MAGNETICS®

Division of Spang & Company

Fundamentals of Tape Wound Core Design

Foreword

If a trade has tricks, and art has refinements, then designing an efficient magnetic circuit certainly calls for all the imagination and refinements of which the design engineer is capable.

To aid in this work, **MAGNETICS** has set down the following basic information. It primarily deals with the fundamentals of tape wound cores for the purpose of designing magnetic circuits.

You will benefit much more from this material if you go through it from beginning to end, rather than attempt to isolate a part here and a part there as much of the information is dependent on each other. In this way you will gain a more complete background for further analysis of designing with tape wound cores.

We hope the information will be of help to you.

Magnetics
Division of Spang & Company

Index

Section Page

I. How to Reduce Magnetic Circuit Size and Response Time

Part 1 - Basic Formulas

The design of a magnetic circuit is based on certain equations and formulas. The use of these equations in their basic form will allow evaluation of tape wound cores in circuits, and will determine the factors responsible for the specific selection of core size and type.

The relationship between voltage and flux is derived from Faraday's Law. This relationship is of the form:

$$E = N_1 \frac{d\phi}{dt} \times 10^{-8}$$

where E = Voltage the core will support in volts
N_1 = Number of turns on core
$d\phi$ = Rate of change of core flux in maxwells
dt = Rate of change of time in seconds

Transposing this equation into another form, ($Edt = N_1\, d\phi \times 10^{-8}$), it becomes evident that the turns on a core and its flux capacity determine how many volts will be supported in a specified time.

The second equation of importance is Ampere's Law. Current and magnetizing force are related by the formula:

$$H = \frac{0.4\pi N_2 I}{M1}$$

where H = Magnetizing force in oersteds
N_2 = Number of turns on core
I = Amperes required
$M1$ = Mean magnetic path length of core in centimeters

In a reduced form this formula becomes:

$$N_2 I = 0.794 \times H \times Ml$$

Since H is a constant determined by the type of magnetic material selected, a reduction in the mean length of the core used in a specific design will therefore decrease the ampere turns required to saturate or magnetize the core.

The third equation to consider in core selection for a magnetic circuit is the formula which determines the number of turns of wire that can be wound on a given toroidal core size.

Winding factor K is the utilization of the available window area of the toroid and is usually between 0.35 and 0.55 depending on the wire size, shuttle size and toroid height.

$$\text{Factor } K = \frac{N_T A_W}{W}$$

where N_T = Total number of turns on core
A_W = Wire area including insulation in circular mils or cm^2
W = Window area of core in circular mils or cm^2

The response time of a magnetic circuit is related to the time available to saturate a core or to switch its total flux. The minimum possible response time of a core therefore, would be the time to go from negative to positive peak drive with the associated waveform or 1/2 cycle. With a unidirectional pulse, 1/2 wave drive, or constant current resetting conditions, it would be the time required to change saturation state. In this case, the higher the drive energy available, the faster the core will switch, and therefore the faster the response time.

Response time is further related to the associated impedances contributed by the various windings on the core. The response time is therefore greater than the time required to saturate the core at a given drive condition and is related to the amount of winding impedances present. It is then necessary to reduce the control turns to a minimum to keep the response time as short as possible. This can be done by proper core selection and a maximum reduction in core mean length.

Part 2 - Factors In Size Reduction

Before miniaturization can be accomplished, the factors covered in Part 1 must be carefully analyzed to determine the implications set forth in the basic magnetic formulas. After the analysis, one then can see where reductions in size can be made, and what must be done in associated circuitry to make use of these reductions.

In analyzing Faraday's Law, which is reduced to $Edt = N_1\, d\phi \times 10^{-8}$, it is evident that in order to make the circuit size smaller we must reduce either N_1 (the turns on the core required to support the voltage E), $d\phi$ (the core flux change), or both of these parameters. Since the circuit must support a predetermined voltage "E", a reduction in N_1 or $d\phi$ means that dt must be reduced also. A reduction in dt demands that the circuit be operated at a higher frequency. Therefore, to reduce circuit size by analyzing Faraday's Law, we must **operate the magnetic circuit at a higher frequency,** or somehow **cause the core flux to be changed at a faster rate.**

Ampere's Law, which is condensed to $N_2 I = 0.794 \times H \times Ml$, says that the NI required to reset or to saturate the core is directly related to the mean length of the magnetic path. Since H is a constant determined by the core material used, and I is dictated by the associated circuitry, a reduction in circuit size can most easily be accomplished by a **decrease in core mean length** along with the additional **decrease in the turns required to saturate the core.** A twofold reduction is evident here by a reduction in the physical size of the core, and a reduction of the turns on it.

In determining how much reduction in size can be made, careful analysis must be made as to what type and size of wire is being used, what make and model of toroidal winding machines are available, and the window area of the core in question.

Response time is determined by the operating frequency (or the switching rate of the core) and the impedances of the circuit. It can be decreased or shortened by **increasing the operating frequency** and **decreasing the turns on the various windings** (usually the control windings).

In summary, the following points are most important in reducing circuit size and response time:

1. Increase operating frequency or make the core switch faster.

2. Choose a smaller diameter core to reduce mean length to a minimum, while considering the turns, wire size and type, and winding machine used.
3. Reduce turns where possible by considering Faraday's and Ampere's Laws.
4. Choose a core with a reduced flux capacity while evaluating the reduction in turns in point (3) and the increase in frequency in point (1).

Part 3 - Other Considerations

There are certain implications that must be analyzed before making an "across-the-board" reduction in size and response time:

Q: Where is the higher frequency obtained if only lower frequencies are available?

A: Higher operating frequency can be obtained by auxiliary frequency conversion circuitry. Although additional circuitry is required, the reduction in overall package size can be reduced by increasing frequency.

Q: What happens to the core's magnetic parameters when operation is at higher frequencies?

A: In general, core loss is increased. This means that magnetizing currents required to saturate the core are greater. A reduction in size due to an increase in operating frequency also requires an adjustment of the magnetizing force requirements. Therefore a full analysis of the various magnetic formulas and a change in the various magnetic constants used is in order each time an attempt at miniaturization is made.

Q: How can the core be made to switch faster?

A: The rate at which the core will switch its flux is dictated by the material selected, its thickness, and the amount of energy available for the switch. Thus as the operating frequency is increased, careful analysis of the material type and thickness must be made. In general, as the frequency is increased, the energy or ampere-turns available must also be increased. Curves showing the relationship of magnetizing force (H) and switching rate are presented for various materials and thicknesses, in "Designing Magnetic Circuits for Higher Frequencies" (section II).

Proper substitution of the magnetic constants (at the frequency selected) into the applicable formulas, and full analysis to determine how much circuit size and response time is reduced, can be made if basic magnetic circuit equations are understood. Faraday's Law and Ampere's Law are the basis for that understanding.

Part 4 - Example

Example: Determine the reduction in size that can be made by increasing the operating frequency of a full wave self-saturating dc magnetic amplifier designed to support 120 volts input with an output of 100 volts into a load of 500 ohms. The unit is to be controlled from two separate windings and these windings must control from full ON to full OFF with 20 milliamperes and 10 milliamperes respectively. The increase in frequency is from 60 to 6000 Hertz sine wave drive.

