   |                                 |
| 85                                  | 1.125              | 1.625 | .500  | 1.050              | 1.035              | 1.705 | 1.725              | .607  | .610               | .605                          | .685        | .726             | 4.320  | 10.97                  | .866  | .841  | .714                             | .1609 | 72.99       | .1082                                   |                                 |
| 487                                 | 1.375              | 1.875 | .500  | 1.295              | 1.275              | 1.965 | 1.985              | .607  | .631               | .605                          | .685        | .726             | 5.105  | 12.97                  | 1.317 | 1.277 | .733                             | .1902 | 86.26       | .1646                                   |                                 |
| 14                                  | 1.500              | 2.000 | .500  | 1.400              | 1.400              | 2.110 | 2.110              | .607  | .620               | .605                          | .685        | .726             | 5.498  | 13.96                  | 1.539 | 1.539 | .750                             | .205  | 92.89       | .1924                                   |                                 |
| 84                                  | 1.750              | 2.250 | .500  | 1.650              | 1.650              | 2.350 | 2.350              | .607  | .600               | .605                          | .685        | .726             | 6.283  | 15.96                  | 2.138 | 2.138 | .778                             | .234  | 106.16      | .267                                    |                                 |
| 17                                  | 2.000              | 2.500 | .500  | 1.860              | 1.860              | 2.652 | 2.652              | .607  | .610               | .605                          | .685        | .726             | 7.069  | 17.95                  | 2.717 | 2.717 | .800                             | .263  | 119.43      | .340                                    |                                 |
| 18                                  | 2.500              | 3.000 | .500  | 2.360              | 2.360              | 3.152 | 3.152              | .607  | .620               | .605                          | .685        | .726             | 8.639  | 21.94                  | 4.373 | 4.374 | .833                             | .322  | 145.97      | .547                                    |                                 |
| 151                                 | .750               | 1.500 | .375  | .685               | .665               | 1.575 | 1.595              | .452  | .475               | .680                          | .771        | .817             | 3.534  | 8.98                   | .369  | .347  | .500                             | .1481 | 67.18       | .0518                                   |                                 |
| 75                                  | 1.250              | 2.000 | .375  | 1.170              | 1.160              | 2.110 | 2.110              | .452  | .465               | .680                          | .771        | .817             | 5.105  | 12.97                  | 1.075 | 1.057 | .625                             | .214  | 97.04       | .1512                                   |                                 |
| 243                                 | 2.000              | 2.750 | .375  | 1.910              | 1.890              | 2.850 | 2.870              | .452  | .485               | .680                          | .771        | .817             | 7.461  | 18.95                  | 2.865 | 2.806 | .727                             | .313  | 141.83      | .403                                    |                                 |
| 385                                 | 3.000              | 3.750 | .375  | 2.900              | 2.880              | 3.860 | 3.880              | .452  | .467               | .680                          | .771        | .817             | 10.603 | 26.93                  | 6.605 | 6.514 | .800                             | .444  | 201.54      | .929                                    |                                 |
| 125                                 | 1.000              | 1.750 | .500  | .920               | .900               | 1.840 | 1.860              | .607  | .610               | .907                          | 1.028       | 1.089            | 4.320  | 10.97                  | .665  | .636  | .571                             | .241  | 109.48      | .1246                                   |                                 |
| 60                                  | 1.250              | 2.000 | .500  | 1.170              | 1.170              | 2.110 | 2.110              | .607  | .620               | .907                          | 1.028       | 1.089            | 5.105  | 12.97                  | 1.075 | 1.075 | .625                             | .285  | 129.39      | .202                                    |                                 |
| 488                                 | 1.500              | 2.250 | .500  | 1.420              | 1.400              | 2.340 | 2.360              | .607  | .631               | .907                          | 1.028       | 1.089            | 5.890  | 14.96                  | 1.584 | 1.539 | .667                             | .329  | 149.29      | .297                                    |                                 |
| 490                                 | 1.625              | 2.375 | .500  | 1.535              | 1.515              | 2.475 | 2.495              | .607  | .631               | .907                          | 1.028       | 1.089            | 6.283  | 15.96                  | 1.851 | 1.803 | .684                             | .351  | 159.24      | .347                                    |                                 |
| 83                                  | 1.750              | 2.500 | .500  | 1.650              | 1.650              | 2.600 | 2.600              | .607  | .600               | .907                          | 1.028       | 1.089            | 6.676  | 16.96                  | 2.138 | 2.138 | .700                             | .373  | 169.20      | .401                                    |                                 |
| 493                                 | 1.875              | 2.625 | .500  | 1.785              | 1.765              | 2.725 | 2.745              | .607  | .631               | .907                          | 1.028       | 1.089            | 7.069  | 17.95                  | 2.502 | 2.447 | .714                             | .395  | 179.15      | .469                                    |                                 |
| 475                                 | 2.250              | 3.000 | .500  | 2.160              | 2.140              | 3.100 | 3.120              | .607  | .631               | .907                          | 1.028       | 1.089            | 8.247  | 20.95                  | 3.664 | 3.597 | .750                             | .461  | 209.01      | .687                                    |                                 |
| 498                                 | 2.500              | 3.250 | .500  | 2.400              | 2.380              | 3.360 | 3.380              | .607  | .631               | .907                          | 1.028       | 1.089            | 9.032  | 22.94                  | 4.524 | 4.449 | .769                             | .505  | 228.91      | .848                                    |                                 |
| 381                                 | 1.250              | 2.250 | .500  | 1.170              | 1.150              | 2.340 | 2.360              | .607  | .631               | 1.210                         | 1.371       | 1.452            | 5.498  | 13.96                  | 1.075 | 1.039 | .556                             | .410  | 185.78      | .269                                    |                                 |
| 15                                  | 1.500              | 2.500 | .500  | 1.400              | 1.395              | 2.600 | 2.615              | .607  | .610               | 1.210                         | 1.371       | 1.452            | 6.283  | 15.96                  | 1.539 | 1.528 | .600                             | .468  | 212.33      | .385                                    |                                 |
| 335                                 | 1.750              | 2.750 | .500  | 1.660              | 1.640              | 2.850 | 2.870              | .607  | .631               | 1.210                         | 1.371       | 1.452            | 7.069  | 17.95                  | 2.164 | 2.112 | .636                             | .527  | 238.87      | .541                                    |                                 |
| 76                                  | 2.000              | 3.000 | .500  | 1.910              | 1.895              | 3.100 | 3.115              | .607  | .610               | 1.210                         | 1.371       | 1.452            | 7.854  | 19.95                  | 2.865 | 2.820 | .667                             | .585  | 265.41      | .716                                    |                                 |
| 19                                  | 2.500              | 3.500 | .500  | 2.313              | 2.380              | 3.688 | 3.630              | .607  | .610               | 1.210                         | 1.371       | 1.452            | 9.425  | 23.94                  | 4.202 | 4.449 | .714                             | .702  | 318.49      | 1.050                                   |                                 |
| 334                                 | 1.000              | 1.500 | 1.000 | .935               | .915               | 1.575 | 1.595              | 1.135 | 1.112              | 1.210                         | 1.371       | 1.452            | 3.927  | 9.97                   | .687  | .658  | .667                             | .293  | 132.70      | .1717                                   |                                 |
| 55                                  | 1.250              | 1.750 | 1.000 | 1.170              | 1.170              | 1.820 | 1.822              | 1.135 | 1.105              | 1.210                         | 1.371       | 1.452            | 4.712  | 11.97                  | 1.075 | 1.075 | .714                             | .351  | 159.24      | .269                                    |                                 |
| 95                                  | 1.500              | 2.000 | 1.000 | 1.400              | 1.400              | 2.110 | 2.110              | 1.135 | 1.110              | 1.210                         | 1.371       | 1.452            | 5.498  | 13.96                  | 1.539 | 1.539 | .750                             | .410  | 185.78      | .385                                    |                                 |
| 128                                 | 1.750              | 2.250 | 1.000 | 1.670              | 1.650              | 2.340 | 2.360              | 1.135 | 1.110              | 1.210                         | 1.371       | 1.452            | 6.283  | 15.96                  | 2.190 | 2.138 | .778                             | .468  | 212.33      | .548                                    |                                 |

\*For gross core weights of other materials, see table XII  
For other sizes, refer to factory.

| TABLE VII - CORE DIMENSIONS (Cont.) |                    |       |       |                    |                    |       |                    |       |                    |                   |             |                  |        |                        |        |        |                      |        |             |                                         |                     |
|-------------------------------------|--------------------|-------|-------|--------------------|--------------------|-------|--------------------|-------|--------------------|-------------------|-------------|------------------|--------|------------------------|--------|--------|----------------------|--------|-------------|-----------------------------------------|---------------------|
| CORE SIZE                           | CORE DIMENSIONS IN |       |       | CASE DIMENSIONS IN |                    |       |                    |       |                    | NET CORE AREA CM² |             |                  |        | MEAN PATH LENGTH IN CM |        |        | CASE WINDOW AREA IN² |        | RATIO ID/OD | GR. CORE WEIGHT SQUARE 50* Pounds Grams | PRODUCT Wa X Ca IN⁴ |
|                                     | ID                 | OD    | HT    | ID                 |                    | OD    |                    | HT    |                    | .001 SF=.75       | .002 SF=.85 | .004 .006 SF=.90 | Metal  |                        |        |        | Plastic or End Caps  |        |             |                                         |                     |
|                                     |                    |       |       | Metal              | Plastic or End Cap | Metal | Plastic or End Cap | Metal | Plastic or End Cap |                   |             |                  |        |                        |        |        |                      |        |             |                                         |                     |
| 59                                  | 2.000              | 2.500 | 1.000 | 1.860              | 1.890              | 2.652 | 2.620              | 1.135 | 1.152              | 1.210             | 1.371       | 1.452            | 7.069  | 17.95                  | 2.717  | 2.806  | .800                 | .527   | 238.87      | .679                                    |                     |
| 225                                 | 2.500              | 3.000 | 1.000 | 2.410              | 2.390              | 3.100 | 3.120              | 1.135 | 1.120              | 1.210             | 1.371       | 1.452            | 8.639  | 21.94                  | 4.562  | 4.468  | .833                 | .644   | 291.95      | 1.140                                   |                     |
| 164                                 | 1.250              | 2.000 | 1.000 | 1.170              | 1.150              | 2.090 | 2.110              | 1.135 | 1.110              | 1.815             | 2.056       | 2.177            | 5.105  | 12.97                  | 1.075  | 1.039  | .625                 | .570   | 258.77      | .403                                    |                     |
| 186                                 | 1.500              | 2.250 | 1.000 | 1.420              | 1.400              | 2.340 | 2.360              | 1.135 | 1.110              | 1.815             | 2.056       | 2.177            | 5.890  | 14.96                  | 1.584  | 1.5    | .667                 | .658   | 298.58      | .594                                    |                     |
| 491                                 | 1.625              | 2.375 | 1.000 | 1.545              | 1.515              | 2.465 | 2.495              | 1.135 | 1.162              | 1.815             | 2.056       | 2.177            | 6.238  | 15.96                  | 1.875  | 1.803  | .684                 | .702   | 318.49      | .703                                    |                     |
| 494                                 | 2.000              | 2.750 | 1.000 | 1.910              | 1.890              | 2.850 | 2.870              | 1.135 | 1.162              | 1.815             | 2.056       | 2.177            | 7.461  | 18.95                  | 2.865  | 2.806  | .727                 | .834   | 378.20      | 1.074                                   |                     |
| 340                                 | 1.250              | 2.250 | 1.000 | 1.170              | 1.150              | 2.340 | 2.280              | 1.135 | 1.162              | 2.419             | 2.742       | 2.903            | 5.498  | 13.96                  | 1.075  | 1.039  | .556                 | .819   | 371.57      | .538                                    |                     |
| 169                                 | 1.500              | 2.500 | 1.000 | 1.410              | 1.390              | 2.600 | 2.620              | 1.135 | 1.120              | 2.419             | 2.742       | 2.903            | 6.283  | 15.96                  | 1.561  | 1.517  | .600                 | .936   | 424.65      | .781                                    |                     |
| 97                                  | 1.750              | 2.750 | 1.000 | 1.650              | 1.650              | 2.850 | 2.850              | 1.135 | 1.120              | 2.419             | 2.742       | 2.903            | 7.069  | 17.95                  | 2.138  | 2.138  | .636                 | 1.053  | 477.73      | 1.069                                   |                     |
| 58                                  | 2.000              | 3.000 | 1.000 | 1.860              | 1.860              | 3.152 | 3.152              | 1.135 | 1.198              | 2.419             | 2.742       | 2.903            | 7.854  | 19.95                  | 2.717  | 2.717  | .667                 | 1.170  | 530.81      | 1.359                                   |                     |
| 20                                  | 2.500              | 3.500 | 1.000 | 2.313              | 2.313              | 3.688 | 3.688              | 1.135 | 1.188              | 2.419             | 2.742       | 2.903            | 9.425  | 23.94                  | 4.202  | 4.202  | .714                 | 1.404  | 636.98      | 2.101                                   |                     |
| 199                                 | 3.000              | 4.000 | 1.000 | 2.900              | 2.880              | 4.110 | 4.130              | 1.135 | 1.130              | 2.419             | 2.742       | 2.903            | 10.996 | 27.93                  | 6.605  | 6.514  | .750                 | 1.638  | 743.14      | 3.303                                   |                     |
| 492                                 | 1.750              | 3.000 | 1.000 | 1.660              | 1.640              | 3.100 | 3.120              | 1.135 | 1.162              | 3.024             | 3.427       | 3.692            | 7.461  | 18.95                  | 2.164  | 2.112  | .583                 | 1.390  | 630.34      | 1.353                                   |                     |
| 495                                 | 2.000              | 3.250 | 1.000 | 1.900              | 1.880              | 3.360 | 3.380              | 1.135 | 1.162              | 3.024             | 3.427       | 3.692            | 8.247  | 20.95                  | 2.835  | 2.776  | .615                 | 1.536  | 696.69      | 1.772                                   |                     |
| 496                                 | 2.250              | 2.500 | 1.000 | 2.150              | 2.130              | 3.610 | 3.630              | 1.135 | 1.162              | 3.024             | 3.427       | 3.692            | 9.032  | 22.94                  | 3.360  | 3.563  | .643                 | 1.682  | 763.04      | 2.269                                   |                     |
| 133                                 | 1.750              | 2.750 | 1.500 | 1.650              | 1.650              | 2.850 | 2.850              | 1.685 | 1.688              | 3.629             | 4.113       | 4.355            | 7.069  | 17.95                  | 2.138  | 2.138  | .636                 | 1.580  | 716.60      | 1.604                                   |                     |
| 441                                 | 2.000              | 3.000 | 1.500 | 1.910              | 1.890              | 3.100 | 3.120              | 1.685 | 1.662              | 3.629             | 4.113       | 4.355            | 7.854  | 19.95                  | 2.865  | 2.821  | .667                 | 1.755  | 796.22      | 2.149                                   |                     |
| 200                                 | 3.000              | 4.000 | 1.500 | 2.900              | 2.880              | 4.110 | 4.130              | 1.685 | 1.640              | 3.629             | 4.113       | 4.355            | 10.996 | 27.93                  | 6.605  | 6.514  | .750                 | 2.458  | 1114.71     | 4.954                                   |                     |
| 22                                  | 2.500              | 3.750 | 1.500 | 2.313              | 2.313              | 3.938 | 3.398              | 1.685 | 1.688              | 4.536             | 5.141       | 5.444            | 9.817  | 24.94                  | 4.202  | 4.202  | .667                 | 2.743  | 1244.09     | 3.939                                   |                     |
| 23                                  | 3.250              | 4.500 | 1.500 | 3.062              | 3.062              | 4.688 | 4.688              | 1.685 | 1.688              | 4.536             | 5.141       | 5.444            | 12.174 | 30.92                  | 7.364  | 7.364  | .722                 | 3.401  | 1542.68     | 6.904                                   |                     |
| 185                                 | 2.000              | 3.500 | 1.500 | 1.900              | 1.880              | 3.610 | 3.360              | 1.685 | 1.640              | 5.444             | 6.169       | 6.532            | 8.639  | 21.94                  | 2.835  | 2.776  | .571                 | 2.896  | 1313.76     | 3.190                                   |                     |
| 201                                 | 3.000              | 4.500 | 1.500 | 2.870              | 2.880              | 4.640 | 4.630              | 1.685 | 1.640              | 5.444             | 6.169       | 6.532            | 11.781 | 29.92                  | 6.469  | 6.514  | .667                 | 3.950  | 1791.49     | 7.278                                   |                     |
| 203                                 | 3.250              | 4.750 | 1.500 | 3.120              | 3.100              | 4.890 | 4.910              | 1.685 | 1.660              | 5.444             | 6.169       | 6.532            | 12.566 | 31.92                  | 7.645  | 7.548  | .684                 | 4.213  | 1910.93     | 8.601                                   |                     |
| 442                                 | 3.500              | 5.000 | 1.500 | 3.370              | 3.350              | 5.140 | 5.160              | 1.635 | 1.662              | 5.444             | 6.169       | 6.532            | 13.352 | 33.91                  | 8.920  | 8.814  | .700                 | 4.476  | 2030.36     | 10.035                                  |                     |
| 211                                 | 4.500              | 6.000 | 1.500 | 4.370              | 4.350              | 6.140 | 6.160              | 1.685 | 1.660              | 5.444             | 6.169       | 6.532            | 16.493 | 41.89                  | 14.999 | 14.862 | .750                 | 5.529  | 2508.09     | 16.873                                  |                     |
| 497                                 | 2.250              | 3.500 | 2.000 | 2.150              | 2.130              | 3.610 | 3.630              | 2.195 | 2.180              | 6.048             | 6.855       | 7.258            | 9.032  | 22.94                  | 3.630  | 3.630  | .643                 | 3.643  | 1526.09     | 4.538                                   |                     |
| 499                                 | 3.000              | 4.250 | 2.000 | 2.870              | 2.850              | 4.390 | 4.410              | 2.195 | 2.182              | 6.048             | 6.855       | 7.258            | 11.388 | 28.93                  | 6.469  | 6.469  | .706                 | 4.242  | 1924.20     | 8.087                                   |                     |
| 24                                  | 3.250              | 4.500 | 2.000 | 3.062              | 3.062              | 4.688 | 4.688              | 2.195 | 2.188              | 6.048             | 6.855       | 7.258            | 12.174 | 30.92                  | 7.364  | 7.364  | .722                 | 4.535  | 2056.90     | 9.205                                   |                     |
| 25                                  | 4.000              | 5.250 | 2.000 | 3.813              | 3.813              | 5.438 | 5.438              | 2.195 | 2.188              | 6.048             | 6.855       | 7.258            | 14.530 | 36.91                  | 11.419 | 11.419 | .762                 | 5.412  | 2455.01     | 14.274                                  |                     |
| 190                                 | 2.250              | 4.000 | 1.500 | 2.150              | 2.130              | 4.110 | 4.130              | 1.685 | 1.640              | 6.351             | 7.198       | 7.621            | 9.817  | 24.94                  | 3.630  | 3.563  | .563                 | 3.840  | 1741.73     | 4.765                                   |                     |
| 500                                 | 3.000              | 4.750 | 1.500 | 2.870              | 2.850              | 4.890 | 4.910              | 1.635 | 1.662              | 6.351             | 7.198       | 7.621            | 12.174 | 30.92                  | 6.469  | 6.379  | .632                 | 4.761  | 2159.75     | 8.491                                   |                     |
| 77                                  | 3.250              | 5.000 | 1.500 | 3.062              | 3.062              | 5.188 | 5.188              | 1.685 | 1.688              | 6.351             | 7.198       | 7.621            | 12.959 | 32.92                  | 7.364  | 7.364  | .650                 | 5.069  | 2299.08     | 9.665                                   |                     |
| 501                                 | 3.250              | 5.250 | 1.500 | 3.120              | 3.100              | 5.390 | 5.410              | 1.635 | 1.662              | 7.258             | 8.226       | 8.710            | 13.352 | 33.91                  | 7.645  | 7.598  | .619                 | 5.968  | 2707.15     | 11.468                                  |                     |
| 502                                 | 4.000              | 6.000 | 1.500 | 3.870              | 3.850              | 6.140 | 5.160              | 1.635 | 1.662              | 7.258             | 8.226       | 8.710            | 15.708 | 39.90                  | 11.763 | 11.642 | .667                 | 7.021  | 3184.88     | 17.644                                  |                     |
| 26                                  | 4.500              | 6.500 | 1.500 | 4.313              | 4.312              | 6.688 | 6.188              | 1.685 | 1.688              | 7.258             | 8.226       | 8.710            | 17.279 | 43.89                  | 14.610 | 14.603 | .692                 | 7.724  | 3503.37     | 21.915                                  |                     |
| 202                                 | 3.000              | 5.000 | 2.000 | 2.870              | 2.850              | 5.140 | 5.160              | 2.195 | 2.170              | 9.677             | 10.968      | 11.613           | 12.566 | 31.92                  | 6.469  | 6.379  | .600                 | 7.490  | 3397.20     | 12.938                                  |                     |
| 78                                  | 4.000              | 6.000 | 2.000 | 3.813              | 3.813              | 6.188 | 6.188              | 2.195 | 2.188              | 9.677             | 10.968      | 11.613           | 15.708 | 39.90                  | 11.419 | 11.419 | .667                 | 9.362  | 4246.50     | 22.938                                  |                     |
| 503                                 | 4.000              | 6.500 | 2.000 | 3.840              | 3.820              | 6.670 | 6.690              | 2.195 | 2.182              | 12.097            | 13.710      | 14.516           | 16.493 | 41.89                  | 11.581 | 11.461 | .615                 | 22.288 | 5573.54     | 28.953                                  |                     |
| 504                                 | 4.500              | 7.000 | 2.000 | 4.340              | 4.320              | 7.170 | 7.190              | 2.195 | 2.182              | 12.097            | 13.710      | 14.516           | 18.064 | 45.88                  | 14.793 | 14.657 | .643                 | 13.458 | 6104.35     | 36.984                                  |                     |

\*For gross core weights of other materials, see table XII  
For other sizes, refer to factory.

## TABLES: TEST LIMITS, STACKING FACTORS

**TABLE VIII - TEST CONDITIONS APPLICABLE TO CCFR LIMITS**

| Performance Designation            | Frequency Hertz | Peak Excitation (Oersteds)                            |                          | B <sub>1</sub> for Measurement of H <sub>1</sub> (Gausses) | B <sub>2</sub> for Measurement of H <sub>2</sub> or H-H <sub>2</sub> -H <sub>1</sub> (Gausses) |
|------------------------------------|-----------------|-------------------------------------------------------|--------------------------|------------------------------------------------------------|------------------------------------------------------------------------------------------------|
|                                    |                 | For B <sub>m</sub> and B <sub>r</sub> /B <sub>m</sub> | For H <sub>1</sub> and H |                                                            |                                                                                                |
| SuperSquare 80                     | 400             | .05                                                   | 1.0                      | 5,000                                                      | 10,000                                                                                         |
| Square 80                          | 400             | 0.5                                                   | 1.0                      | 5,000                                                      | 10,000                                                                                         |
| Square 50                          | 400             | 1.0                                                   | 2.0                      | 10,000                                                     | 20,000                                                                                         |
| Microsil (.004 inches and thinner) | 400             | 3.0                                                   | 6.0                      | 10,000                                                     | 20,000                                                                                         |
| Microsil (0.12 inches thick)       | 60              | 3.0                                                   | 6.0                      | 10,000                                                     | 20,000                                                                                         |
| Supermendur                        | 400             | 3.5                                                   | 7.0                      | 14,000                                                     | 28,000                                                                                         |

**TABLE IX - STACKING FACTORS - STANDARD VALUES FOR TEST LIMITS**

|                           |       |      |      |      |      |      |
|---------------------------|-------|------|------|------|------|------|
| Tape Thickness (Inches)   | .0005 | .001 | .002 | .004 | .006 | .012 |
| Stacking Factor (Percent) | 50    | 75   | 85   | 90   | 90   | 95   |

**TABLE X - 400 HZ CONSTANT CURRENT FLUX RESET TEST LIMITS**  
See Table XI for values of H.

| Performance Designation | Core | Thickness (Inches) | B <sub>m</sub> (Gausses*) | B <sub>m</sub> -B <sub>r</sub> (Gausses*) | H <sub>1</sub> (Oersteds) |
|-------------------------|------|--------------------|---------------------------|-------------------------------------------|---------------------------|
| SuperSquare 80          | 87   | .001               | 7200-8400                 | 600-1250                                  | .038-.052                 |
|                         |      | .002               | 7200-8400                 | 725-1350                                  | .034-.048                 |
|                         |      | .004               | 7200-8400                 | 750-1400                                  | .040-.054                 |
| Square 80               | 81   | .001               | 6800-8200                 | 560-1500                                  | .025-.052                 |
|                         |      | .002               | 6800-8200                 | 700-1600                                  | .023-.045                 |
|                         |      | .004               | 6800-8200                 | 770-1800                                  | .025-.050                 |
|                         |      | .001               | 14,000-15,500             | 140-1000                                  | .15-.25                   |

|                          |     |        |               |           |            |
|--------------------------|-----|--------|---------------|-----------|------------|
| Square 50                | 46  | .002   | 14,000-15,500 | 140-1050  | .15-.25    |
|                          |     | .004   | 14,000-15,500 | 140-1150  | .18-.30    |
| Microsil (Bare or Cased) | 33  | .001   | 13,000-16,000 | 2000 max. | 1.20 max.  |
|                          |     | .002   | 15,000-18,000 | 2500 max. | .70 max.   |
|                          |     | .004   | 15,000-18,000 | 3500 max. | .60 max.   |
|                          |     | .012** | 15,000-18,000 | 4000 max. | .35 max.** |
| Microsil-Selected        | 34  | .004   | 17,500-18,500 | 3500 max. | .60 max.   |
| Supermendur              | 107 | .002   | 20,000-22,000 | 1000-2000 | .55-.75    |
|                          |     | .004   | 20,000-22,000 | 1000-2000 | .50-.70    |

| TABLE XI - MAXIMUM VALUES OF H BY ID/OD RATIO |                         |                                   |           |                       |           |                 |
|-----------------------------------------------|-------------------------|-----------------------------------|-----------|-----------------------|-----------|-----------------|
| Performance Designation                       | Tape Thickness (inches) | Maximum H (Oersteds) at 400 Hertz |           |                       |           |                 |
|                                               |                         | .600-.649                         | .650-.699 | ID/OD Ratio .700-.749 | .750-.799 | .800 or Greater |
| SuperSquare 80                                | .0100                   | .0100                             | .0090     | .0085                 | .0080     | .0070           |
|                                               | .002                    | .0100                             | .0090     | .0085                 | .0080     | .0070           |
|                                               | .004                    | .0150                             | .0140     | .0135                 | .0130     | .0120           |
| Square 80                                     | .001                    | .0130                             | .0120     | .0110                 | .0100     | .0085           |
|                                               | .002                    | .0130                             | .0120     | .0110                 | .0100     | .0090           |
|                                               | .004                    | .0228                             | .0195     | .0172                 | .0150     | .0130           |
| Square 50                                     | .001                    | .0435                             | .0390     | .0360                 | .0330     | .0300           |
|                                               | .002                    | .0475                             | .0450     | .0400                 | .0375     | .0320           |
|                                               | .004                    | .0563                             | .0525     | .0488                 | .0450     | .0430           |
| Microsil                                      | .001                    | .240                              | .205      | .195                  | .185      | .175            |
|                                               | .002                    | .1420                             | .1380     | .1340                 | .1300     | .1250           |
|                                               | .004                    | .1530                             | .1460     | .1390                 | .1320     | .1250           |
|                                               | .012*                   | .072*                             | .067*     | .062*                 | .057*     | .055*           |
| Supermendur                                   | .002                    | .1200                             | .1100     | .1000                 | .0900     | .0800           |
|                                               | .004                    | .1000                             | .0920     | .0850                 | .0780     | .0700           |

| TABLE XII - PERMEABILITY TEST LIMITS - ROUND LOOP MATERIALS |                   |                     |                    |                                             |
|-------------------------------------------------------------|-------------------|---------------------|--------------------|---------------------------------------------|
| Performance Designation                                     | Frequency (Hertz) | Induction (Gausses) | Thickness (Inches) | Minimum Permeability (Impedance Measurment) |

|                                |        |       |            |        |
|--------------------------------|--------|-------|------------|--------|
| <b>Supermalloy</b>             | 100    | 20    | .001       | 55,000 |
|                                |        |       | .002       | 55,000 |
|                                |        |       | .004       | 55,000 |
|                                |        |       | .006       | 55,000 |
| <b>SuperPerm 80</b>            | 10,000 | 20    | .001       | 20,000 |
|                                |        |       | .002       | 15,000 |
|                                |        |       | .004       | 10,000 |
|                                |        |       | .006       | 6,000  |
| <b>SuperPerm 49</b>            | 1,000  | 40    | .001       | 4,500  |
|                                |        |       | .002       | 4,500  |
|                                |        |       | .004       | 4,500  |
|                                |        |       | .006       | 3,500  |
| <b>Microsil (Epoxy Coated)</b> | 60     | 6,000 | .001       | 5,000  |
|                                |        |       | .002       | 10,000 |
|                                |        |       | .004, .006 | 15,000 |
|                                |        |       | .012       | 20,000 |

| TABLE XIII - GROSS CORE WEIGHT CONVERSION TABLE |        |                         |                |              |        |
|-------------------------------------------------|--------|-------------------------|----------------|--------------|--------|
| Designation                                     | Factor | Designation             | Factor         | Designation  | Factor |
| Supersquare 80                                  | 1.059  | Microsil<br>Supermendur | 0.927<br>0.988 | Supermalloy  | 1.059  |
| Square 80                                       | 1.059  |                         |                | SuperPerm 49 | 1.000  |
| Square 50                                       | 1.000  |                         |                | SuperPerm 80 | 1.059  |

**WIRE TABLE**

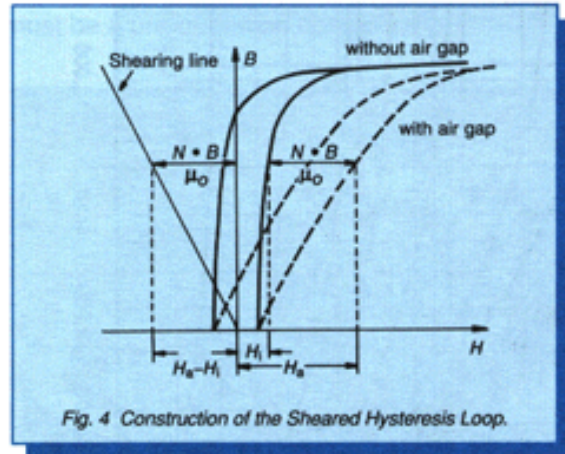
| <b>Wire Size<br/>AWG</b> | <b>Diameter<br/>With<br/>Heavy<br/>Insulation<br/>(Inches)</b> | <b>Area<br/>Circular<br/>Mills<br/>Nominal</b> | <b>Resistance<br/>Ohms Per<br/>1000 Ft.</b> | <b>Weight<br/>Pounds<br/>Per<br/>1000<br/>Ft.</b> | <b>Layer<br/>Winding<br/>Turns<br/>Per<br/>Inch</b> | <b>Random<br/>Winding<br/>Turns<br/>Per<br/>Inch<sub>2</sub></b> | <b>Machine<br/>Minimum<br/>Wound I.<br/>D.<br/>(Inches)</b> | <b>Maximum<br/>Turns For<br/>Case I.D. of<br/>0.5 In. 1.0<br/>In.</b> |        |
|--------------------------|----------------------------------------------------------------|------------------------------------------------|---------------------------------------------|---------------------------------------------------|-----------------------------------------------------|------------------------------------------------------------------|-------------------------------------------------------------|-----------------------------------------------------------------------|--------|
| <b>8</b>                 | .132                                                           | 16510                                          | .628                                        | 50.4                                              | 6                                                   | 42                                                               | 2.000                                                       | -                                                                     | -      |
| <b>9</b>                 | .118                                                           | 13090                                          | .793                                        | 40.4                                              | 7                                                   | 57                                                               | 1.750                                                       | -                                                                     | -      |
| <b>10</b>                | .106                                                           | 10380                                          | .999                                        | 31.7                                              | 8                                                   | 75                                                               | 1.500                                                       | -                                                                     | -      |
| <b>11</b>                | .094                                                           | 8230                                           | 1.26                                        | 25.2                                              | 9                                                   | 95                                                               | 1.250                                                       | -                                                                     | -      |
| <b>12</b>                | .084                                                           | 6530                                           | 1.59                                        | 20.1                                              | 11                                                  | 130                                                              | 1.000                                                       | -                                                                     | -      |
| <b>13</b>                | .075                                                           | 5190                                           | 2.00                                        | 15.9                                              | 12                                                  | 159                                                              | .875                                                        | -                                                                     | -      |
| <b>14</b>                | .067                                                           | 4110                                           | 2.52                                        | 12.6                                              | 13                                                  | 193                                                              | .875                                                        | -                                                                     | -      |
| <b>15</b>                | .060                                                           | 3260                                           | 3.18                                        | 10.0                                              | 15                                                  | 248                                                              | .875                                                        | -                                                                     | -      |
| <b>16</b>                | .054                                                           | 2580                                           | 4.02                                        | 7.95                                              | 17                                                  | 316                                                              | .750                                                        | -                                                                     | 120    |
| <b>17</b>                | .048                                                           | 2050                                           | 5.05                                        | 6.32                                              | 19                                                  | 394                                                              | .750                                                        | -                                                                     | 180    |
| <b>18</b>                | .043                                                           | 1620                                           | 6.39                                        | 5.02                                              | 21                                                  | 487                                                              | .750                                                        | -                                                                     | 260    |
| <b>19</b>                | .039                                                           | 1290                                           | 8.05                                        | 3.99                                              | 23                                                  | 596                                                              | .500                                                        | 60                                                                    | 360    |
| <b>20</b>                | .035                                                           | 1020                                           | 10.13                                       | 3.16                                              | 26                                                  | 792                                                              | .500                                                        | 80                                                                    | 450    |
| <b>21</b>                | .031                                                           | 812                                            | 12.77                                       | 2.51                                              | 29                                                  | 982                                                              | .500                                                        | 90                                                                    | 560    |
| <b>22</b>                | .028                                                           | 640                                            | 16.20                                       | 1.99                                              | 32                                                  | 1210                                                             | .438                                                        | 120                                                                   | 680    |
| <b>23</b>                | .025                                                           | 510                                            | 20.30                                       | 1.59                                              | 36                                                  | 1260                                                             | .438                                                        | 150                                                                   | 850    |
| <b>24</b>                | .022                                                           | 404                                            | 25.67                                       | 1.26                                              | 40                                                  | 1550                                                             | .313                                                        | 180                                                                   | 1040   |
| <b>25</b>                | .020                                                           | 320                                            | 32.37                                       | 1.01                                              | 45                                                  | 1940                                                             | .313                                                        | 250                                                                   | 1310   |
| <b>26</b>                | .018                                                           | 253                                            | 41.02                                       | .799                                              | 50                                                  | 2700                                                             | .300                                                        | 310                                                                   | 1560   |
| <b>27</b>                | .016                                                           | 202                                            | 51.44                                       | .634                                              | 55                                                  | 3550                                                             | .300                                                        | 370                                                                   | 1870   |
| <b>28</b>                | .014                                                           | 159                                            | 65.31                                       | .504                                              | 62                                                  | 4180                                                             | .300                                                        | 470                                                                   | 2500   |
| <b>29</b>                | .013                                                           | 128                                            | 81.21                                       | .401                                              | 68                                                  | 5160                                                             | .300                                                        | 620                                                                   | 3250   |
| <b>30</b>                | .012                                                           | 100.0                                          | 103.7                                       | .318                                              | 77                                                  | 6560                                                             | .250                                                        | 750                                                                   | 4000   |
| <b>31</b>                | .011                                                           | 79.2                                           | 130.9                                       | .254                                              | 85                                                  | 8090                                                             | .250                                                        | 920                                                                   | 5050   |
| <b>32</b>                | .010                                                           | 64.0                                           | 162.0                                       | .202                                              | 94                                                  | 10000                                                            | .250                                                        | 1250                                                                  | 6870   |
| <b>33</b>                | .009                                                           | 50.4                                           | 205.7                                       | .161                                              | 105                                                 | 12500                                                            | .250                                                        | 1510                                                                  | 8740   |
| <b>34</b>                | .008                                                           | 39.7                                           | 261.3                                       | .127                                              | 119                                                 | 16250                                                            | .218                                                        | 1920                                                                  | 10620  |
| <b>35</b>                | .007                                                           | 31.4                                           | 330.7                                       | .101                                              | 133                                                 | 20600                                                            | .218                                                        | 2440                                                                  | 18120  |
| <b>36</b>                | .0060                                                          | 25.0                                           | 414.8                                       | .0803                                             | 145                                                 | 25000                                                            | .218                                                        | 2930                                                                  | 16250  |
| <b>37</b>                | .0055                                                          | 20.2                                           | 512.1                                       | .0641                                             | 161                                                 | 30900                                                            | .218                                                        | 3500                                                                  | 19370  |
| <b>38</b>                | .0049                                                          | 16.0                                           | 648.2                                       | .0509                                             | 181                                                 | 39300                                                            | .218                                                        | 4300                                                                  | 23750  |
| <b>39</b>                | .0043                                                          | 12.2                                           | 846.6                                       | .0403                                             | 205                                                 | 51500                                                            | .218                                                        | 5300                                                                  | 30000  |
| <b>40</b>                | .0038                                                          | 9.61                                           | 1079                                        | .0319                                             | 226                                                 | 72000                                                            | .218                                                        | 7450                                                                  | 42500  |
| <b>41</b>                | .0034                                                          | 7.84                                           | 1323                                        | .0252                                             | 250                                                 | 89800                                                            | .218                                                        | 9950                                                                  | 58120  |
| <b>42</b>                | .0030                                                          | 6.25                                           | 1659                                        | .0199                                             | 283                                                 | 116500                                                           | .218                                                        | 12600                                                                 | 72500  |
| <b>43</b>                | .0027                                                          | 4.84                                           | 2143                                        | .0159                                             | 315                                                 | 143000                                                           | .187                                                        | 14900                                                                 | 85000  |
| <b>44</b>                | .0025                                                          | 4.00                                           | 2593                                        | .0127                                             | 240                                                 | 168500                                                           | .187                                                        | 17400                                                                 | 100000 |

## GAPPED TOROIDAL CORES

The design of a storage choke or transformer which also carries direct current normally requires air gaps which prevent the core from being magnetized by the dc current above  $1/2 B_{max}$ .

An air gap in a core has the effect of flattening/ shearing the B-H loop of the material, lowering the residual flux and the permeability, extending the incremental a.c. permeability to higher values of B and H. Precise control of the inductance L, or the remanence  $B_r$  is therefore possible with gapped toroids.

Figure 4 shows a comparison of hysteresis loops for a core with and without gaps.



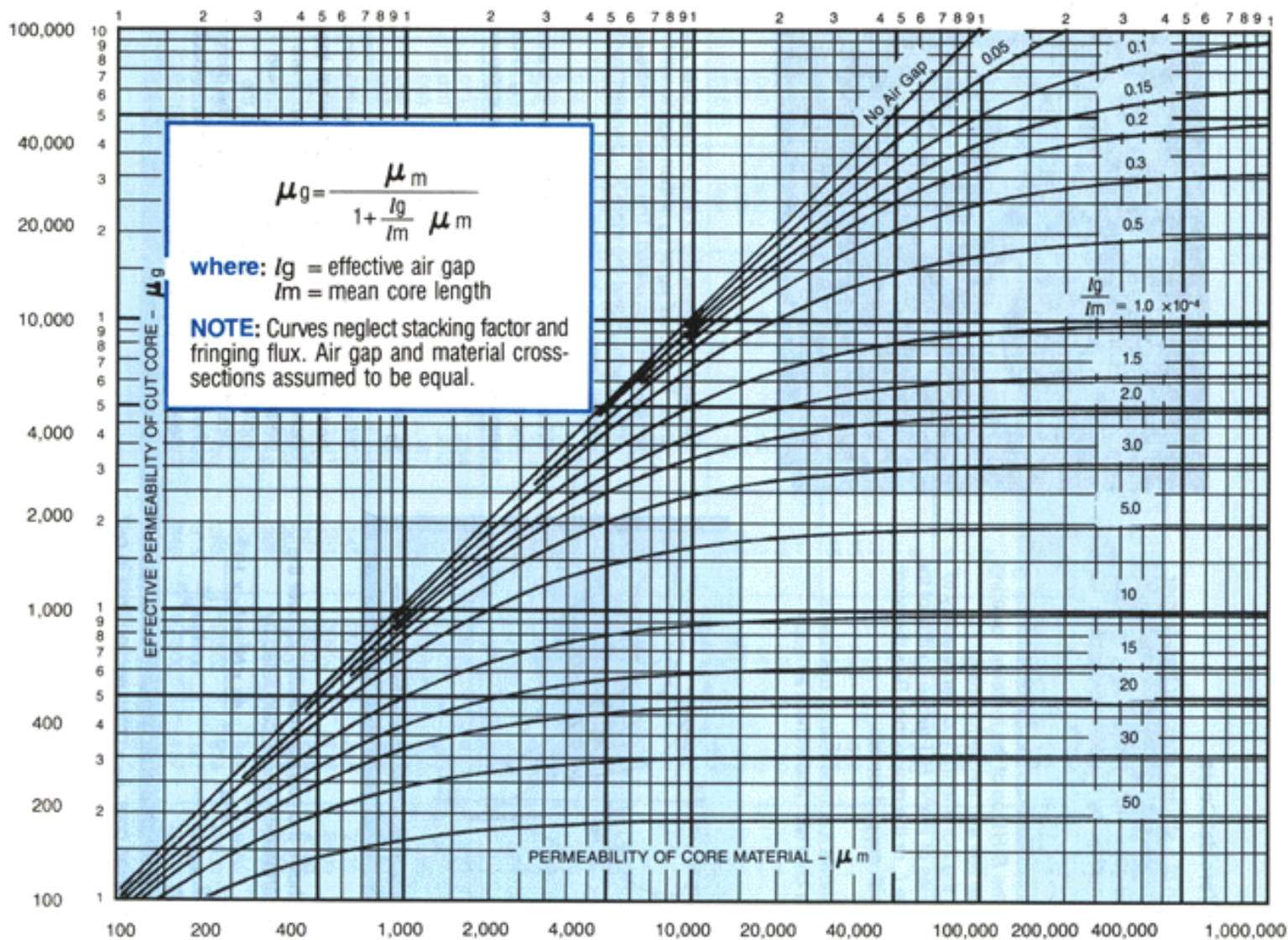
For larger air gaps, the B field fringes over a larger area. The actual  $\mu_g$  or  $L_g$  is then significantly greater than calculated. The deviation increases with  $l_g$ , with  $1/A_c$  and the more  $A_c$  deviates from a square area.