$E = N \frac{d\phi}{dt} \times 10^{-8}$, which for sinusoidal drive reduces to $E = 2.22\ \phi\ Nf \times 10^{-8}$;

transposing, $N\phi = \frac{E \times 10^8}{2.22 \times f}$

I. Solving for 60 Hertz operation

$$N\phi = \frac{120 \times 10^8}{2.22 \times 60} = 90 \times 10^6 \text{ maxwell-turns}$$

Assume nominal gate windings in the vicinity of 2000-2500 turns for convenience of winding. Solve for a nominal ϕ and select a flux value in the range listed below based on a common available tape wound core size.

$$\phi = \frac{90 \times 10^6}{N} \approx 40000 \text{ maxwells}$$

A standard core flux capacity of approximately this value is 40700 maxwells for cores with cross-sections of 1.452 cm². Flux can be calculated from available core tables by the formula $\phi = 2\,B_m A_c$.

$$\text{Therefore } N = \frac{90 \times 10^6}{40700} = 2210 \text{ turns}$$

$$\text{Average dc load current } \frac{100 \text{ volts}}{500 \text{ ohms}} = 0.200 \text{ amperes}$$

Find average current in each gate winding and convert to rms:

$$\text{Rms current in each gate winding} = \frac{0.200}{2} \times 1.57 = 0.157 \text{amperes}$$

Wire size to carry 0.157 amperes = #28 awg

Area of #28 awg = 207 cir mils

Assume winding factor K = 0.40, and that 85% of available window area is taken up by gate windings.

Solve for window area:

$$W = \frac{NA_W}{K}$$

$$W = \frac{2210 \text{ X } 207}{0.34} = 1.345 \times 10^6 \text{ cir mils}$$

The tape wound core having the window area and flux closest to these values is the **50012-4A.**

Solving for the control winding turns:

$$H = \frac{0.4\pi NI}{M1}$$

$$\text{Transposing: } NI = \frac{HM1}{0.4\pi}$$

H to reset 50012-4A at 60 Hertz = 0.3 oersteds

Mean length of 50012-4A = 11.96 cm.

$$NI = \frac{0.3 \times 11.96}{1.26} = 2.85 \text{ ampere-turns}$$

N_1 for 20 milliamperes winding = 143 turns

N_2 for 10 milliamperes winding = 285 turns

Wire size for control winding = #32 awg

Area of #32 awg = 88.3 circular mils

(Assume that the windings must be capable of carrying 3x nominal reset current. For convenience, wind both control windings with #32 awg since control windings utilize such a small portion of available window area.)

Checking window area utilization:

$$K = \frac{(2210x207)+(428x\ \ 88.3)}{1.368 \text{ x } 10^6}$$

$$K = \frac{458{,}000 + 37{,}800}{1.368 \text{ x } 10^6} = 0.364$$

Checking voltage (IR) drop in gate windings:

VD = I x total length of wire used x resistance of wire

VD = 0.157 x 600 ft. x 0.066 ohms/ft.

VD = 6.22 volts

II. Solving for 6000 Hertz operation

$$N\,\phi = \frac{120x\ 10^8}{2.22x6000} = 90 \text{ x } 10^4 \text{ maxwell-turns}$$

Assume a reduction in gate windings of 10 times, giving turns of 200 to 250.

Solving for nominal ϕ for core selection:

$$\phi = \frac{90 \text{ x } 10^4}{N} \approx 4000 \text{ maxwells}$$

A common core flux capacity of this value is 4230 maxwells for cores with a cross-section of 0.151 cm^2 .

Therefore, $N = \frac{90 \text{ x } 10^4}{4230} = 213$ turns

Average dc load current = $\frac{100}{500}$ = 0.200 amperes

Wire size to carry 0.157 amperes = #28 awg

Area of #27 awg = 207 circular mils

Assume winding factor K = 0.40, and that 65% of the available window area is taken up by gate windings (because of small number of turns on gate windings)

$$W = \frac{213 \text{ x } 207}{0.26} = 0.170 \text{ x } 10^6 \text{ circular mils}$$

The tape wound core having the window area and flux closest to these values is the **50176-1A.**

Solving for the control winding turns:

H = 0.65 oersteds to reset 50176-1A at 6000 Hertz

$$NI = \frac{0.65\ X4.99}{1.26} = 2.57 \text{ ampere-turns}$$

N_1 for 20 milliamperes winding = 129 turns

N_2 for 10 milliamperes winding = 257 turns

(Assume windings must be capable of carrying 3x nominal reset current.)

Wire size for control windings N_1= #32 awg

Area of #32 awg = 88.3 circular mils

Wire size for control windings N_2 = #35 awg

Area of #35 awg = 44.9 circular mils

Checking Window area utilization:

$$K = \frac{(213 \times 207 + (129 \times 88.3) + (257 \times 44.9)}{0.194 \times 10^6}$$

$$K = \frac{44{,}100 + 11{,}400 + 11{,}500}{0.194 \times 10^6} = 0.345$$

Comparison of physical sizes:

60 Hertz Operation

Core Size	50012-4A
Physical size (cased core)	I.D. =1.17 inches O.D. = 1.82 inches Ht. = 1.11 inches
Weight (1 core)	150 grams approx.

Volume required for 2 cores + windings = 12 cu. in. approx.

Minimum possible response time = 8.3 milliseconds

6000 Hertz Operation

Core Size	50176-1A
Physical Size	ID. = 0.440 inches O.D. = 0.810 inches Ht. = 0.320 inches
Weight (1 core)	7.5 grams approx.

Volume required for 2 cores + windings = 1 cu. in. approx.

Minimum possible response time = 83 microseconds

Conclusions:

By raising frequency from 60 to 6000 Hertz:

1. Volume of package is reduced to 1/12 of the original size.
2. Weight of package is reduced to 1/20 of the original weight.
3. Possible response time is reduced to l/l00 of the original response time.

II. Designing Magnetic Circuits For Higher Frequencies

The designing of magnetic circuits depends to a great extent on the frequency at which the unit will be operated. The operating frequency dictates the relative size of the unit, its interna1 losses and the number of turns required to magnetize or saturate the selected core material. It is shown in Section I that the design of a magnetic circuit is dependent upon two formulas:

(1) Faraday's Law: $E = N \frac{d\phi}{dt} \times 10^{-8}$

which for sine wave drive reduces to:

$$E = 2.22\ \phi\ Nf \times 10^{-8}$$

where ϕ = Total core flux in maxwells

N = Turns on the core

f = Operating frequency

(2) Ampere's Law: $H = \frac{0.4\pi NI}{M1}$

which reduces to:

$$NI = 0.794 \times H \times M1$$

where H = Force required to magnetize or saturate the core in oersteds at the operating frequency.

M1 = Average mean length of the core in centimeters.

The operation of a core at higher frequencies does not affect the core's flux capacity (see curves #l, #2, #3, #4, #5, and #6). However, the core flux is changed at a **faster rate**$(\frac{d\phi}{dt})$. Therefore, the application of Faraday's Law permits the core size, or the number of turns, to be reduced.

The determination of the proper reset or control turns for the known available current depends on the substitution of the proper quantities into Ampere's Law formula. Using NI = 0.794 x H x Ml, where Ml = average core mean length in centimeters (a constant based on core size), the only other unknown quantity is the magnetizing (or reset) mmf (H) in oersteds. H varies with material type used, its thickness and the frequency or switching rate at which the core operates. Much data has been presented in the past, especially at 400 Hz, using a particular drive condition. Interpolation to other drives and other frequencies has been made to determine the approximate magnetizing force necessary to substitute into the Ampere's Law formula. However, these have been sketchy and have not fully described the drive condition used nor the methods used to determine them.

In this section, curves show how increased drive frequency affects the shape of the typical hysteresis loop for 1,2, and 4 mil Orthonol® and Square Permalloy 80. These curves were reproduced from B-H loop traces recorded on a **MAGNETICS** B-H Loop Tracer. The cores were excited with a sine wave of voltage (sine flux drive) so values shown represent typical magnetizing force values for materials excited in this way.

In magnetic circuit design, the core is not usually excited with pure sine voltage or pure sine current, but probably somewhere in between. This means that full circuit analysis must first be made to determine the waveform shapes before substitution of absolute quantities is made in the Ampere's Law equation. **However, percentage changes in magnetic parameters can be determined, and, from records on specialized circuit performance, a good prediction of actual values can be made.**

As additional information, two curves are presented to show the increase in current required to saturate Orthonol and Square Permalloy 80 for 1 mil and thinner gauges at frequencies above 1000 Hz. These curves were developed from data in which square current pulses were recorded. The values given represent peak amplitude of the square current waveform. (It is interesting to note that these materials can be operated to quite a high frequency before eddy currents become an appreciable factor in selecting material thickness.) Below is a tabulation of a suggested frequency limit, taken from the curves for each thickness of material:

Material Thickness	Suggested Frequency Limit*
0.001"	10,000 Hz
0.0005"	25,000 Hz
0.00025"	50,000 Hz
0.000125"	100,000 Hz

* This table **does not limit** the use of these various gauges to the upper frequency listed. The table serves only as a guide to alert the designer to allow for further considerations in his circuit analysis for eddy current effects. Refer to curves for more complete data.

Example # 1

A miniature high frequency magnetic amplifier has been designed to operate at 10 kHz. Orthonol in 0.001" thickness has been selected. The mean length of the core chosen to support the required voltage is 3.25 centimeters. How many control turns are required to excite the core from a current source of 0.05 amperes average?

The solution of Ampere's Law and reference to curve #7 for the magnetizing current requirements will give the answer to this problem.

$$N = \frac{0.794 \times H \times Ml}{I}$$

$$N = \frac{0.794 \times 0.56 \times 3.25}{0.05}$$

$$N = 29 \text{ turns}$$

Example #2

How much of a percentage increase in magnetizing current should be expected if 0.001" thick Square Permalloy 80 is operated at 4800 Hz rather than 400 Hz?

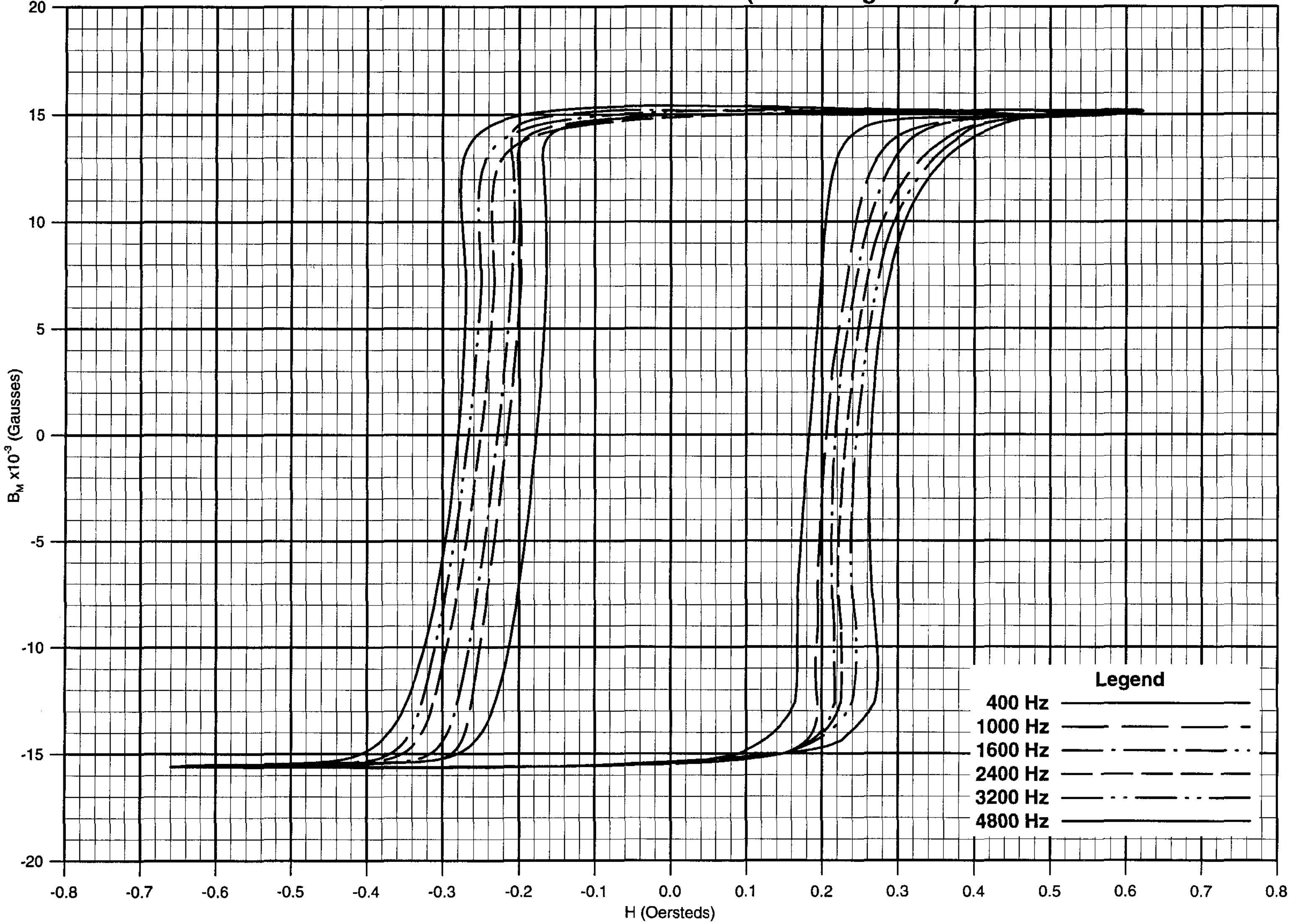
Referring to Curve #4, the coercive force for 0.001" thick Square Permalloy 80 at 400 Hz is 0.035 oersteds, while at 4800 Hz it is 0.065 oersteds. Therefore, the coercive (or magnetizing force) increases by 86% because of the increase in frequency.

The use of the curves presented should be tempered by further circuit analysis of current waveforms and interwinding capacitances. Capacitance becomes an ever-increasing problem as the frequency is increased, so care should be taken to keep it to a minimum. The problem is to keep the voltage between each adjacent turn of wire at a minimum. Any winding technique used to accomplish this will keep capacitance low. Sector winding (using progressive winding techniques in each sector) is good for reducing capacitance. After a winding technique is identified and prototype units are built, care must be taken to describe fully the methods used. The reproduction of similar electrical results on each production unit is much more dependent on the repetition of processes when operating at high frequencies than at lower frequencies. Techniques, therefore, are just as important as component specifications and must be completely identified.