When an unbalanced dc current flows in a winding, the core is subjected to a dc magnetizing force. This results in a flux density which may be expressed as

$$B_{dc} = .4\pi \times N I_{dc} / l_g + I_m / \mu m$$

$I_g$  and  $I_m$  in cm.

If the sum of  $B_{ac}$  and  $B_{dc}$  are over the maximum operating flux density of the core material, the incremental permeability and inductance are greatly reduced; to reduce  $B_{dc}$  the  $I_g$  increases the inductance will decrease, therefore, the designer should balance  $I_g$  to produce maximum inductance. See Hanna curves.



## GAPPED TOROIDS KEY SPECIFICATIONS

ID - Inside diameter

OD - Outside diameter

HT - Strip width or height

Gap - Specify either a mechanical gap or specify the AL value with tolerances including ac voltage, dc current if applicable, number of turns, and frequency.

Material and thickness requirements are the same as any standard toroidal core.

Most gapped toroids are epoxy impregnated and can be gapped as small as .006", then either fluidize bed coated "D" or black epoxy painted "M". We do offer "end caps" as an alternative to the coating process, but quantities and tooling costs to injection mold these caps must be a pre-quotation consideration.

All gapped toroids are numbered in the 3000 series of part numbers - followed by the coating letter designator - followed by the material code and thickness such as 3304 and then the gap is indicated by the letter - G - followed by gap size in three decimals. Example: 3221 D 3304 G. 032

Note: All electrical specifications for gapped toroids must be pre-quote evaluated to determine if requirements can be met on a production basis.

\* Gapped Tolerances (inch)

when gap < .010" .....± .001"

.010 ≤ gap < .100" .....± 10%

.100 ≤ gap < .100" .....± .010

or A<sub>L</sub> value .....± 15%

## GAPPED TOROID DIMENSIONS

### EXAMPLES OF COMMON GAPPED CORES

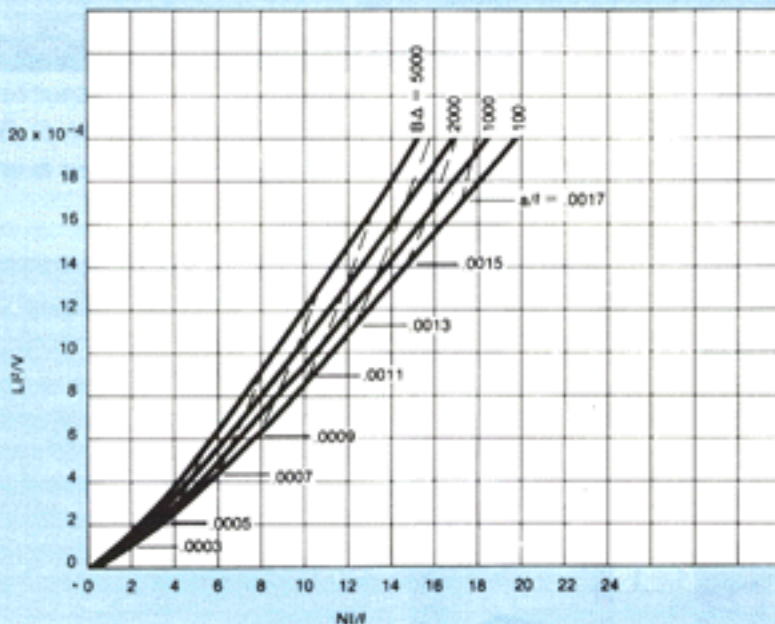
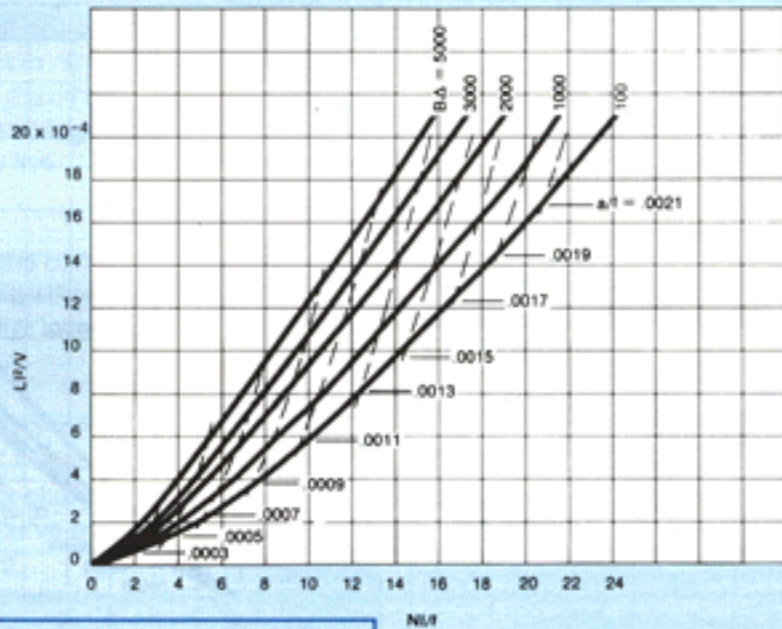
| PART # | I.D.  | O.D.  | HT.   | GROSS AREA (cm <sup>2</sup> ) | MEAN PATH LENGTH - cm | GROSS WEIGHT MICROSIL - lb | PART # |
|--------|-------|-------|-------|-------------------------------|-----------------------|----------------------------|--------|
| 3109   | 0.500 | 0.750 | 0.250 | 0.201                         | 4.983                 | 0.0169                     | 3109   |
| 3092   | 1.000 | 1.500 | 0.250 | 0.403                         | 9.750                 | 0.6780                     | 3092   |
| 3120   | 0.500 | 0.813 | 0.313 | 0.316                         | 5.239                 | 0.0280                     | 3120   |
| 3189   | 0.437 | 0.812 | 0.375 | 0.454                         | 4.980                 | 0.0381                     | 3189   |
| 3151   | 0.500 | 0.750 | 0.375 | 0.302                         | 4.987                 | 0.0254                     | 3151   |
| 3065   | 0.500 | 0.875 | 0.375 | 0.454                         | 5.480                 | 0.0420                     | 3065   |
| 3070   | 0.500 | 1.000 | 0.375 | 0.605                         | 5.985                 | 0.0610                     | 3070   |
| 3024   | 0.625 | 1.000 | 0.375 | 0.454                         | 6.484                 | 0.0496                     | 3024   |
| 3307   | 0.795 | 1.205 | 0.375 | 0.496                         | 7.980                 | 0.0667                     | 3307   |
| 3242   | 0.875 | 1.437 | 0.375 | 0.680                         | 9.225                 | 0.1060                     | 3242   |
| 3174   | 1.000 | 1.500 | 0.375 | 0.605                         | 9.975                 | 0.1020                     | 3174   |
| 3311   | 1.250 | 1.750 | 0.375 | 0.604                         | 11.970                | 0.1220                     | 3311   |
| 3391   | 0.437 | 0.687 | 0.437 | 0.352                         | 4.485                 | 0.2660                     | 3391   |
| 3170   | 0.750 | 1.375 | 0.437 | 0.881                         | 8.479                 | 0.1260                     | 3170   |
| 3431   | 0.940 | 1.500 | 0.437 | 0.789                         | 9.736                 | 0.1290                     | 3431   |
| 3030   | 0.625 | 1.000 | 0.438 | 0.529                         | 6.484                 | 0.0580                     | 3030   |
| 3321   | 0.500 | 1.000 | 0.500 | 0.806                         | 5.985                 | 0.0814                     | 3321   |
| 3066   | 0.625 | 1.000 | 0.500 | 0.605                         | 6.483                 | 0.0661                     | 3066   |
| 3200   | 0.625 | 1.187 | 0.500 | 0.906                         | 7.229                 | 0.110                      | 3200   |
| 3091   | 0.750 | 1.250 | 0.500 | 0.806                         | 7.980                 | 0.1080                     | 3091   |
| 3126   | 0.750 | 1.313 | 0.500 | 0.908                         | 8.231                 | 0.1260                     | 3026   |
| 3043   | 0.750 | 1.500 | 0.500 | 1.208                         | 8.980                 | 0.1840                     | 3043   |
| 3113   | 0.875 | 1.375 | 0.500 | 0.806                         | 8.978                 | 0.1220                     | 3113   |
| 3237   | 0.875 | 1.437 | 0.500 | 0.906                         | 9.220                 | 0.1420                     | 3237   |
| 3093   | 1.000 | 1.500 | 0.500 | 0.806                         | 9.975                 | 0.1360                     | 3093   |
| 3411   | 2.500 | 3.250 | 0.500 | 1.209                         | 22.940                | 0.4680                     | 3411   |
| 3244   | 0.875 | 1.540 | 0.562 | 1.205                         | 9.636                 | 0.1960                     | 3244   |

|             |       |       |       |       |        |        |      |
|-------------|-------|-------|-------|-------|--------|--------|------|
| <b>3075</b> | 0.750 | 1.375 | 0.625 | 1.259 | 8.480  | 0.1800 | 3075 |
| <b>3079</b> | 1.000 | 1.625 | 0.625 | 1.259 | 10.473 | 0.2220 | 3079 |
| <b>3188</b> | 0.437 | 0.812 | 0.750 | 0.907 | 4.985  | 0.0760 | 3188 |
| <b>3138</b> | 0.625 | 1.125 | 0.750 | 1.209 | 6.983  | 0.1420 | 3138 |
| <b>3251</b> | 1.000 | 1.375 | 0.750 | 0.907 | 9.476  | 0.1450 | 3251 |
| <b>3031</b> | 0.875 | 1.437 | 0.750 | 1.360 | 9.225  | 0.2110 | 3031 |
| <b>3191</b> | 0.875 | 1.687 | 0.750 | 1.964 | 10.222 | 0.3390 | 3191 |
| <b>3069</b> | 1.000 | 2.000 | 0.750 | 2.419 | 11.970 | 0.4880 | 3069 |
| <b>3101</b> | 1.125 | 1.875 | 0.750 | 1.814 | 11.970 | 0.3660 | 3101 |
| <b>3432</b> | 0.750 | 1.375 | 1.000 | 2.016 | 8.479  | 0.2880 | 3432 |
| <b>3221</b> | 1.000 | 1.500 | 1.000 | 1.612 | 9.975  | 0.2710 | 3221 |
| <b>3422</b> | 0.875 | 1.550 | 1.125 | 2.449 | 9.676  | 0.4000 | 3422 |
| <b>3263</b> | 0.875 | 1.125 | 1.250 | 1.008 | 7.980  | 0.1360 | 3263 |
| <b>3211</b> | 2.000 | 3.500 | 1.500 | 7.256 | 21.945 | 2.6850 | 3211 |
| <b>3366</b> | 1.945 | 2.903 | 1.625 | 5.020 | 19.343 | 1.6380 | 3366 |

# HANNA DESIGN CURVES

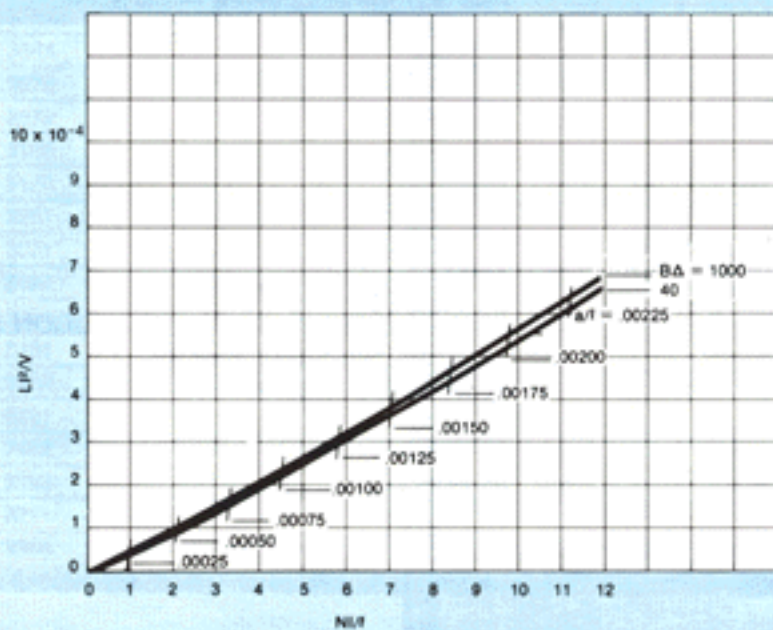
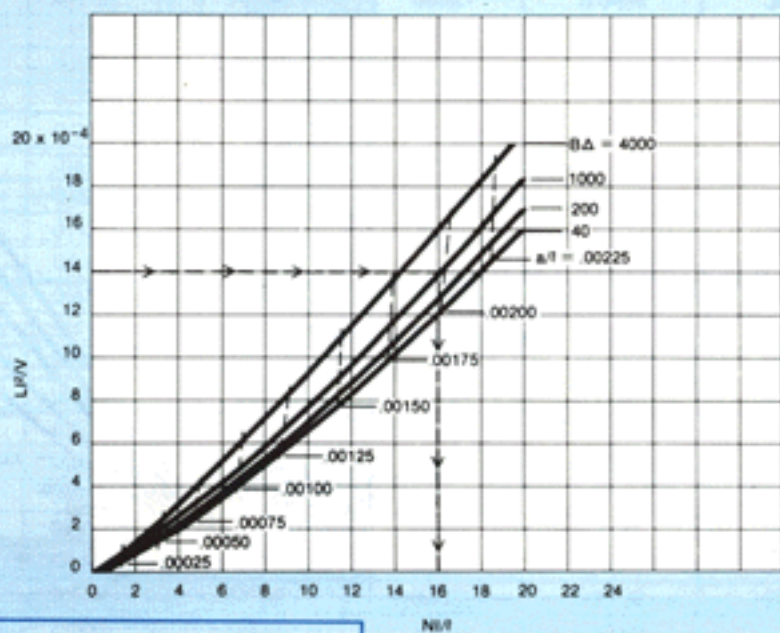
**HANNA CURVES\*** provide a simplified method of calculating inductances with direct current, and for determining the optimum air gap. Where the  $L$  is the a-c inductance in henries,  $I$  is the d-c current in amperes, and  $V$  is the core volume in cubic centimeters; calculate  $LI^2/V$  and enter the left side of the chart at that ordinate. Extend to the right along this ordinate to the appropriate  $B$ , for a-c induction in gauss, and select the indicated abscissa for  $NI/I$ . Calculate required turns by substituting the centimeters of path length in the core material for  $l$ , and for the d-c amperas,  $I$ . The optimum ratio of air gap length to path length ( $a/l$ ) applies to the points indicated.