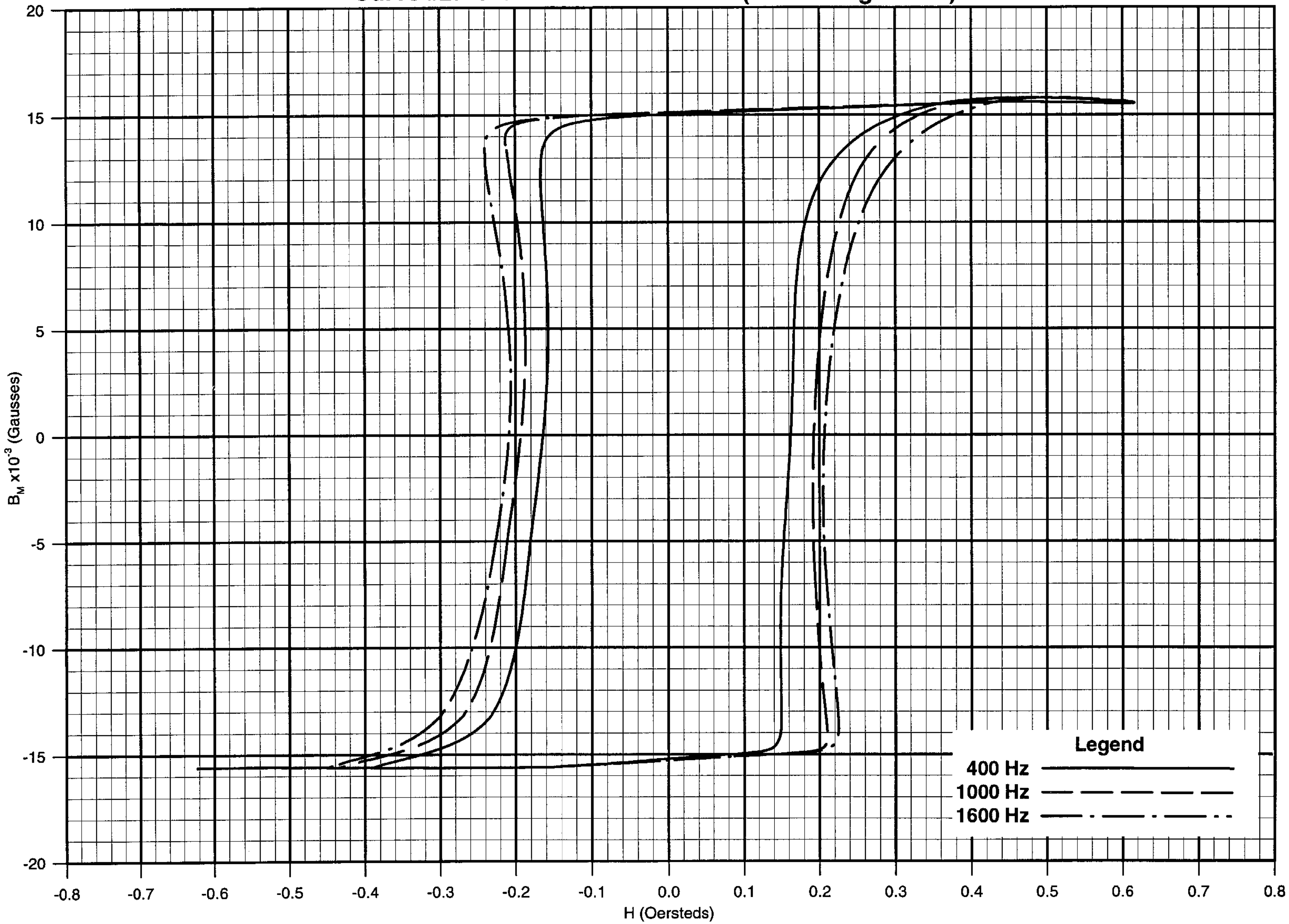
Curve Index - Designing Magnetic Circuits for Higher Frequencies

Curve #l	Hysteresis Loops of 0.001” thick Orthonol at frequencies from 400 Hz to 4800 Hz. Sine voltage drive conditions.
Curve #2	Hysteresis Loops of 0.002” thick Orthonol at frequencies from 400 Hz to 1600 Hz. Sine voltage drive conditions.
Curve #3	Hysteresis Loops of 0.001” thick Square Permalloy 80 at frequencies from 400 Hz to 4800 Hz. Sine voltage drive conditions.
Curve #4	Hysteresis Loops of 0.002” thick Square Permalloy 80 at frequencies from 400 Hz 3200 Hz. Sine voltage drive conditions.
Curve #5	Plot of drive to saturate Orthonol versus frequency for 0.00l”, 0.0005” and 0.00025” thick materials. Current drive çonditions.
Curve #6	Plot of drive to saturate Square Permalloy 80 versus frequency for 0.00l”, 0.0005”, 0.00025” and 0.000125” thick materials. Current drive conditions.

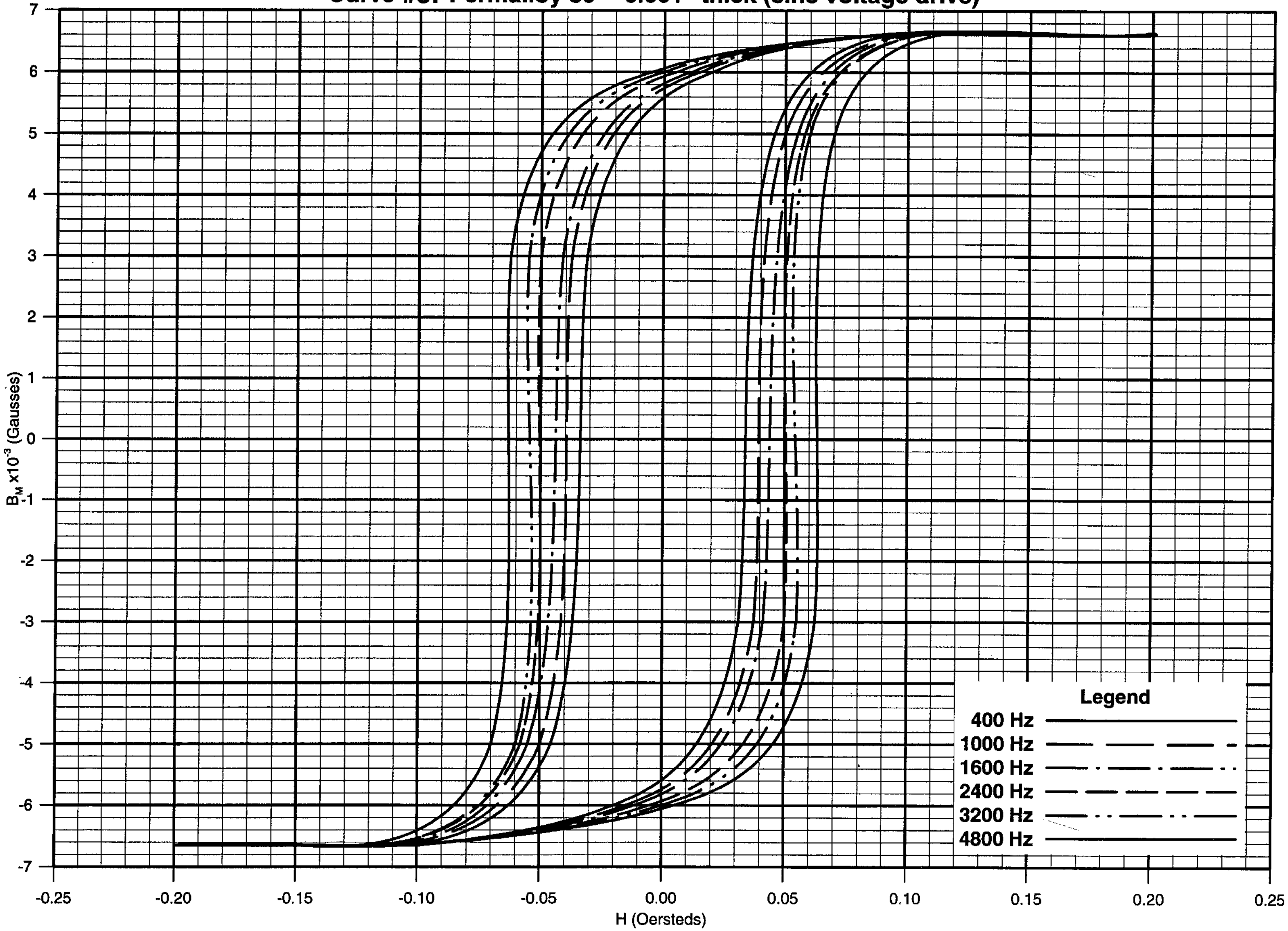
Curve #1: Orthonol -- 0.001" thick (sine voltage drive)