**MICROSIL  
RAIN-ORIENTED SILICON STEEL)  
.004" THICKNESS  
400 HERTZ**



**MICROSIL  
(GRAIN-ORIENTED SILICON STEEL)  
.012" THICKNESS  
60 HERTZ**

**SUPERPERM 49  
.004" THICKNESS  
60/400 HERTZ**



**SUPERPERM 80  
.004" THICKNESS  
60/400 HERTZ**

# Hysteresis Curves

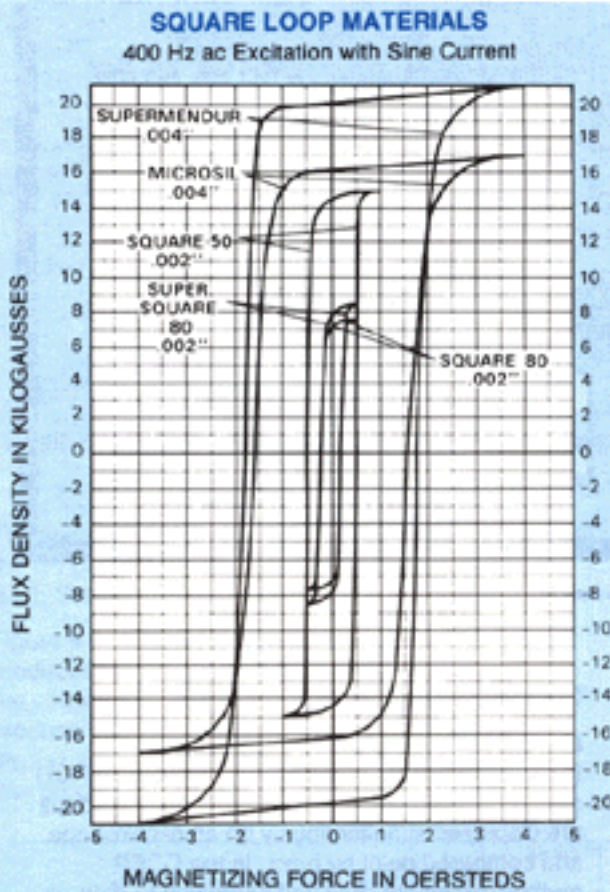


FIGURE 12

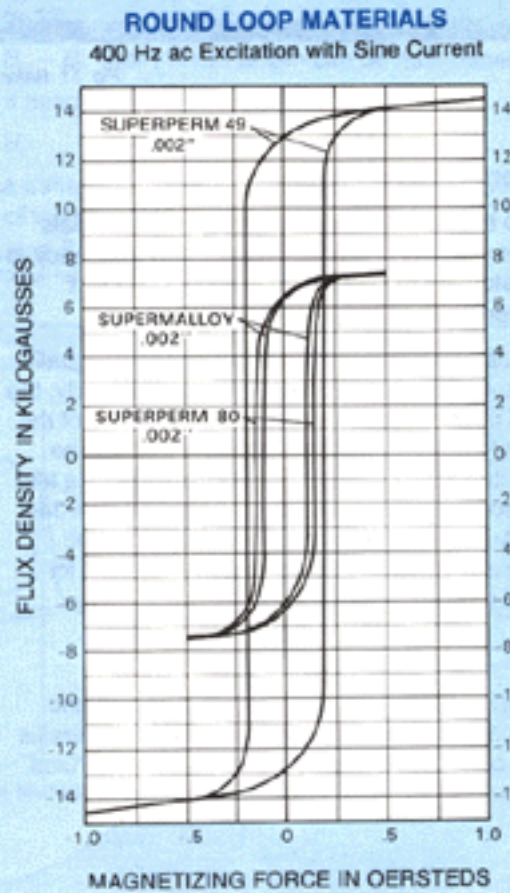
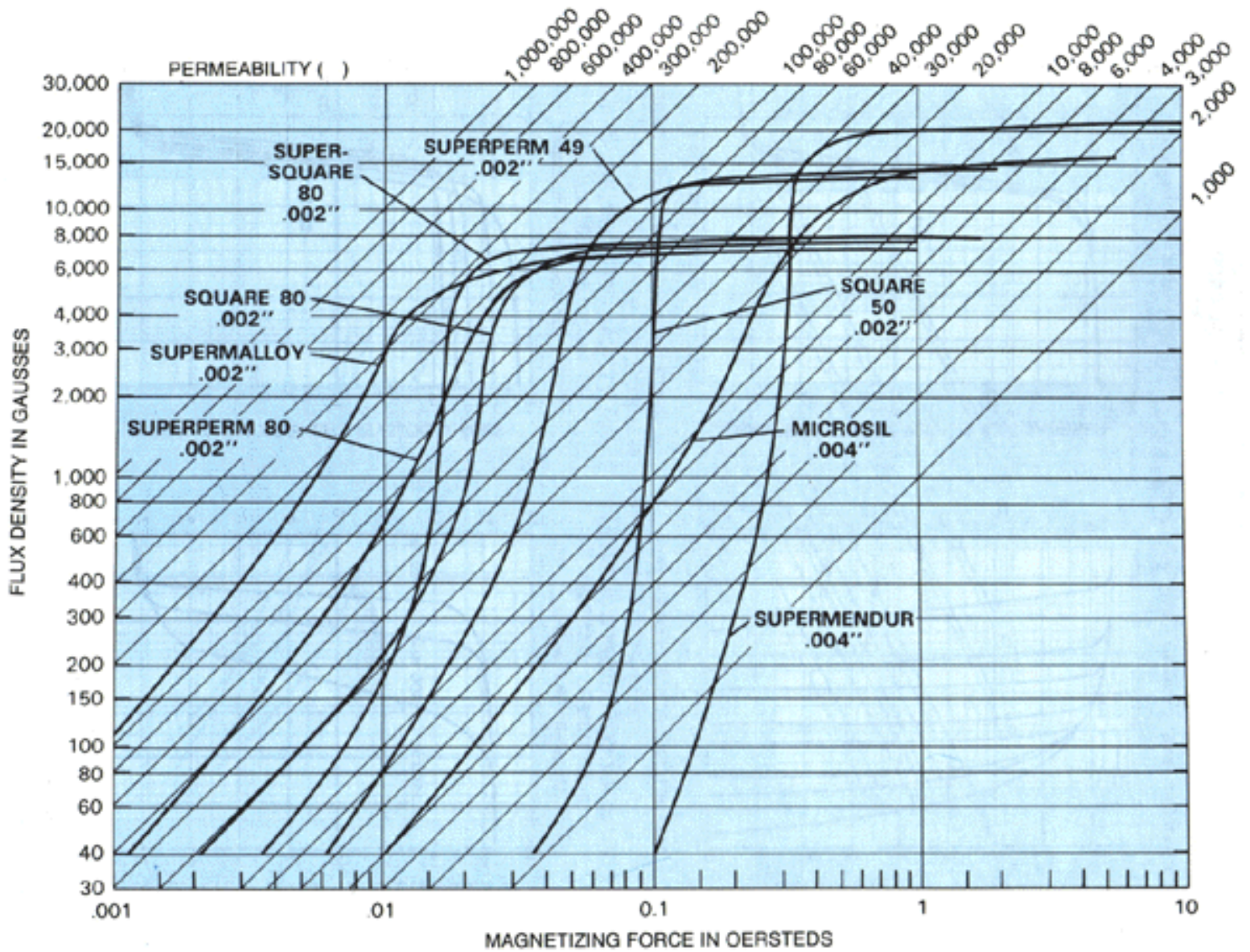


FIGURE 13

# Magnetization Curves



## Constant Current Flux Reset Test

The Constant Current Flux Reset (CCFR) test is widely used to evaluate core performance for magnetic amplifier use. The test is described in IEEE Standard 106. The ac excitation is usually specified at 400 Hertz, but frequencies between 60 and 6000 Hertz may also be specified. The test circuit is shown in Figure 6.

With zero dc control current and full wave ac sine current excitation (S closed), the current in "R" is set to a specified value sufficient to give maximum flux change. The flux change develops a voltage in the pick up winding which is indicated by the integrating flux voltmeter.

With S open in the ac excitation circuit the current changes to half sine wave and the core flux then varies between  $B$  and  $B_r$ , the residual flux level. The flux voltmeter now indicates  $B - B_r$ .

Adjusting the dc level in the dc bias winding resets the flux from  $B$  to other values as shown in the B-H loops, drawn in Figure 7. Plotting flux change against reset magnetizing force gives a curve as shown in Figure 8. Standard test data are determined by reading  $H_r$ , the reset magnetizing force required to obtain a flux change of  $B_r$ . This is approximately one-third of  $2B_r$ .  $H_r$  is the additional magnetizing force required for an additional one-third flux change. The ratio of  $B - B_r$  to  $H_r$  is expressed in kilogausses per oersted; and is referred to as the "gain".

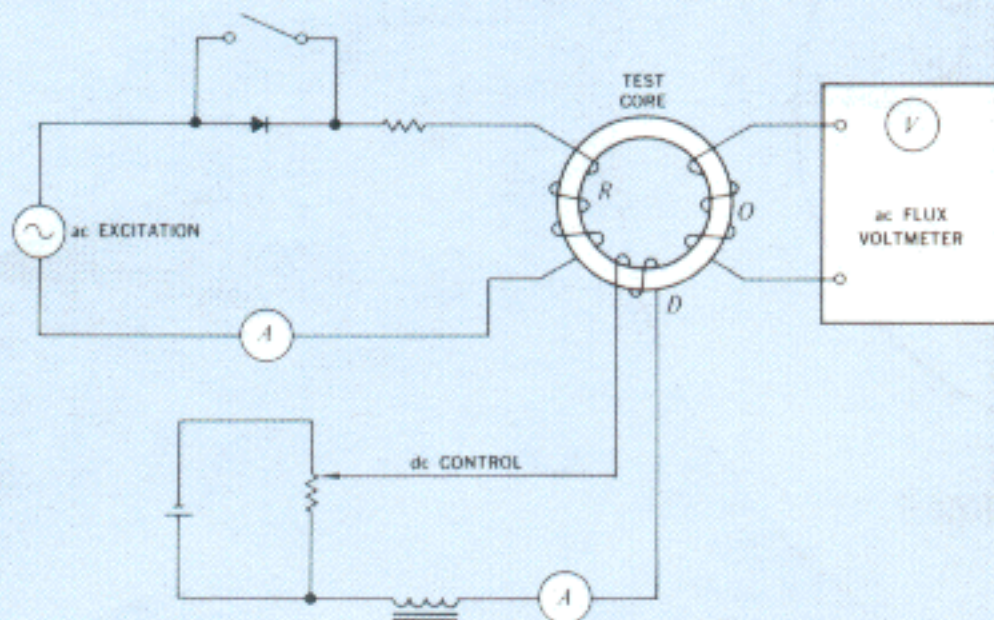
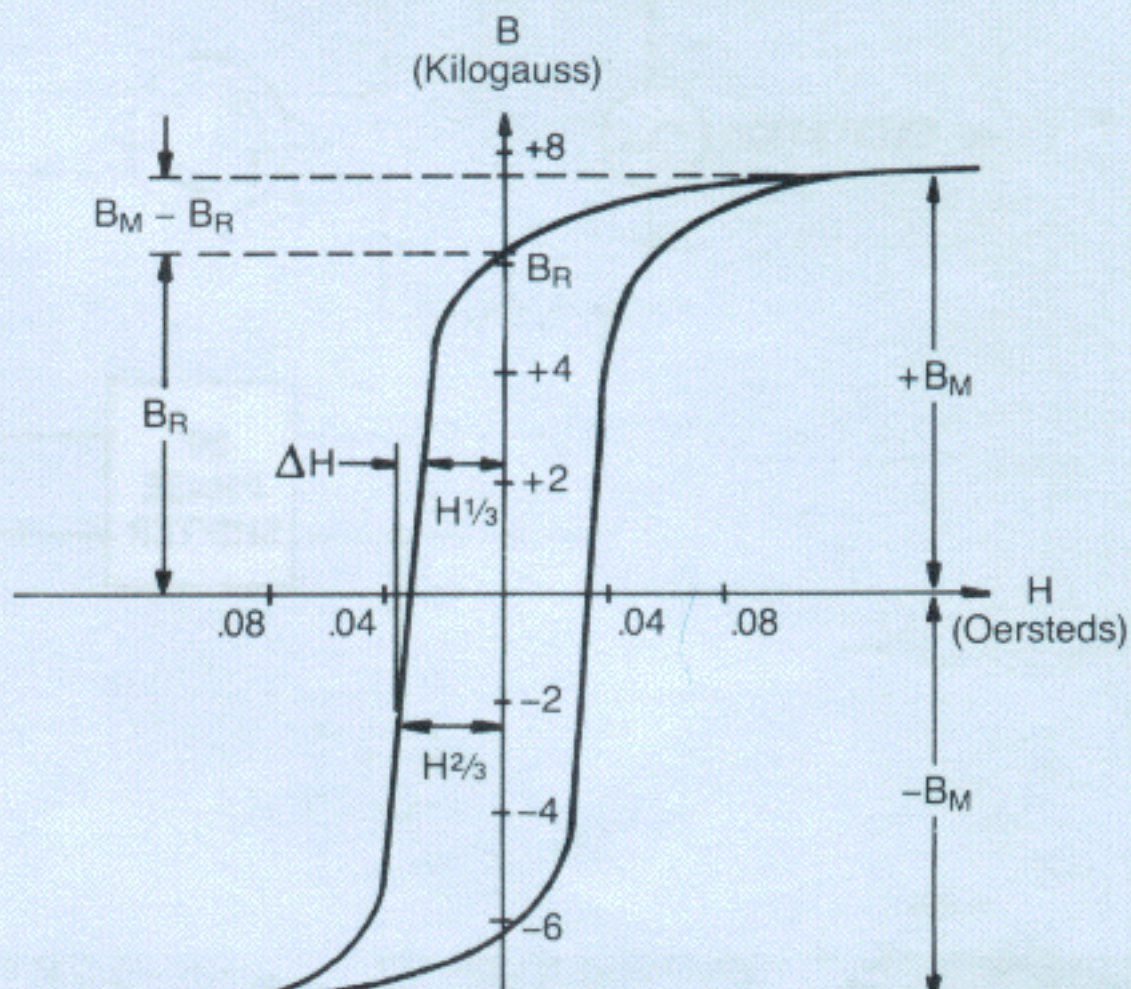


Fig. 6 Basic Constant Current Flux (CCFR) Test Circuit



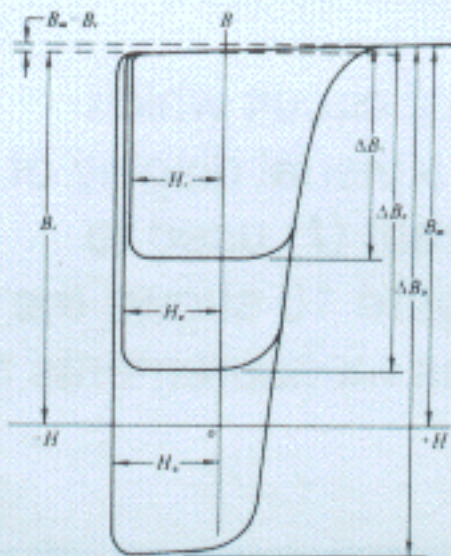
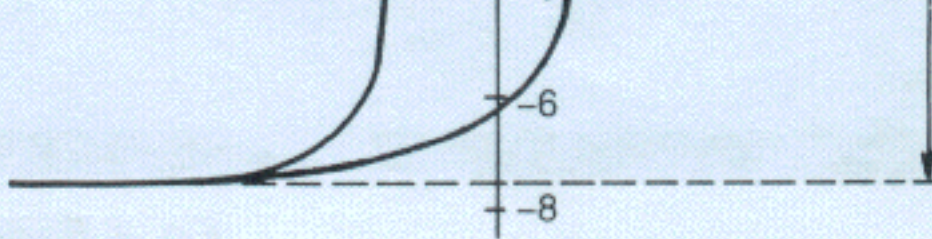


Fig. 7 CCFR Hysteresis Loops

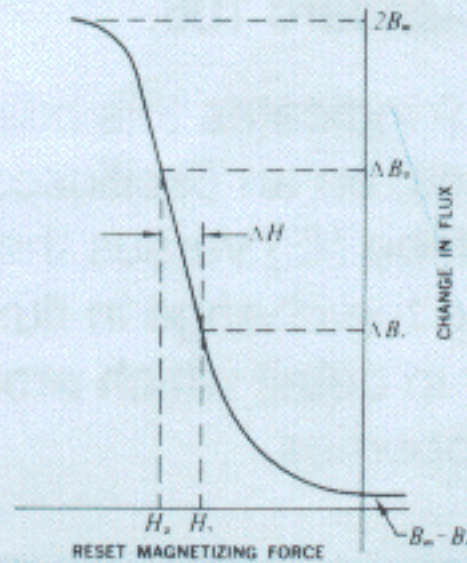


Fig. 8 CCFR Transfer Curve

# Sine Current

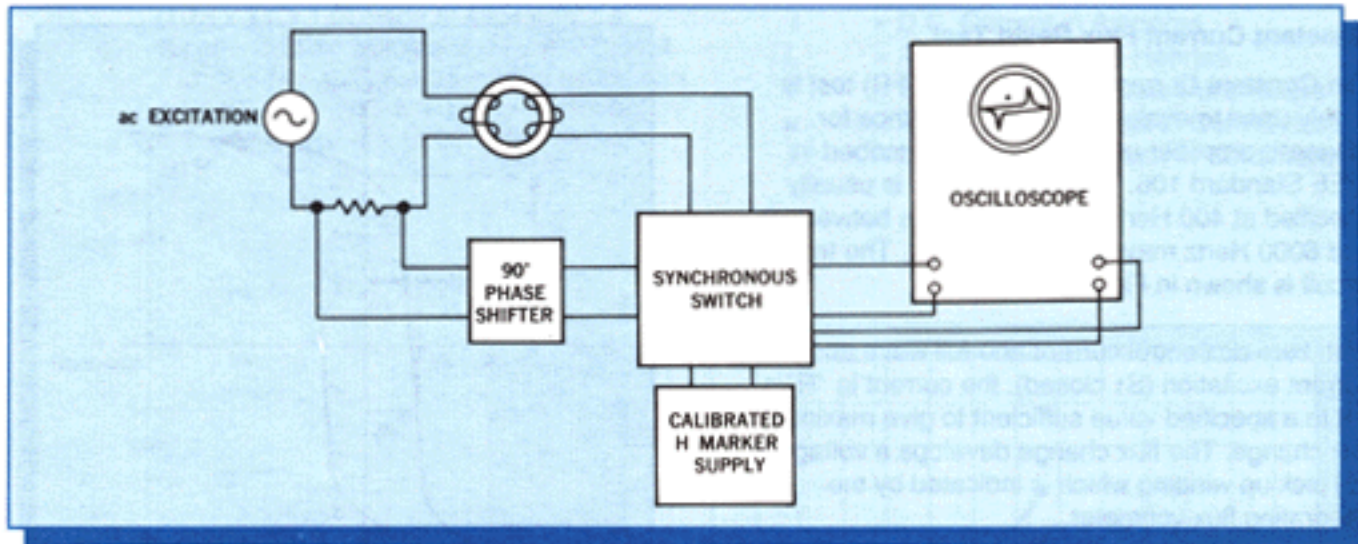
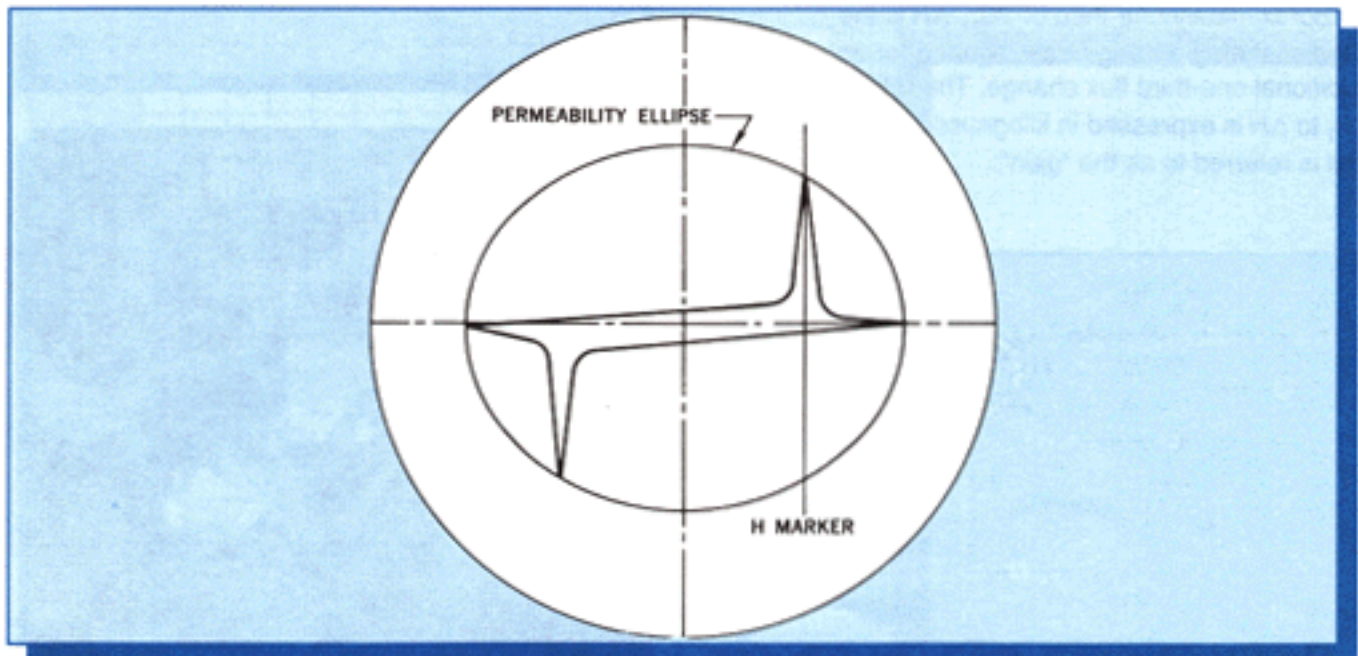


Fig. 9 Basic Sine Current Test Circuit

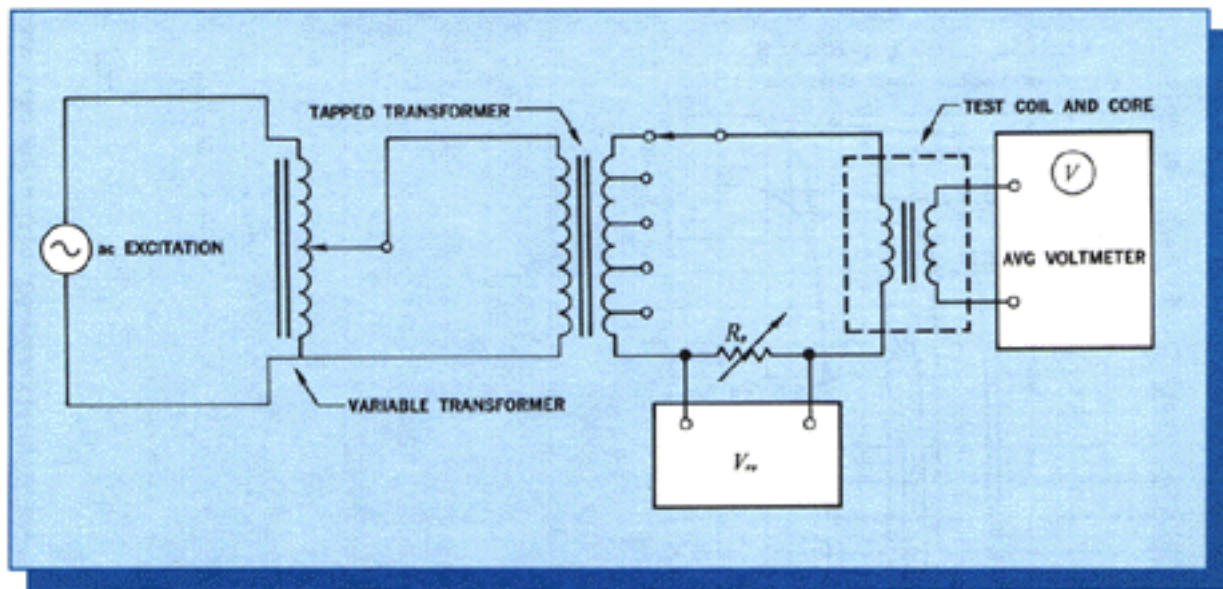
The Sine Current Test (sometimes referred to as the E-I Loop Test) has also been standardized by IEEE Standard 106.

Figure 9 indicates this basic test circuit which produces, on an oscilloscope, a visual display of the voltage ( $E$ ) versus the current ( $I$ ) used to produce the change in flux. Figure 10 shows the display in detail which produces measurements of four properties.