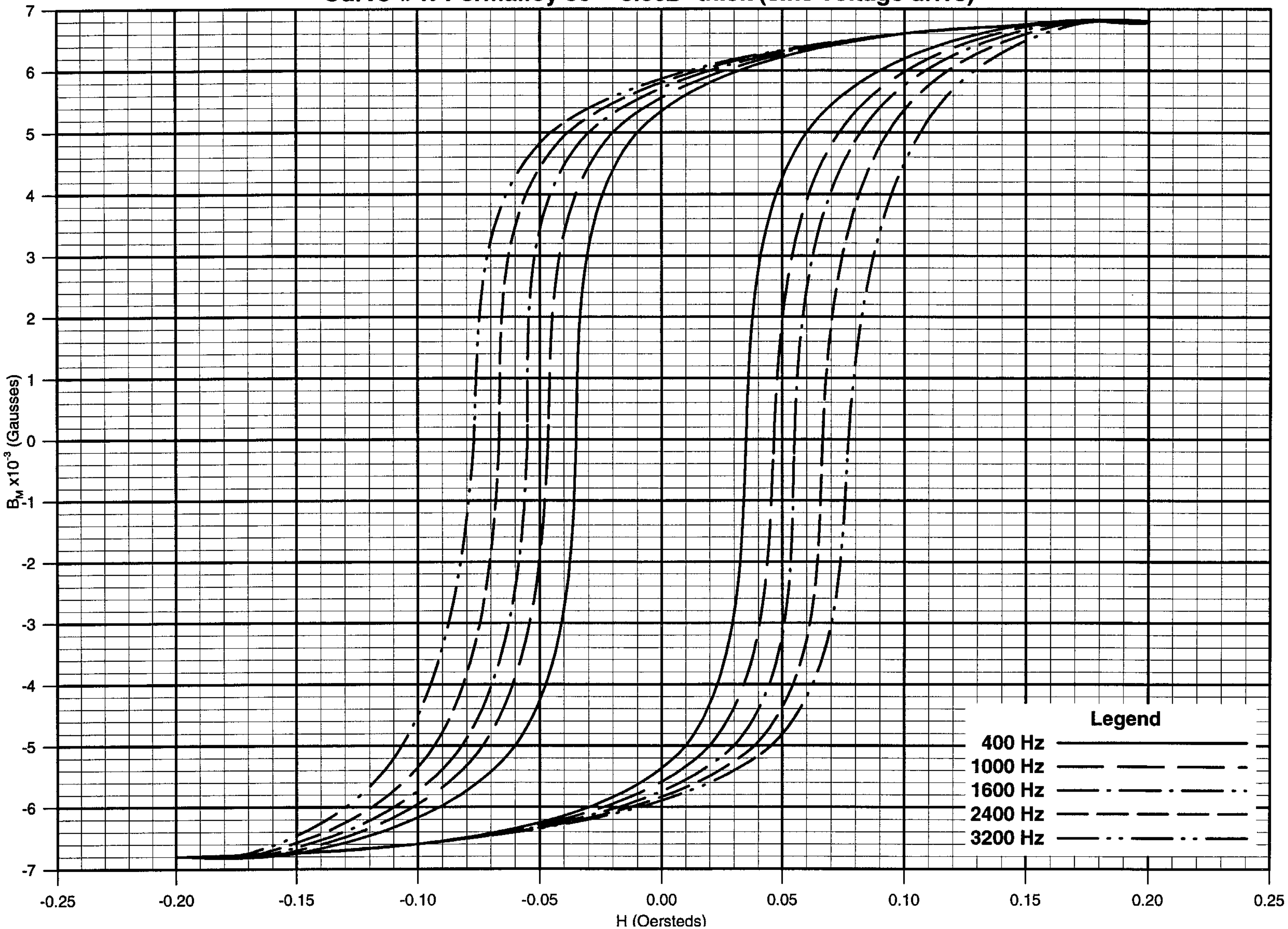
Curve #2: Orthonol -- 0.002" thick (sine voltage drive)



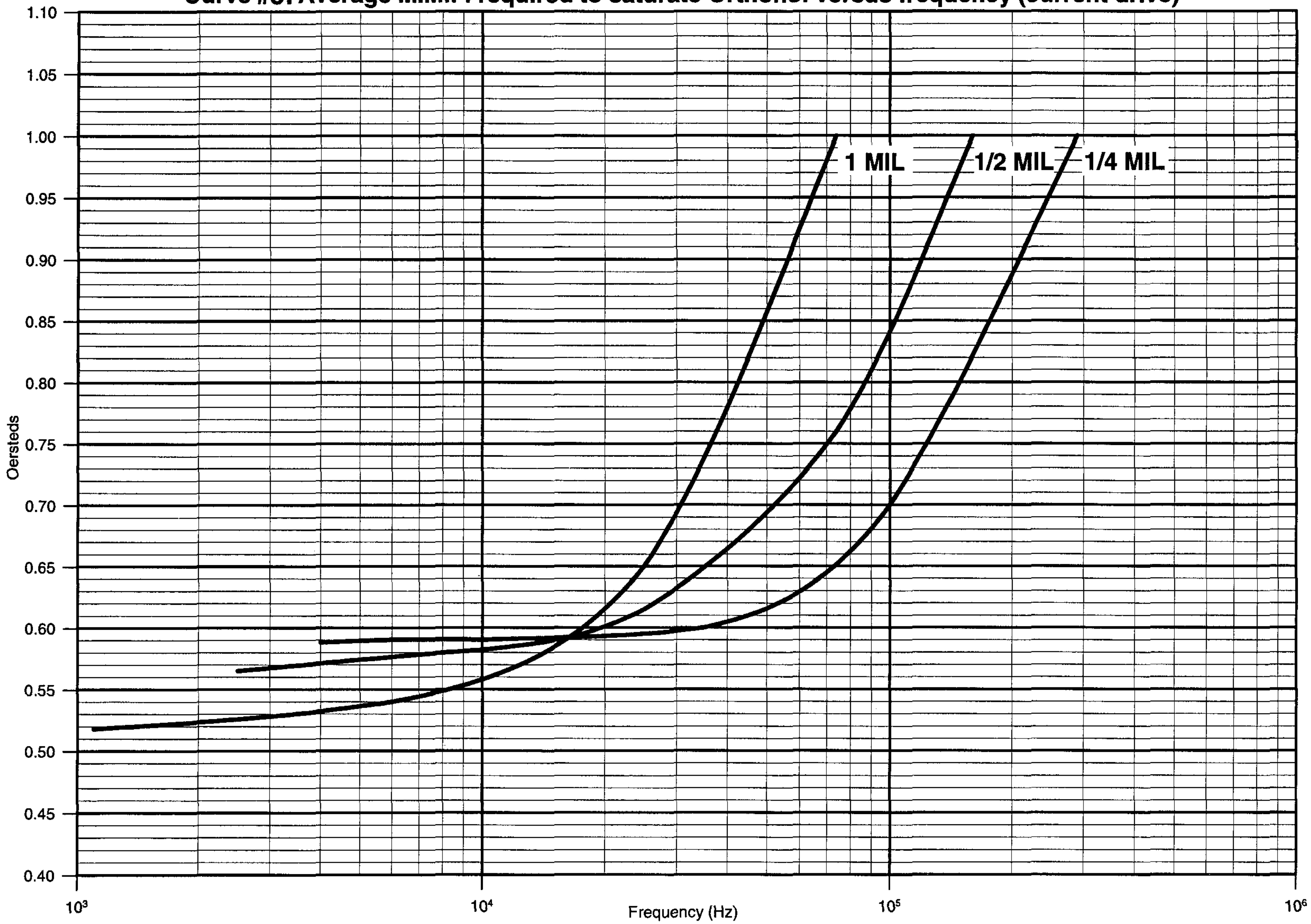
Curve #3: Permalloy 80 -- 0.001" thick (sine voltage drive)



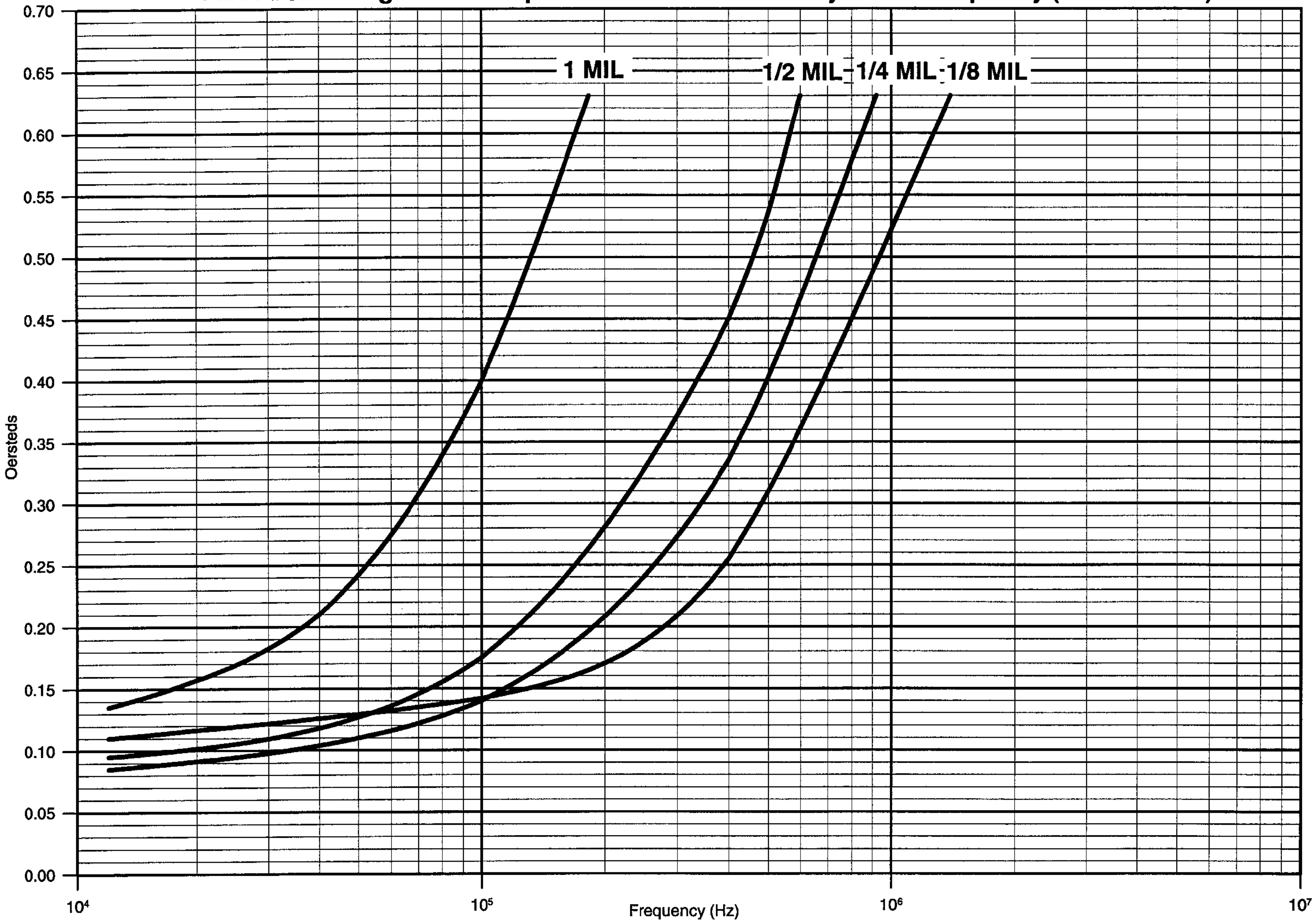
Curve #4: Permalloy 80 -- 0.002" thick (sine voltage drive)



Curve #5: Average M.M.F. required to saturate Orthonol versus frequency (current drive)



Curve #6: Average M.M.F. required to saturate Permalloy versus frequency (current drive)



III. How to Design Magnetic Circuits for Extreme Temperature Environments

Magnetic cores, the heart of all magnetic circuitry, change characteristics as operating temperatures vary. Because of these changes, circuit operation may be adversely affected if no attempt is made to compensate for these variations, or if the design doesn't allow for them.

Magnetic materials are limited in their usefulness at elevated temperatures by the point in temperature where they are no longer magnetic (Curie temperature). This temperature varies due to the basic metallurgy of the alloy; for nickel - iron alloys, Curie temperature is between 400°C and 600°C.

However, due to the strain-sensitivity of nickel - iron alloy types, it is necessary that they be encased in a non-metallic material, or an aluminum case, with damping or cushioning material to protect the core from external stresses during normal production of a magnetic device. Thus, the maximum operating temperature is not limited to the Curie temperature of the magnetic material, but to the maximum operating temperature of the core box or damping compound. Further, a limiting factor may also be the maximum operating temperature of the wire windings, potting compounds, or associated semiconductors which may be used in conjunction with the magnetic core.

After finishing or potting, the maximum continuous operating temperature to which an epoxy-coated aluminum boxed core should be subjected is 200°C. However, this temperature is usually more than the other components in the magnetic device can withstand. Therefore, the collection of magnetic core properties need only cover that range of temperatures dictated by the circuit operational temperatures and the type of environmental test required on the completed unit.