1.  $B_m^*$
  2.  $B_m - B_r$  (from which  $B_r/B_m$  can be determined, if needed).
  3.  $H_c$
  4.  $\Delta \mu_{\max}$  (the maximum differential permeability of the core as it is driven through  $B=0$ ).
- \* $B_m$  and  $B_m - B_r$  are measured from the B-H loop produced when the EI loop is integrated.



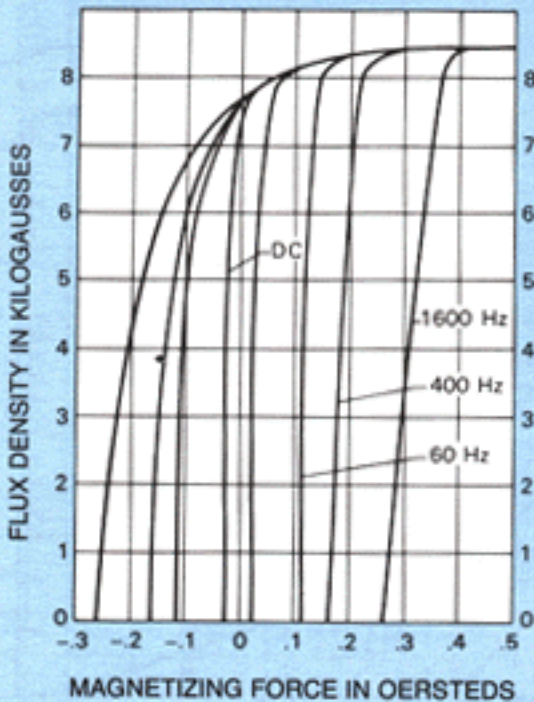
## Core Matching



# SuperSquare 80

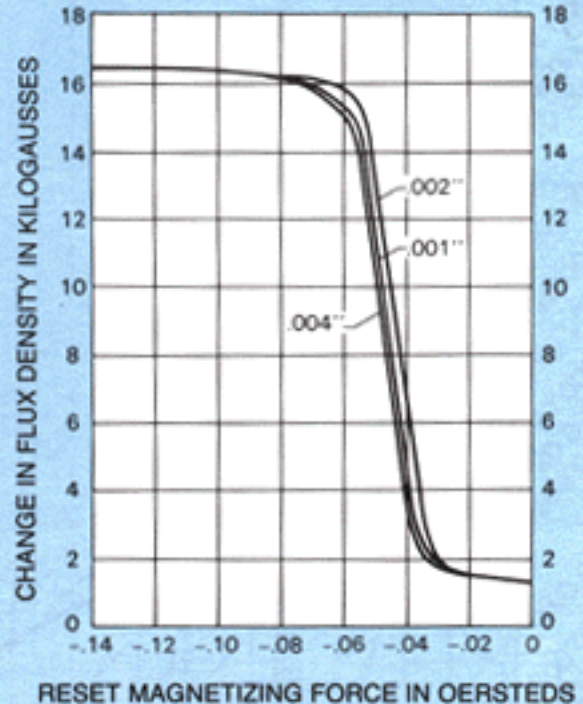
## TYPICAL HYSTERESIS LOOPS .002" SUPERSQUARE 80

Upper Two Quadrants ac Excitation with Sine Current



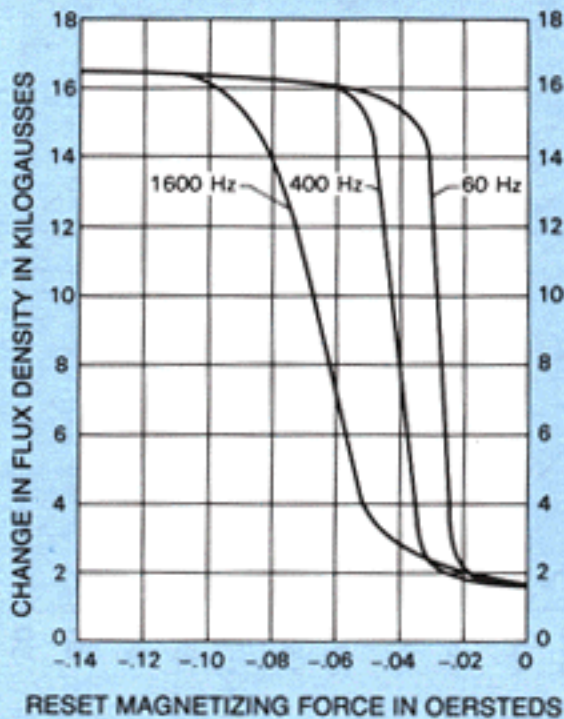
## TYPICAL CCFR CONTROL CURVES SUPERSQUARE 80

Variation with Thickness



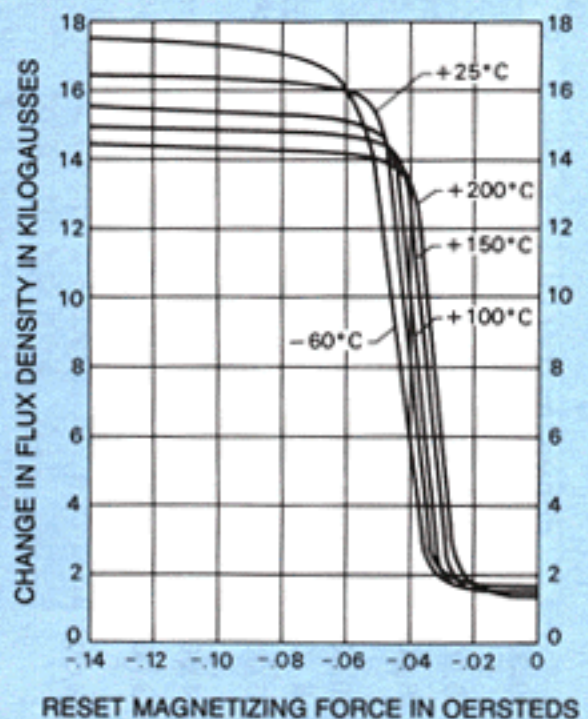
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Variation with Frequency

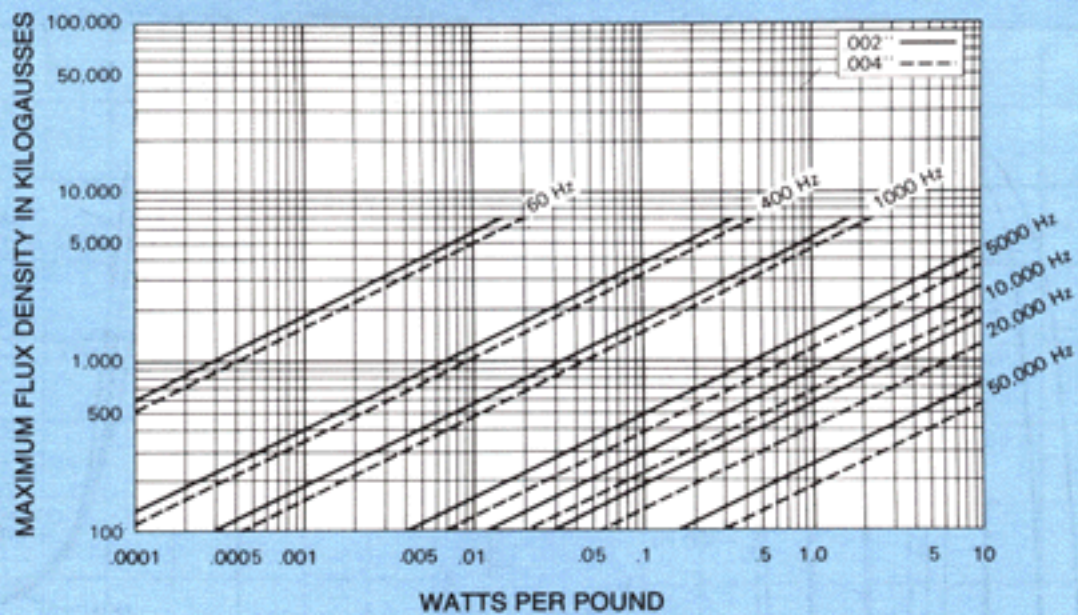


## TYPICAL CCFR CONTROL CURVES .002" SUPERSQUARE 80

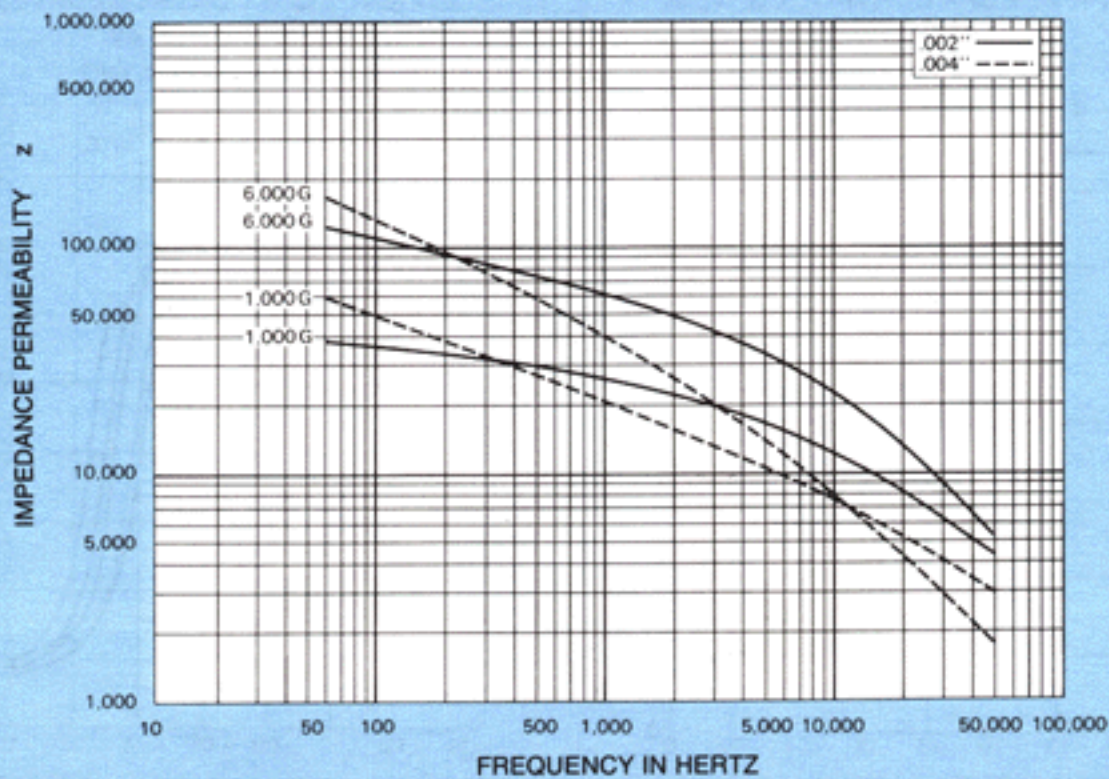
Variation with Temperature



# TYPICAL CORE LOSS CURVES SUPERSQUARE 80



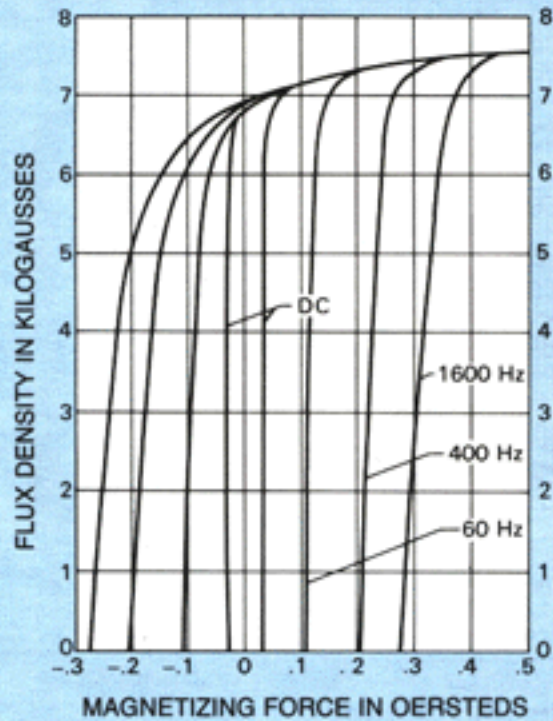
# TYPICAL IMPEDANCE PERMEABILITY CURVES SUPERSQUARE 80



# Square 80

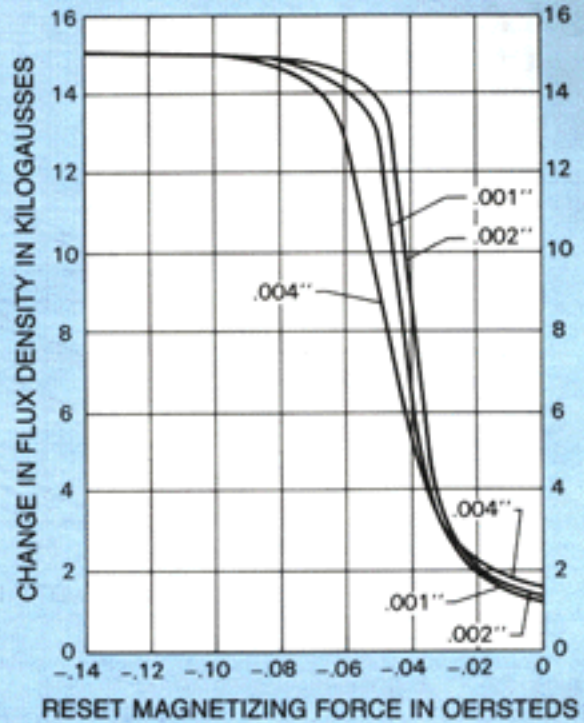
## TYPICAL HYSTERESIS LOOPS .002" SQUARE 80

Upper Two Quadrants ac Excitation with Sine Current



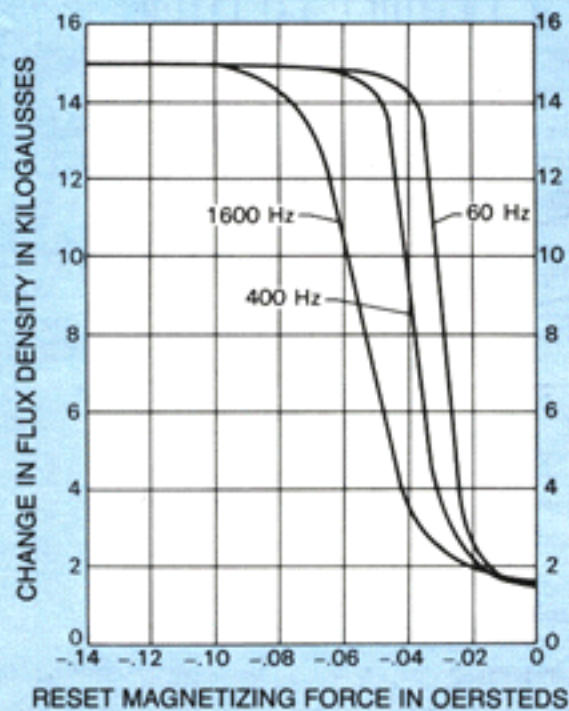
## TYPICAL CCFR CONTROL CURVES SQUARE 80

Variation with Thickness



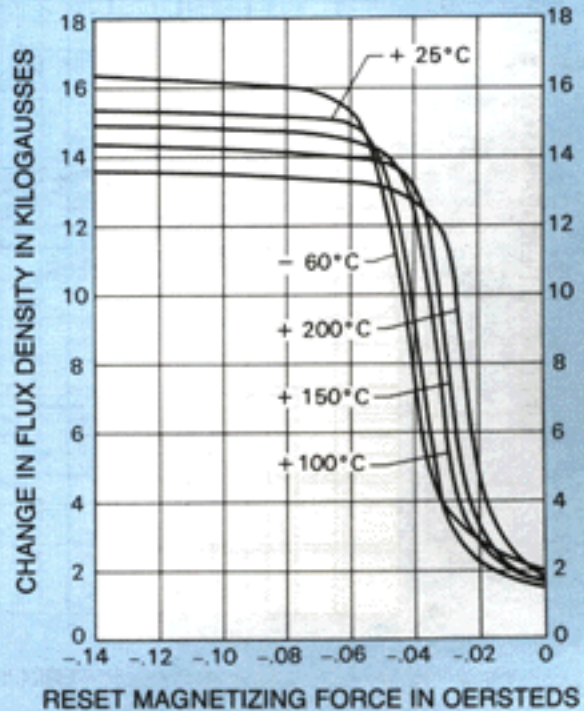
## TYPICAL CCFR CONTROL CURVES .002" SQUARE 80

Variation with Frequency

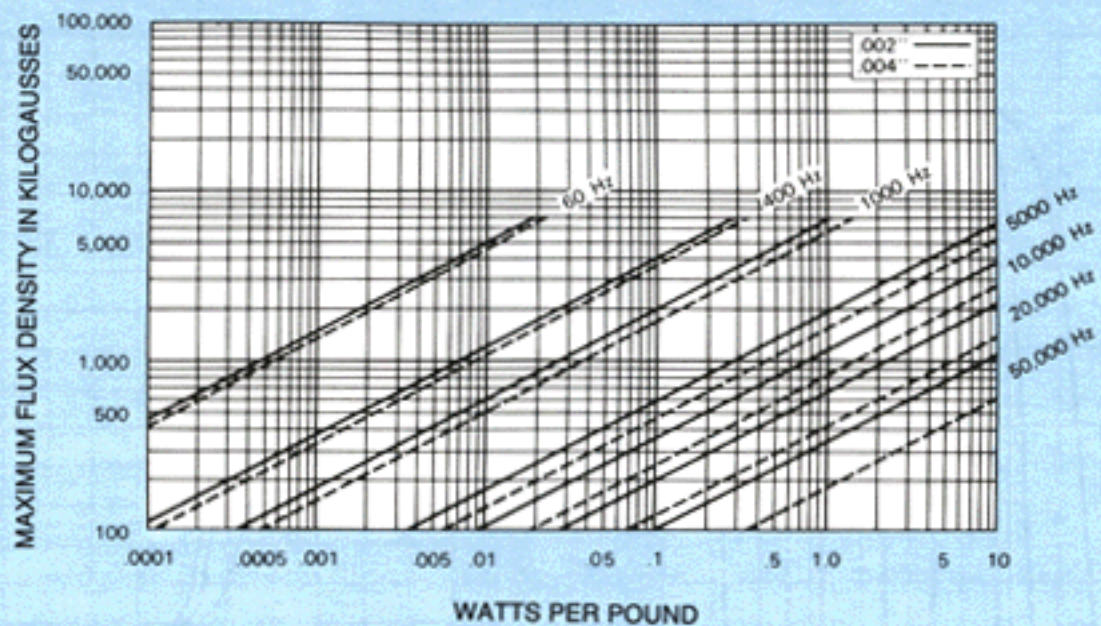


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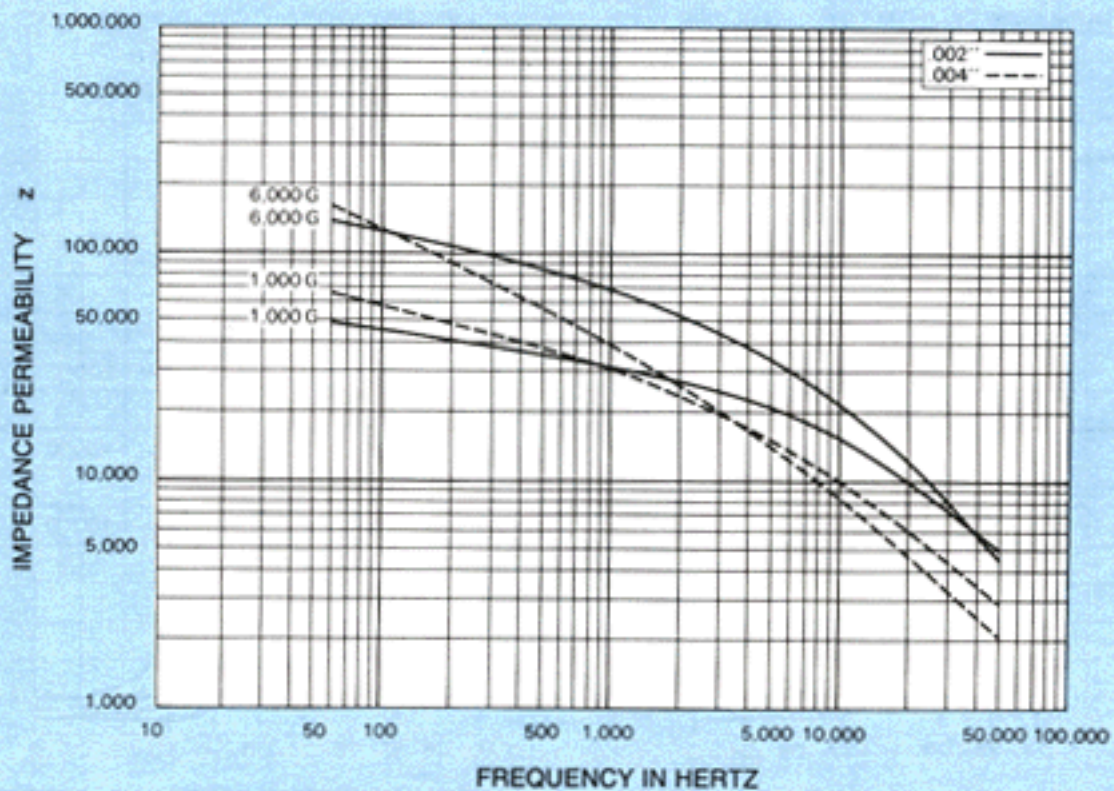
Variation with Temperature



### TYPICAL CORE LOSS CURVES SQUARE 80



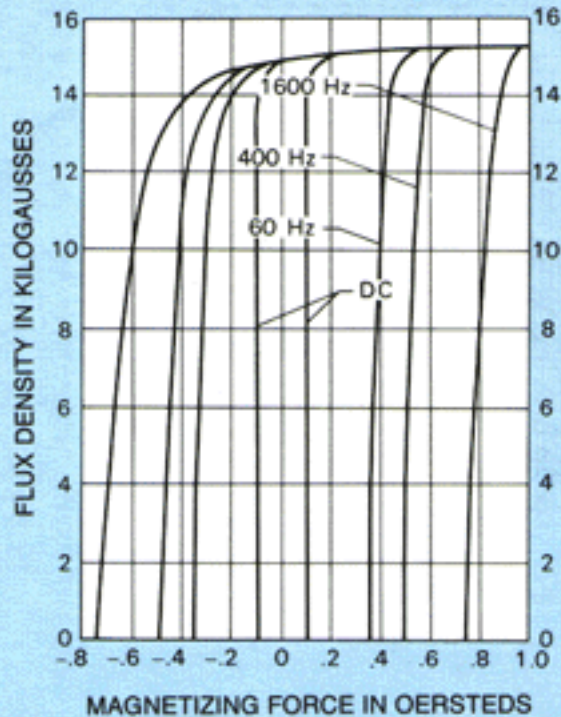
### TYPICAL IMPEDANCE PERMEABILITY CURVES SQUARE 80



# Square 50

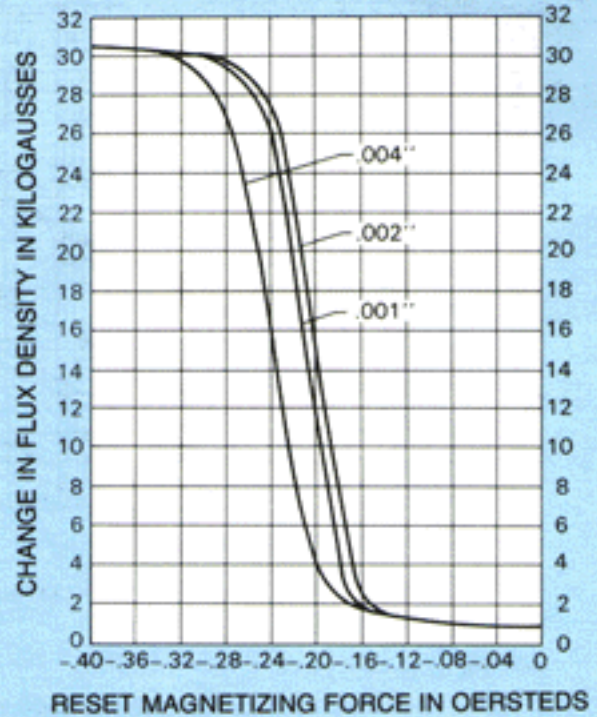
## TYPICAL HYSTERESIS LOOPS .002" SQUARE 50

Upper Two Quadrants ac Excitation with Sine Current



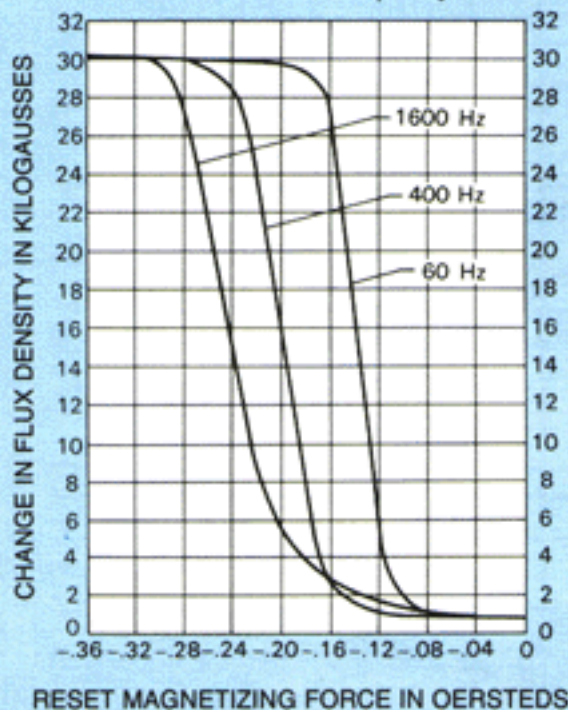
## TYPICAL CCFR CONTROL CURVES SQUARE 50

Variation with Thickness



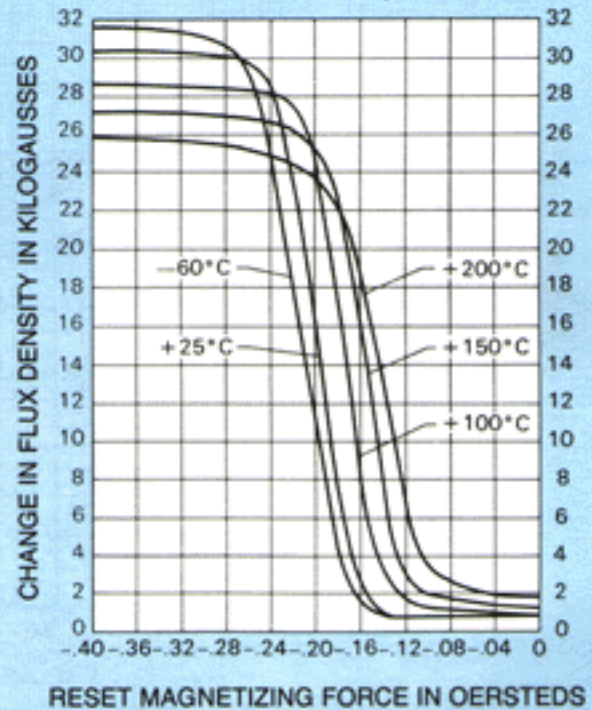
## TYPICAL CCFR CONTROL CURVES .002" SQUARE 50

Variation with Frequency

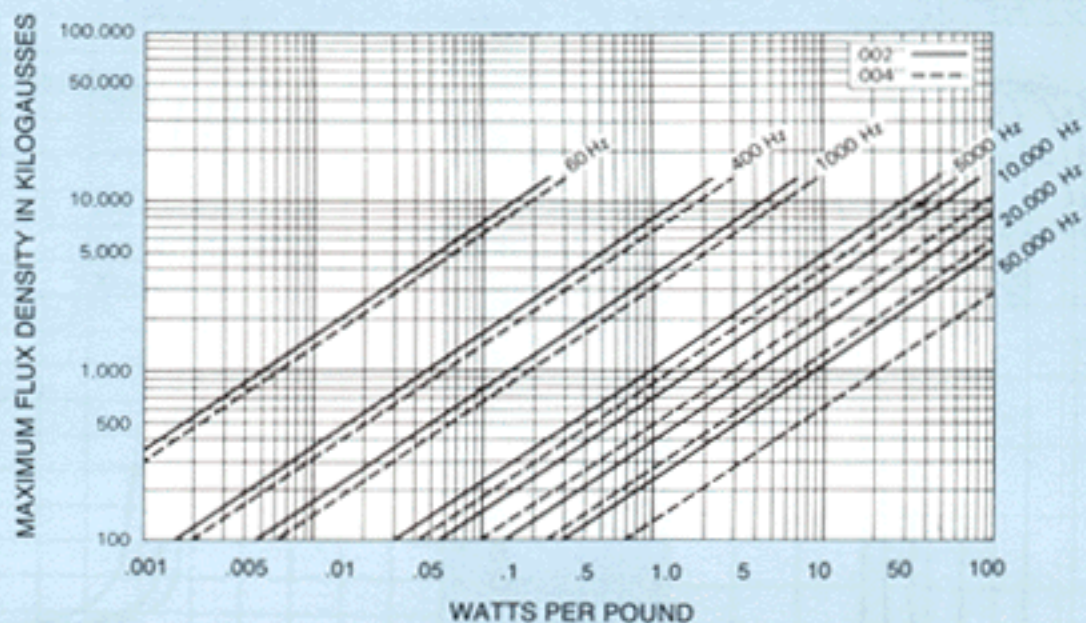


## TYPICAL CCFR CONTROL CURVES .002" SQUARE 50

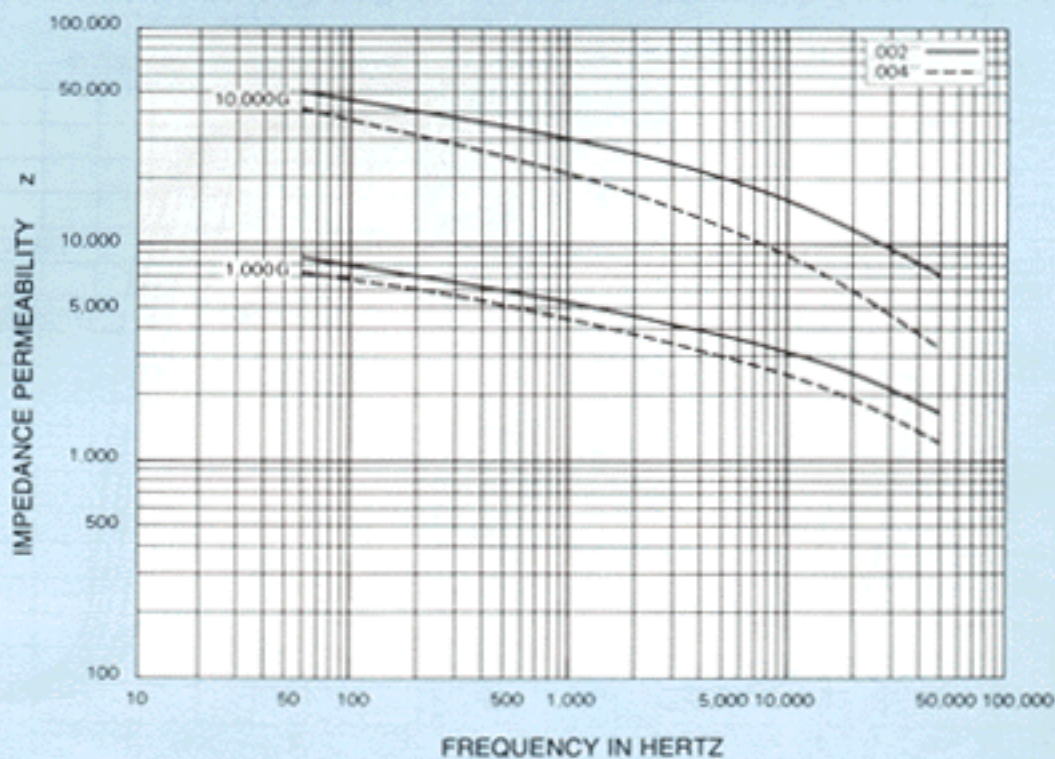
Variation with Temperature



# TYPICAL CORE LOSS CURVES SQUARE 50



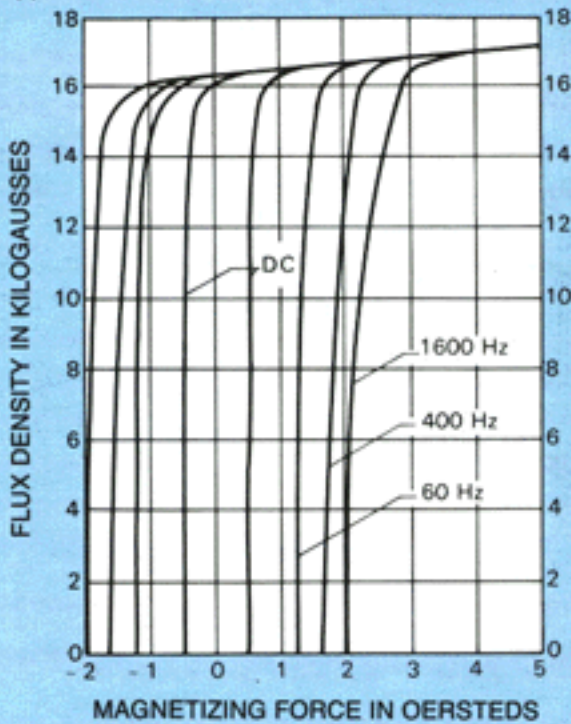
# TYPICAL IMPEDANCE PERMEABILITY CURVES SQUARE 50



# Microsil

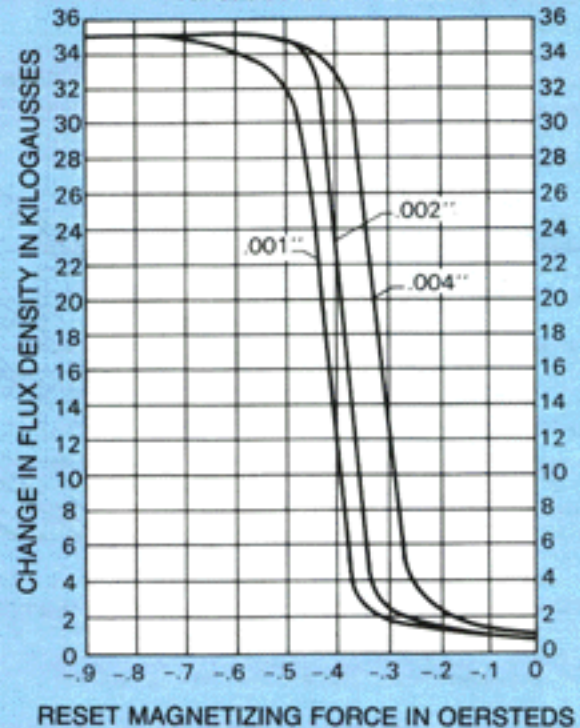
## TYPICAL HYSTERESIS LOOPS .004" MICROSIL

Upper Two Quadrants ac Excitation with Sine Current



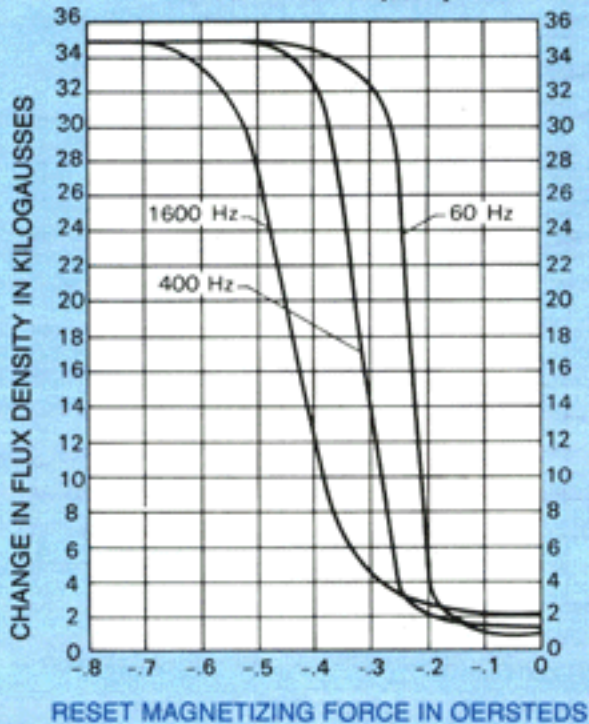
## TYPICAL CCFR CONTROL CURVES MICROSIL

Variation with Thickness



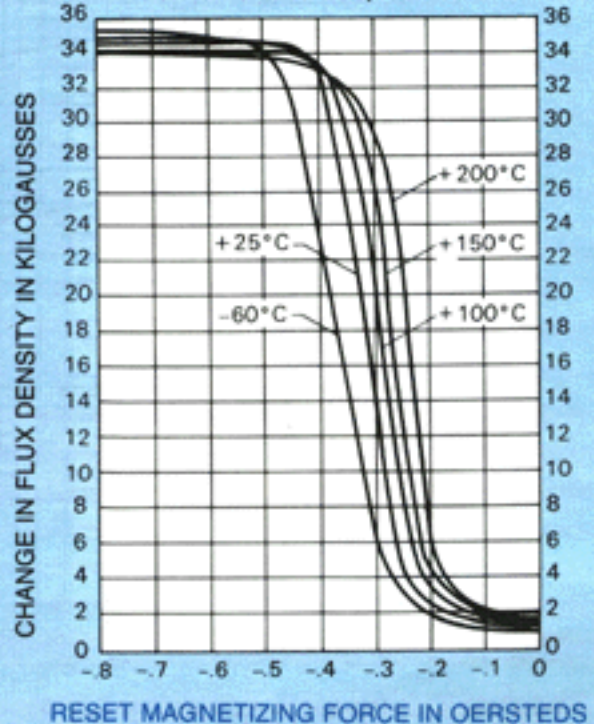
## TYPICAL CCFR CONTROL CURVES .004" MICROSIL