With the advent of standard test procedures (IEEE standards #393) for magnetic cores and using the Constant Current Flux Reset (CCFR) test method as the primary procedure, the most useful temperature data that could be presented would list the variation of properties measured by the CCFR tester. The data in this section covered by this test method is presented over a temperature range of -55°C to +125°C.

This data in curve form is given in percentage changes of the various parameters referenced to a normal ambient temperature of +25°C. Therefore, compensation, if necessary, can be calculated directly, knowing these percentage changes. Also, if compensation is not necessary, a good approximation of the allowable variation in circuit tolerance can be estimated, and minimum operating conditions can be determined.

Using Faraday's and Ampere's Laws, the effects of temperature on typical circuit operation can be investigated.

Faraday's Law states: $E = N_1 \frac{d\phi}{dt} \times 10^{-8}$

which for sine wave drive reduces to:

$$E = 2.22\,\phi\,Nf \times 10^{-8}$$

Core Total Flux Capacity, $\phi = 2\,B_m A_c$

where B_m = maximum flux density of the alloy used.

A_c = effective core cross-sectional area.

N = turns of wire on the core.

f = operating frequency.

Therefore, the Faraday's Law formula becomes:

$$E = 4.44\, B_m A_c\, Nf \times 10^{-8}$$

Curves #l and #5 show the change in B_m with changes in temperature; knowing operating temperature ranges, total variation in B_m, and therefore, E (voltage core will support) can be found.

Ampere's Law states: $H = \frac{0.4\pi NI}{M1}$

where H is the magnetizing mmf or reset mmf required to bias the core to some fixed point on the B-H curve.

Usually, this point is the 1/2 flux reset condition, but it could also be another point, depending on the type, design and purpose of the magnetic circuit. Since this reset mmf varies with temperature, as shown on Curves #3, #4, #7 and #8, the unit must be operated over a smaller linear range, or compensation must be built into the bias or reset winding to correct for the expected variation. Compensation can be obtained from temperature compensation resistors or wire, which will vary bias current to correct the change in the reset mmf value.

Proper selection of the core (flux capacity, mean length and alloy type) becomes increasingly important because of the limitations of compensation, and the allowable circuit tolerances. Trial and error designs may be necessary before final selection of core size, temperature compensation, wire size, etc. of the finished unit is made. However, with information presented here, selection is made much easier.

Example

Part 1 - Determine the range in voltage (E) that a 51035-2A core will support over the temperature range of -55°C to +105°C if the limits of B_m for this core size were 14,000 to 15,500 gausses at +25°C. The core is being operated at 400 Hz with 1,200 turns on the gate winding.

Solving Faraday's Law: $E = 4.44\, B_m A_c\, Nf \times 10^{-8}$

The minimum voltage (E) which the core would support would be with the minimum B_m and the maximum reduction in B_m at +105°C.

B_m = 14,000 min. at +25°C

Max. reduction in B_m at +105°C = 8%

B_m = 12,880 gausses at +105°C.

The maximum voltage (E) which the core would support would be the maximum B_m and the maximum increase in B_m at -55°C.

B_m = 15,500 max. at +25°C

Max. increase in B_m at -55°C = 4.5%

B_m = 16,200 gausses at -55°C

Therefore, the variation in voltage (E) the core will support over the temperature range of -55°C to +105°C can now be determined from these two values of B_m:

$$E = 4.44 \leftrightarrow 12{,}880 \leftrightarrow 0.685 \leftrightarrow 1{,}200 \leftrightarrow 400 \leftrightarrow 10^{-8}$$

= **188 volts minimum**

$$E = 4.44 \leftrightarrow 16{,}200 \leftrightarrow 0.685 \leftrightarrow 1{,}200 \leftrightarrow 400 \leftrightarrow 10^{-8}$$

= **236 volts maximum**

Part 2 - Determine the compensation necessary if the core is being biased to the 1/2 flux reset point over the temperature range previously defined.

From Ampere's Law: $H_O = \frac{0.4\pi N1}{M1}$

Which reduces to:

$$NI = 0.794 \leftrightarrow H_O \leftrightarrow Ml$$

M1 (For core no. 51035-2A) = 11.97 cm.

H_O = 1/2 flux reset point = H_1 + $1/2\Delta H$

H_O increases by the relative increase in H_1 and ΔH from +25°C to -55°C. Since $1/2\,\Delta H$ is about 7% of H_1 in absolute value and H_1 increases 17% while ΔH increases 4% then H_O increases 17% + 0.07 (4%) or 17.3%.

At the high temperature of +105°C, H_1 decreases 15% while ΔH decreases 2%. Using the same reasoning as above, $H_O = H_1 + 1/2\ \Delta H$, then H_O decreases 15% + 0.07% (2%) or 15.1%. Therefore, the H_O value of a core will vary approximately +17% to -15% of the +25 °C recorded value. Since $1/2\,\Delta H$ is about 7% of the H_O value, a core biased at the 90° phase shift or 1/2 flux reset point will shift its bias point completely out of the linear range of the B-H loop unless temperature compensation is built into the bias circuit.

Solving for the necessary change in bias current to compensate for the change in H_O:

$$NI = 0.794 \leftrightarrow H_O \leftrightarrow Ml$$

$$= 0.794 \leftrightarrow H_O \leftrightarrow 11.97$$

$$= 9.5 \leftrightarrow H_O$$

$$Ic = \frac{9.5 \leftrightarrow 1.17 H_O}{N} \text{ at - 55°C}$$

$$Ih = \frac{9.5 \leftrightarrow 0.85\, H_O}{N} \text{ at +105°C}$$

If the control turns are 100 and H_O for this core is 0.22 oersteds at +25°C, then currents are:

$$Ic = \frac{9.5 \leftrightarrow 1.17(0.22)}{100} = \textbf{24.5 milliamperes}$$

$$Ih = \frac{9.5 \leftrightarrow 0.85(0.22)}{100} = \textbf{17.8 milliamperes}$$

Bias winding resistance must also vary by these same percentages; this can be reduced to:

$$\text{Percent change per °C} = \frac{15\% + 17\%}{55°C + 105°C} = \frac{32\%}{160°C} = +0.20\%$$

From this value, temperature compensating resistors or wire can be selected to give the proper temperature coefficient.

Curve Index - How to Design Magnetic Circuits for Extreme Temperature Environments

Curve #1 Variation of B_m of Orthonol with temperature.

Curve #2 Variation of B_r/B_m of Orthonol with temperature.

Curve #3 Variation of H_1 of Orthonol with temperature.

Curve #4 Variation of ΔH of Orthonol with temperature.