Variation with Frequency

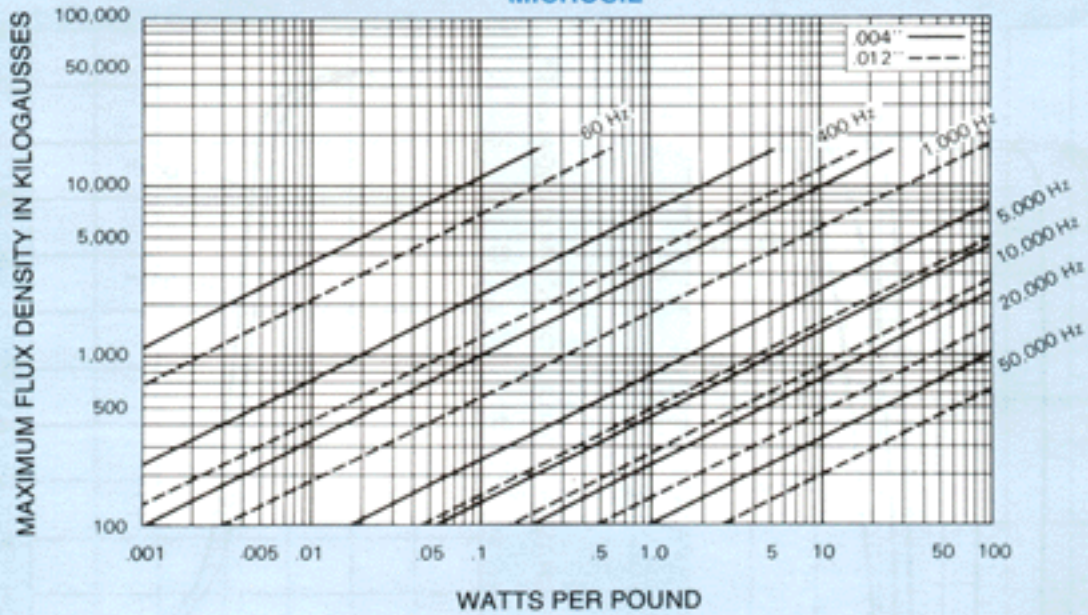


## TYPICAL CCFR CONTROL CURVES .004" MICROSIL

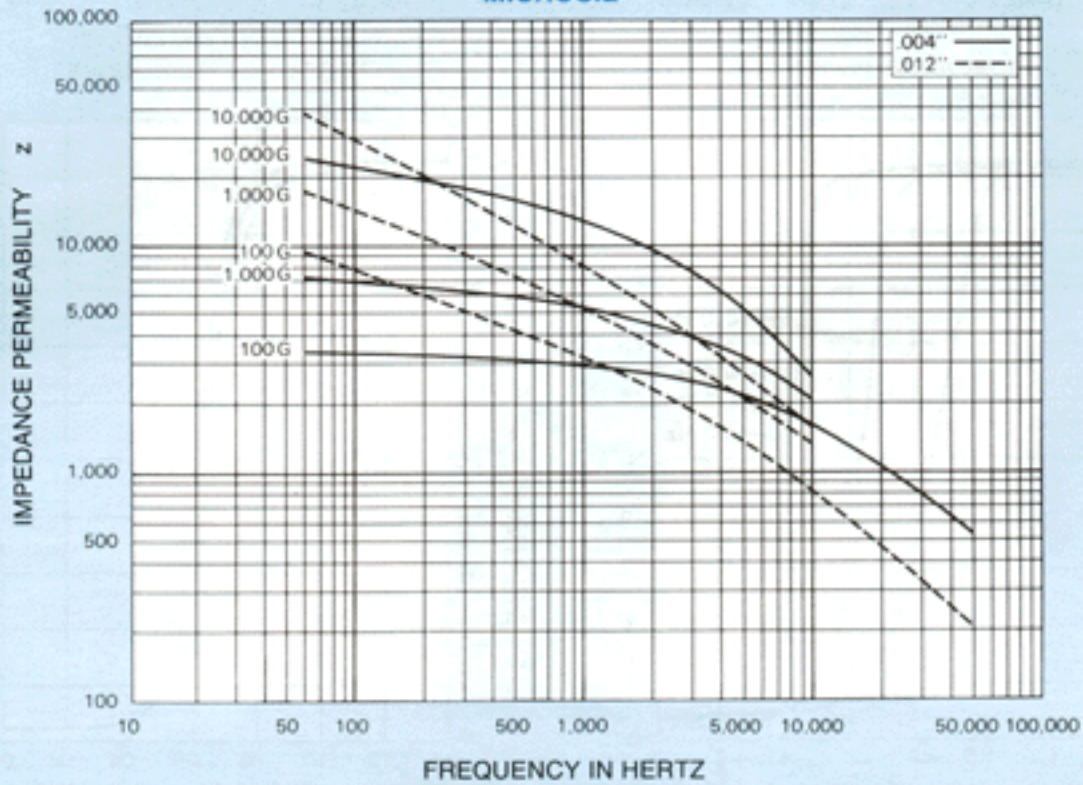
Variation with Temperature



### TYPICAL CORE LOSS CURVES MICROSIL



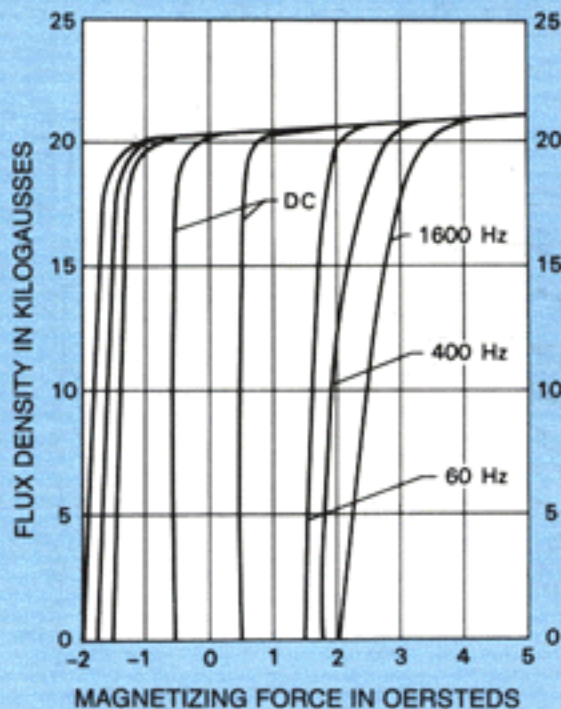
### TYPICAL IMPEDANCE PERMEABILITY CURVES MICROSIL



# Supermendur

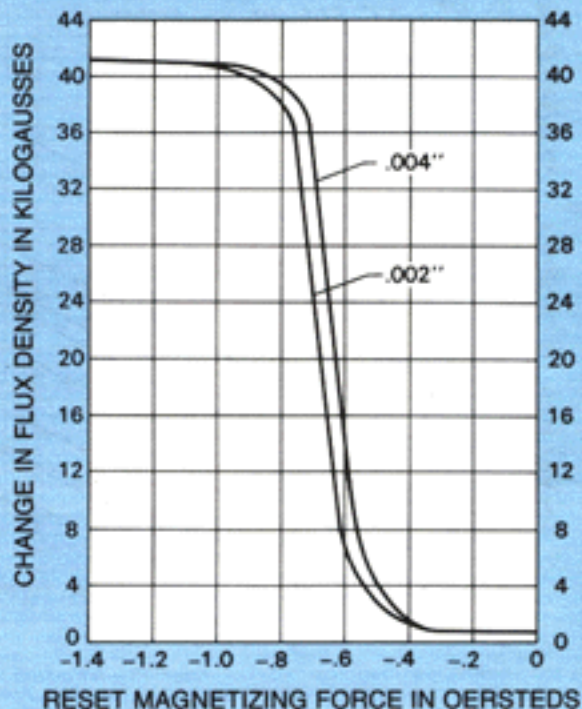
## TYPICAL HYSTERESIS LOOPS .004" SUPERMENDUR

Upper Two Quadrants ac Excitation with Sine Current



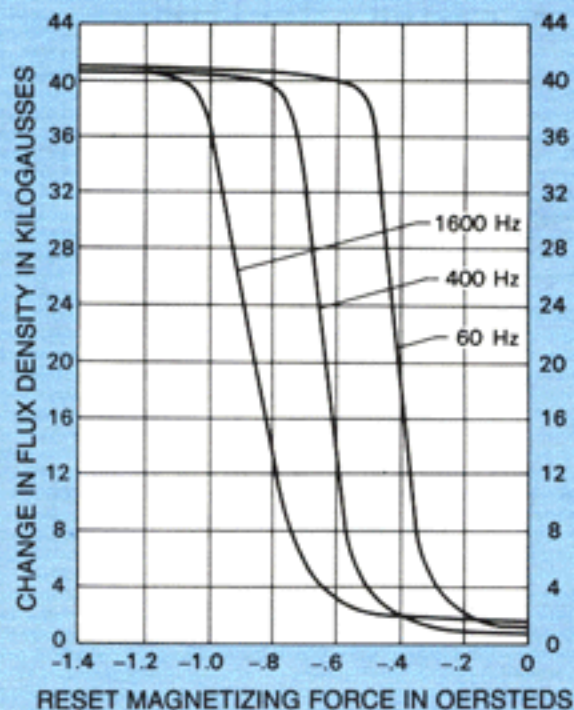
## TYPICAL CCFR CONTROL CURVES SUPERMENDUR

Variation with Thickness



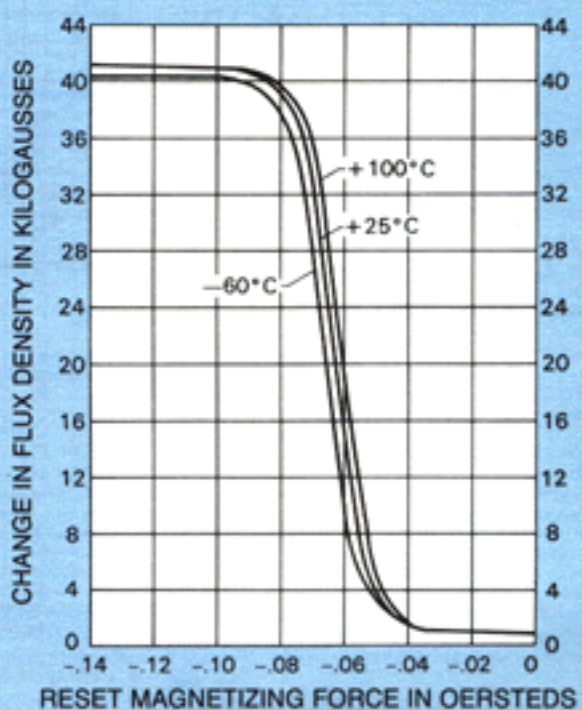
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Variation with Frequency

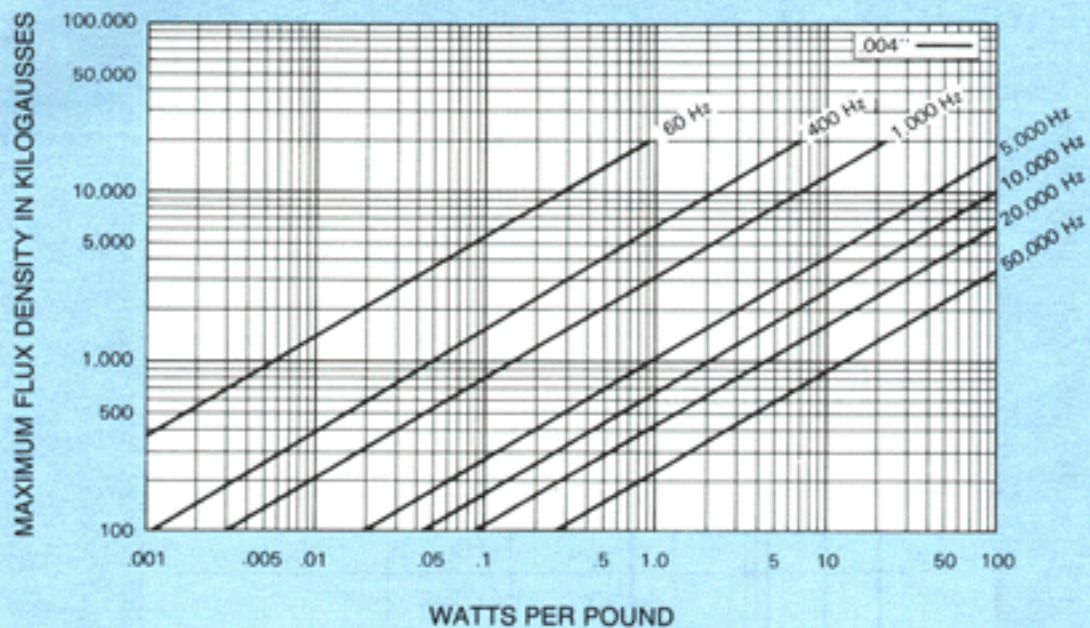


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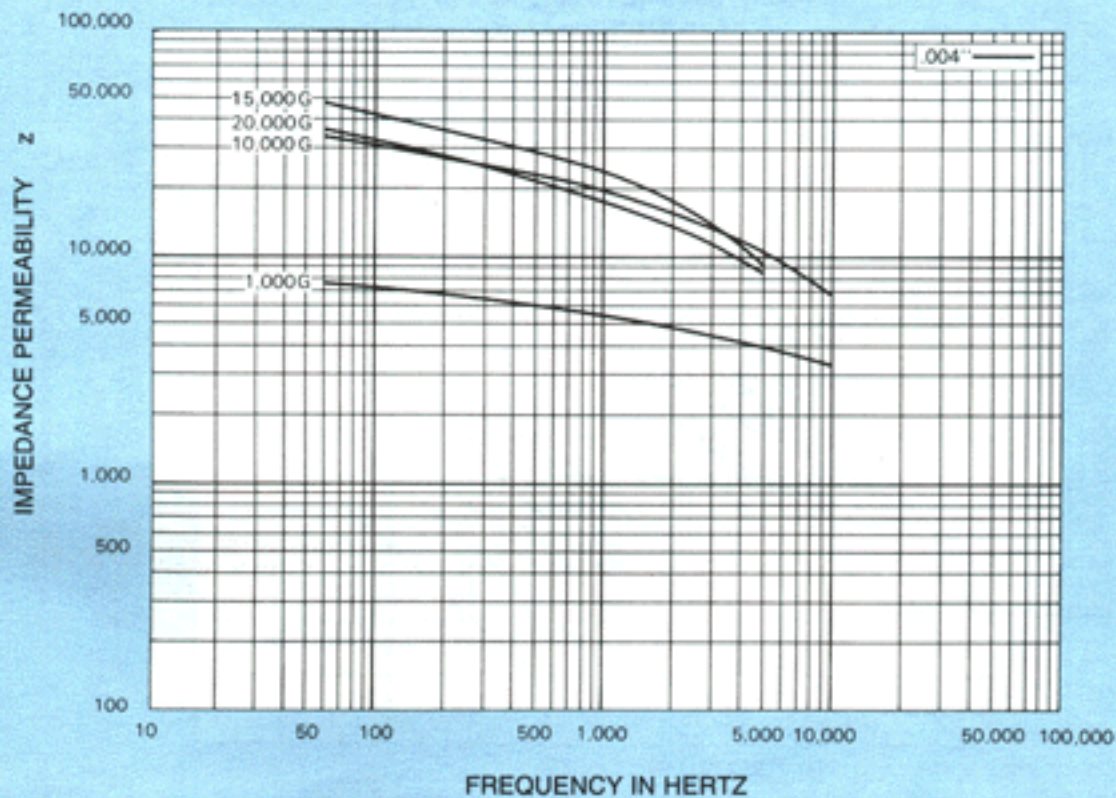
Variation with Temperature



### TYPICAL CORE LOSS CURVES SUPERMENDUR



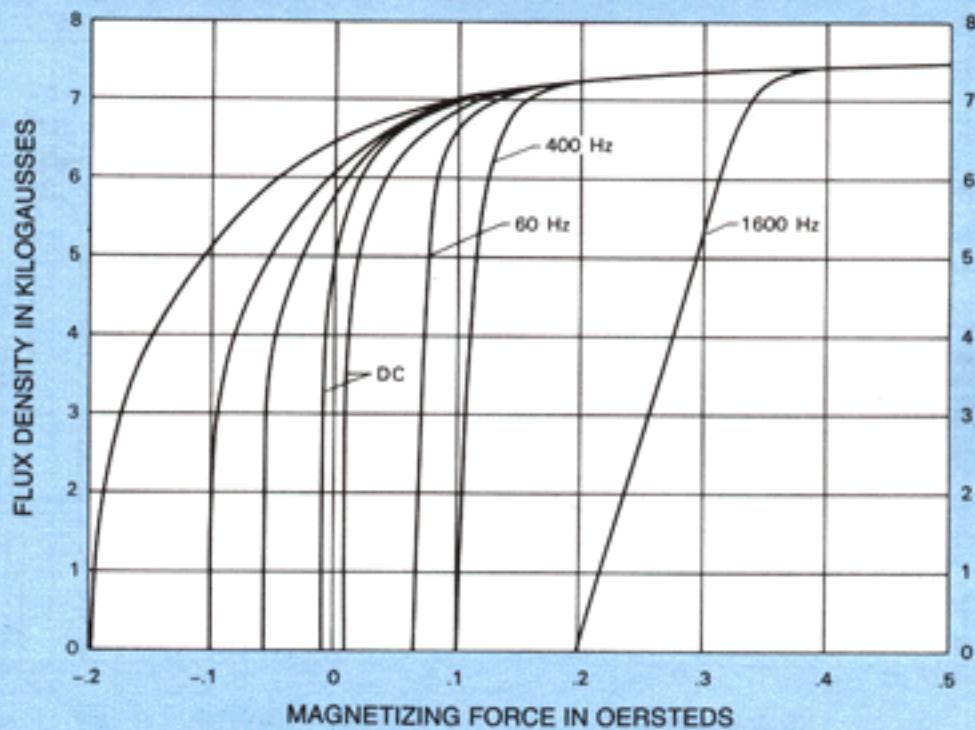
### TYPICAL IMPEDANCE PERMEABILITY CURVES SUPERMENDUR



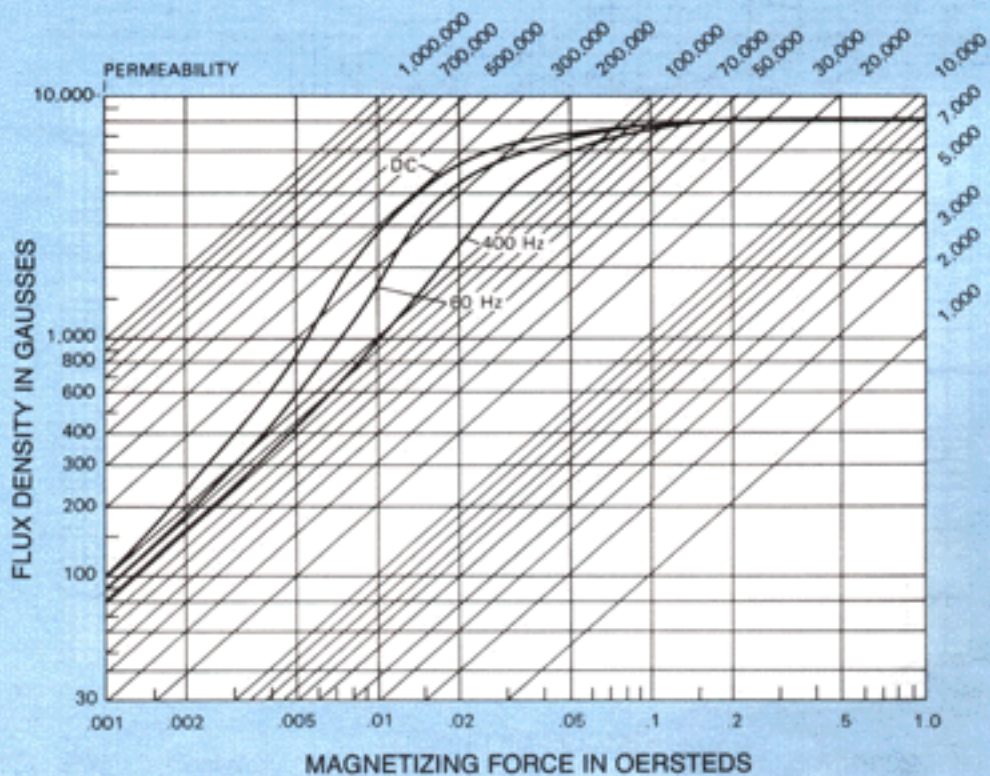
# Supermalloy

## TYPICAL HYSTERESIS LOOPS .002" SUPERMALLOY

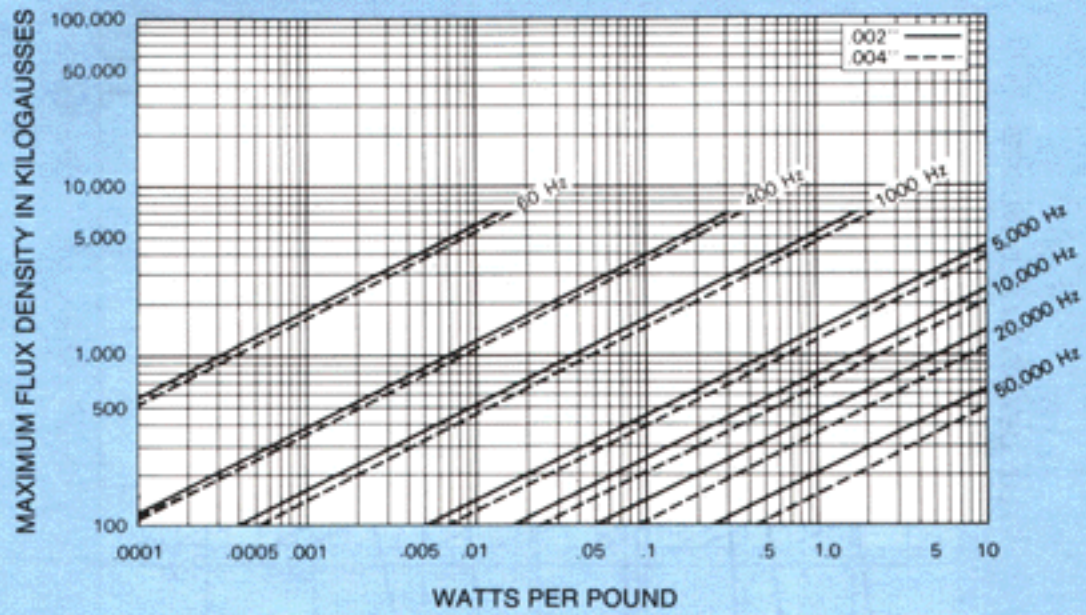
Upper Two Quadrants ac Excitation with Sine Current



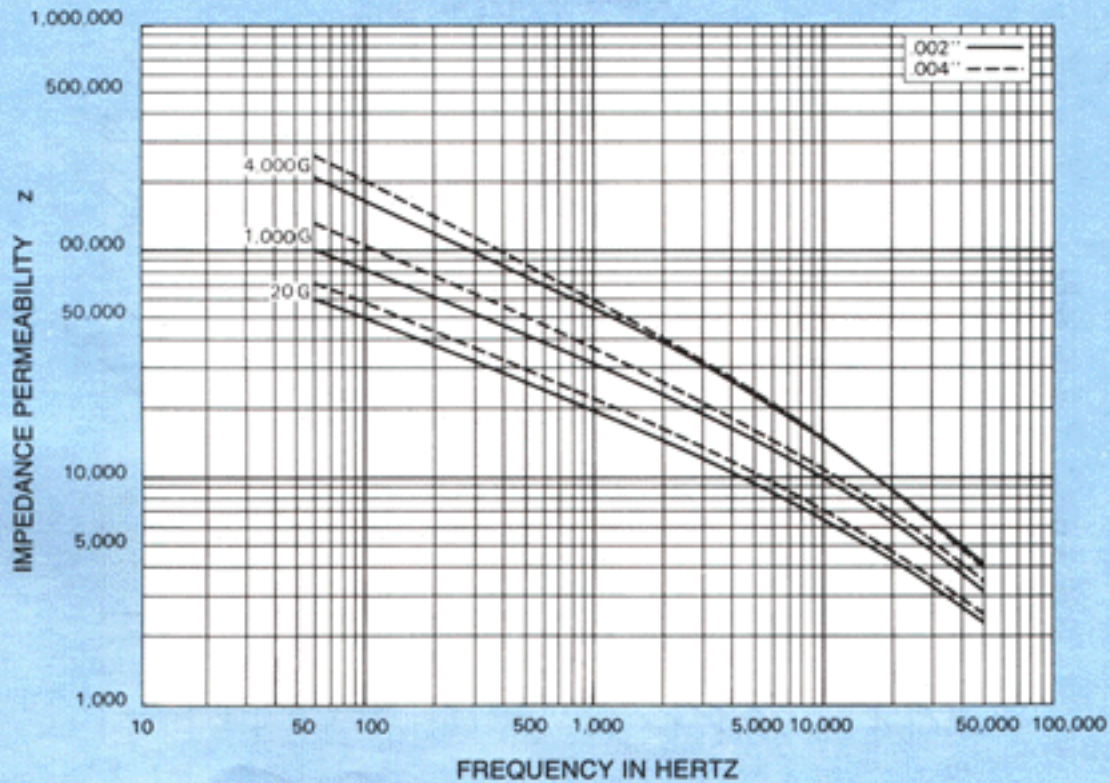
## TYPICAL MAGNETIZATION CURVES .002" SUPERMALLOY



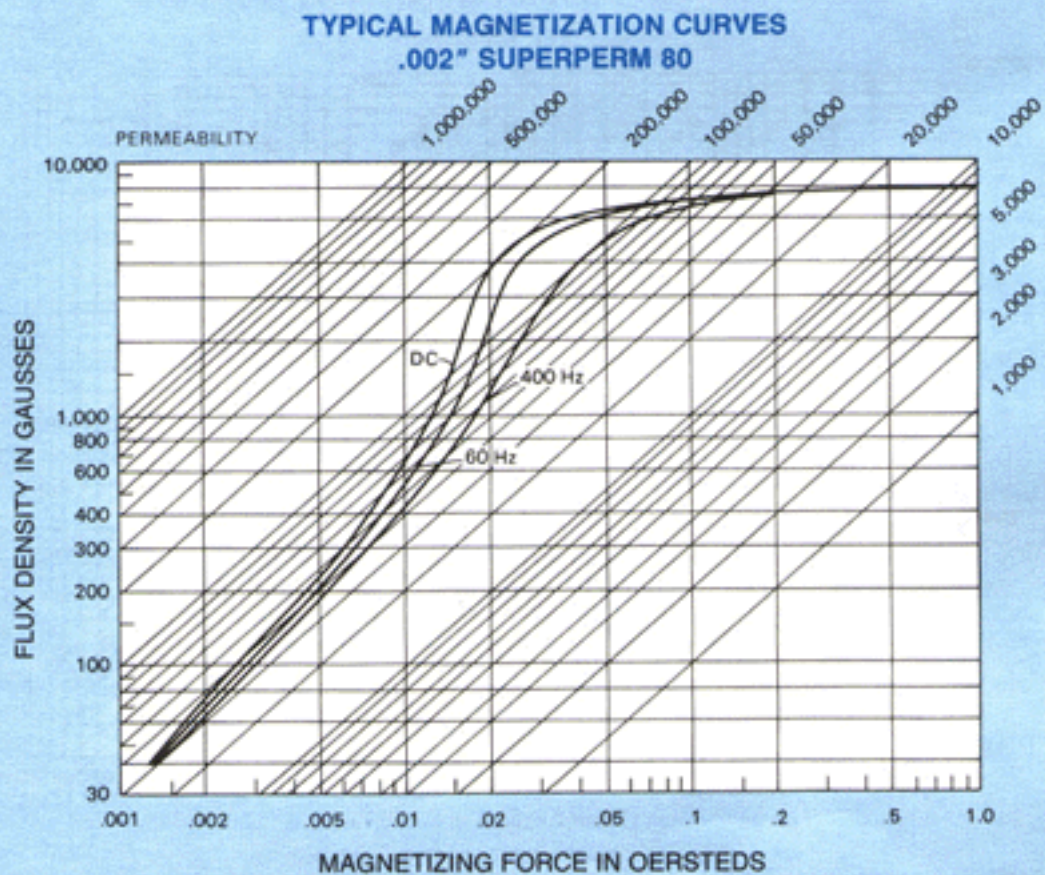
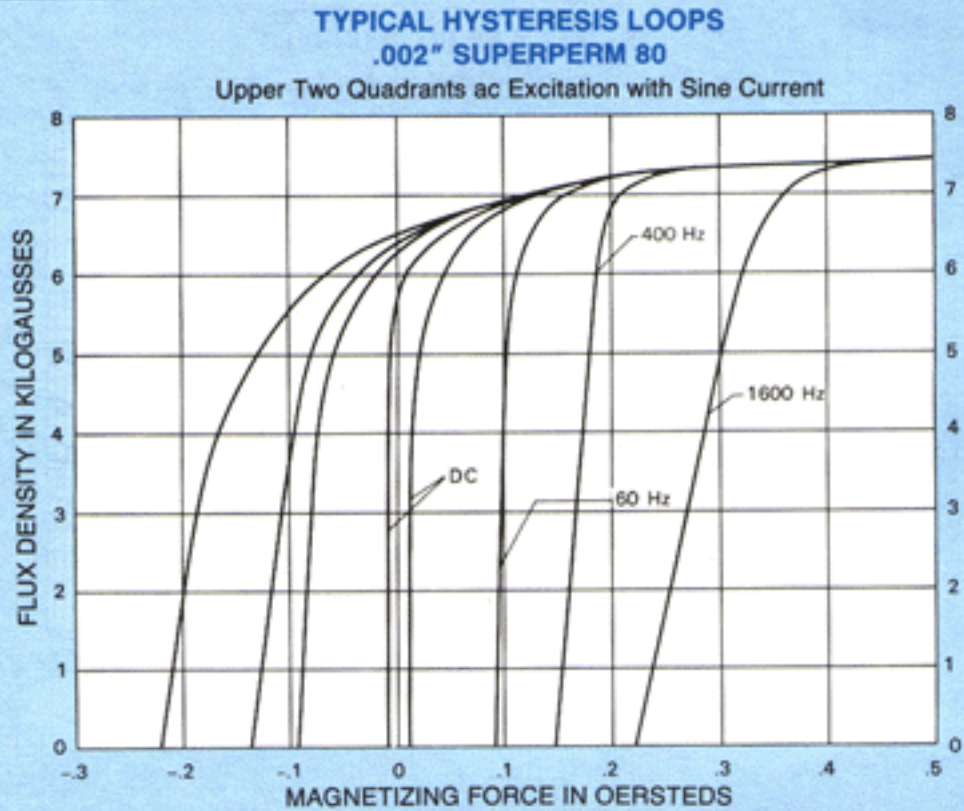
### TYPICAL CORE LOSS CURVES SUPERMALLOY



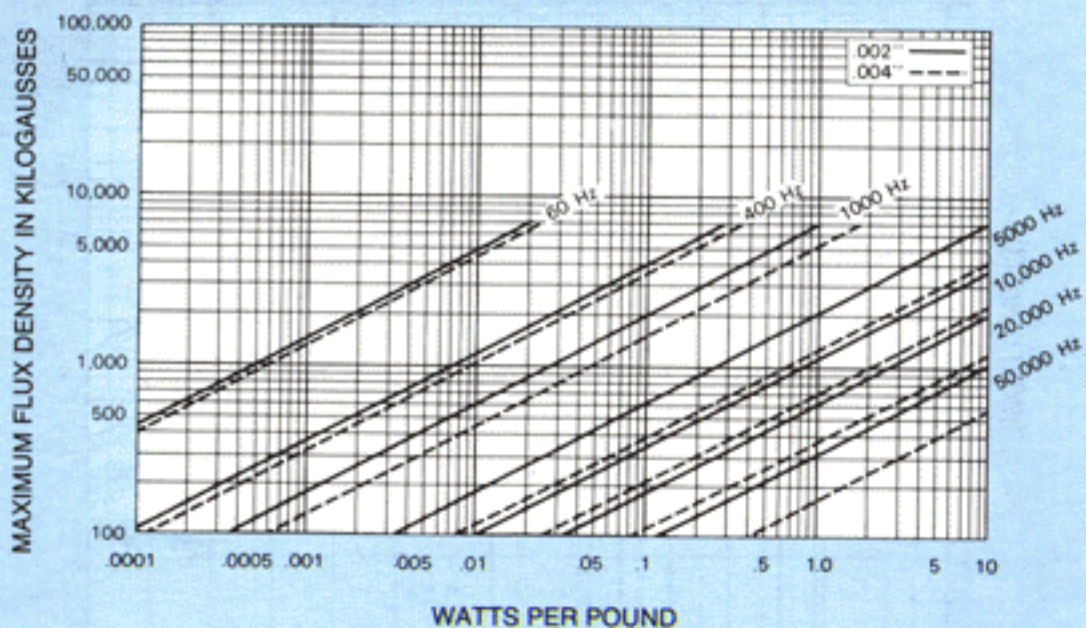
### TYPICAL IMPEDANCE PERMEABILITY CURVES SUPERMALLOY



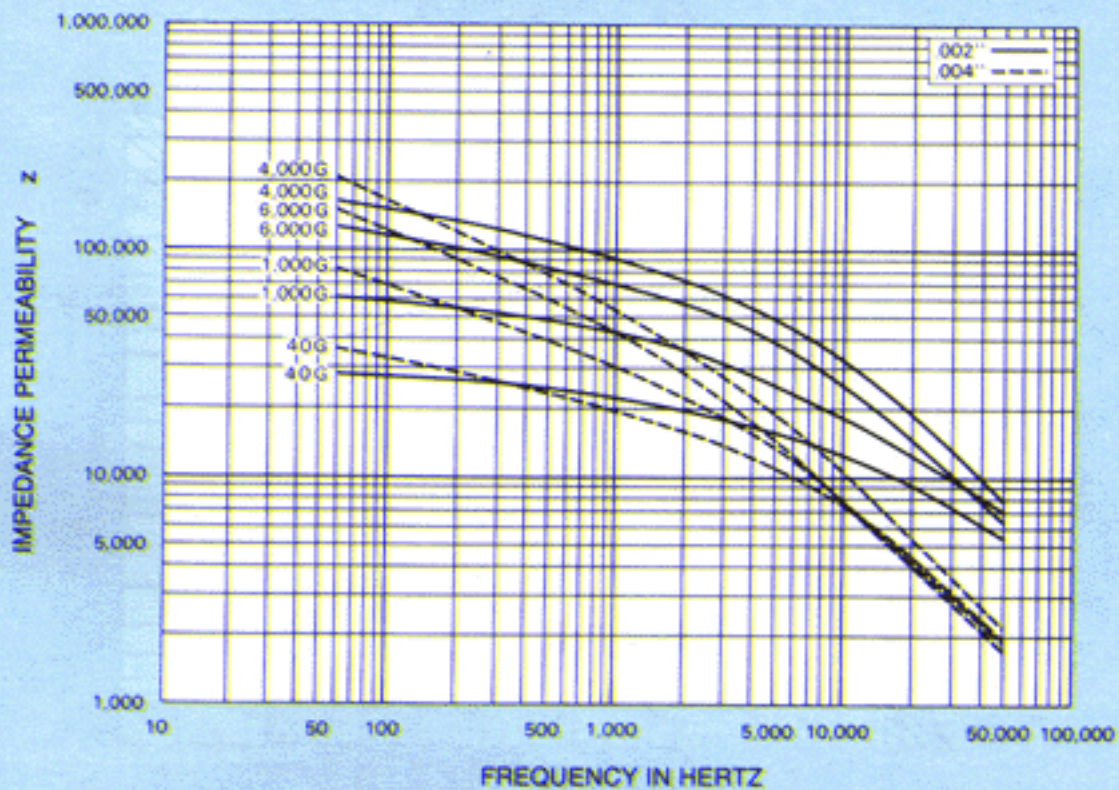
# Superperm 80



# TYPICAL CORE LOSS CURVES SUPERPERM 80



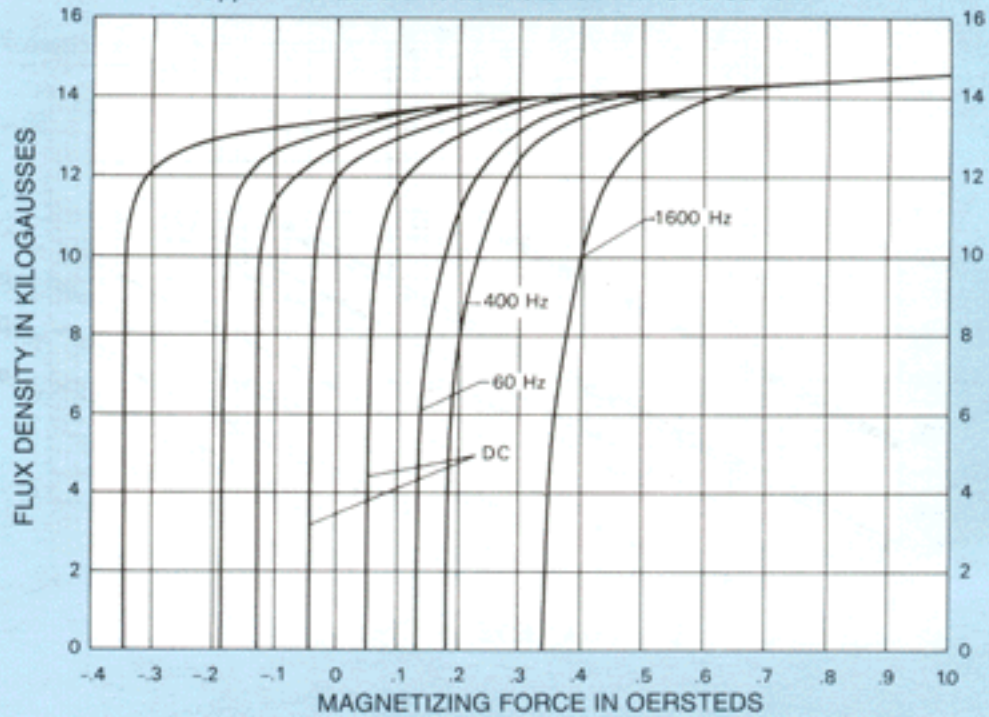
# TYPICAL IMPEDANCE PERMEABILITY CURVES SUPERPERM 80



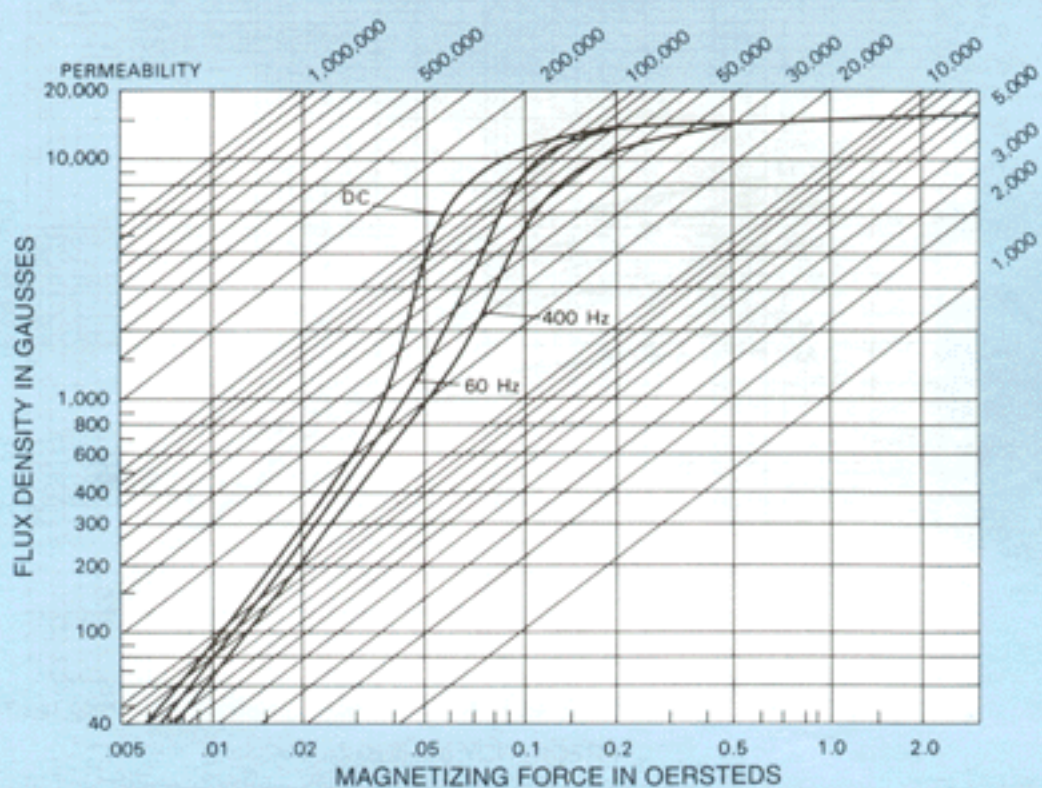
# Superperm 49

## TYPICAL HYSTERESIS LOOPS .002" SUPERPERM 49

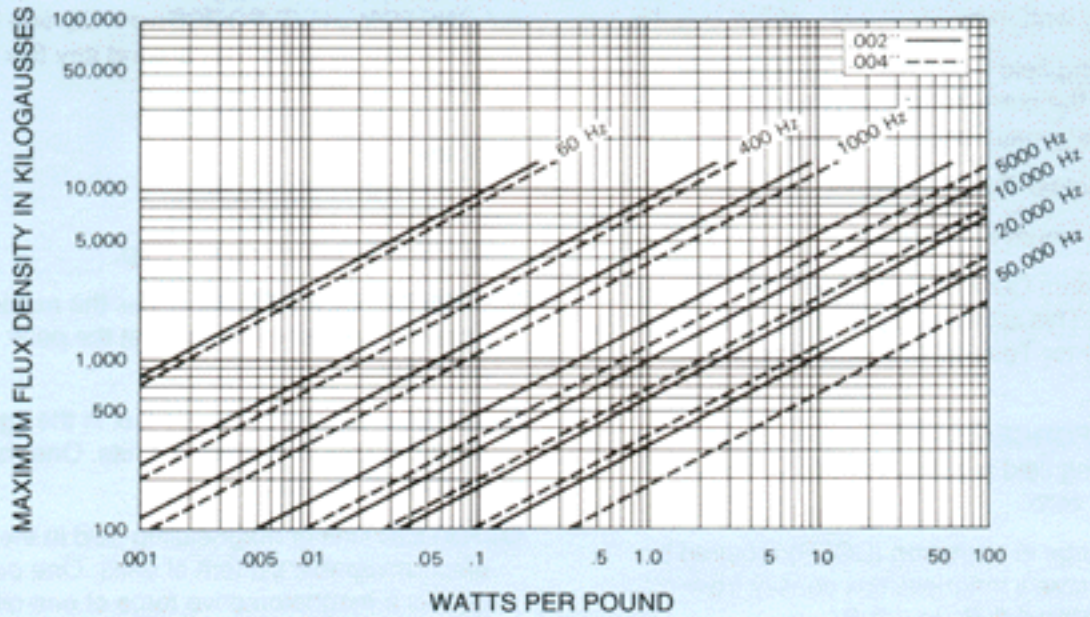
Upper Two Quadrants ac Excitation with Sine Current



## TYPICAL MAGNETIZATION CURVES .002" SUPERPERM 49



### TYPICAL CORE LOSS CURVES SUPERPERM 49



### TYPICAL IMPEDANCE PERMEABILITY CURVES SUPERPERM 49