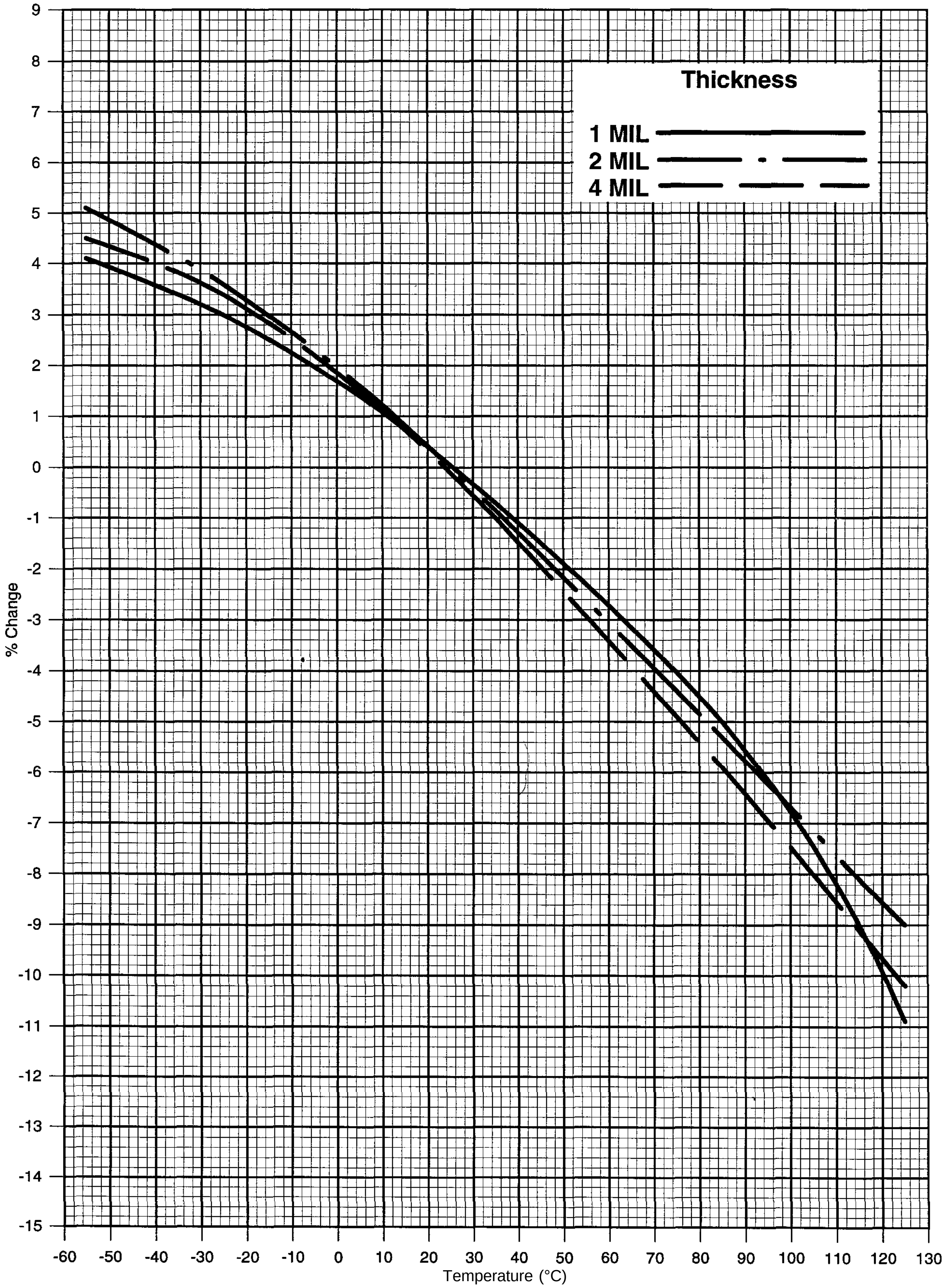
Curve #5 Variation of B_m of Permalloy 80 with temperature.

Curve #6 Variation of B_r/B_m of Permalloy 80 with temperature.

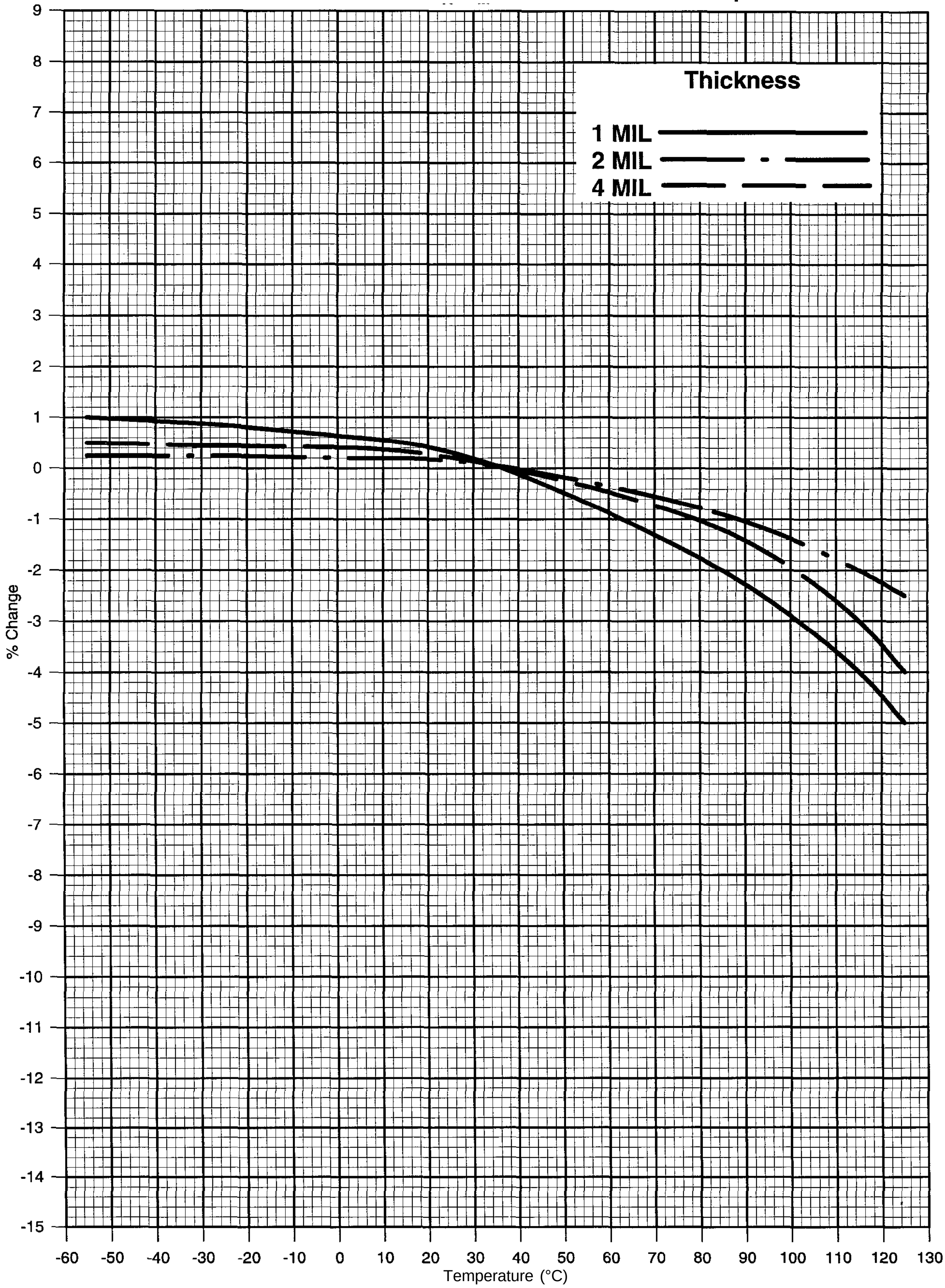
Curve #7 Variation of H_1 of Permalloy 80 with temperature.

Curve #8 Variation of ΔH of Permalloy 80 with temperature.

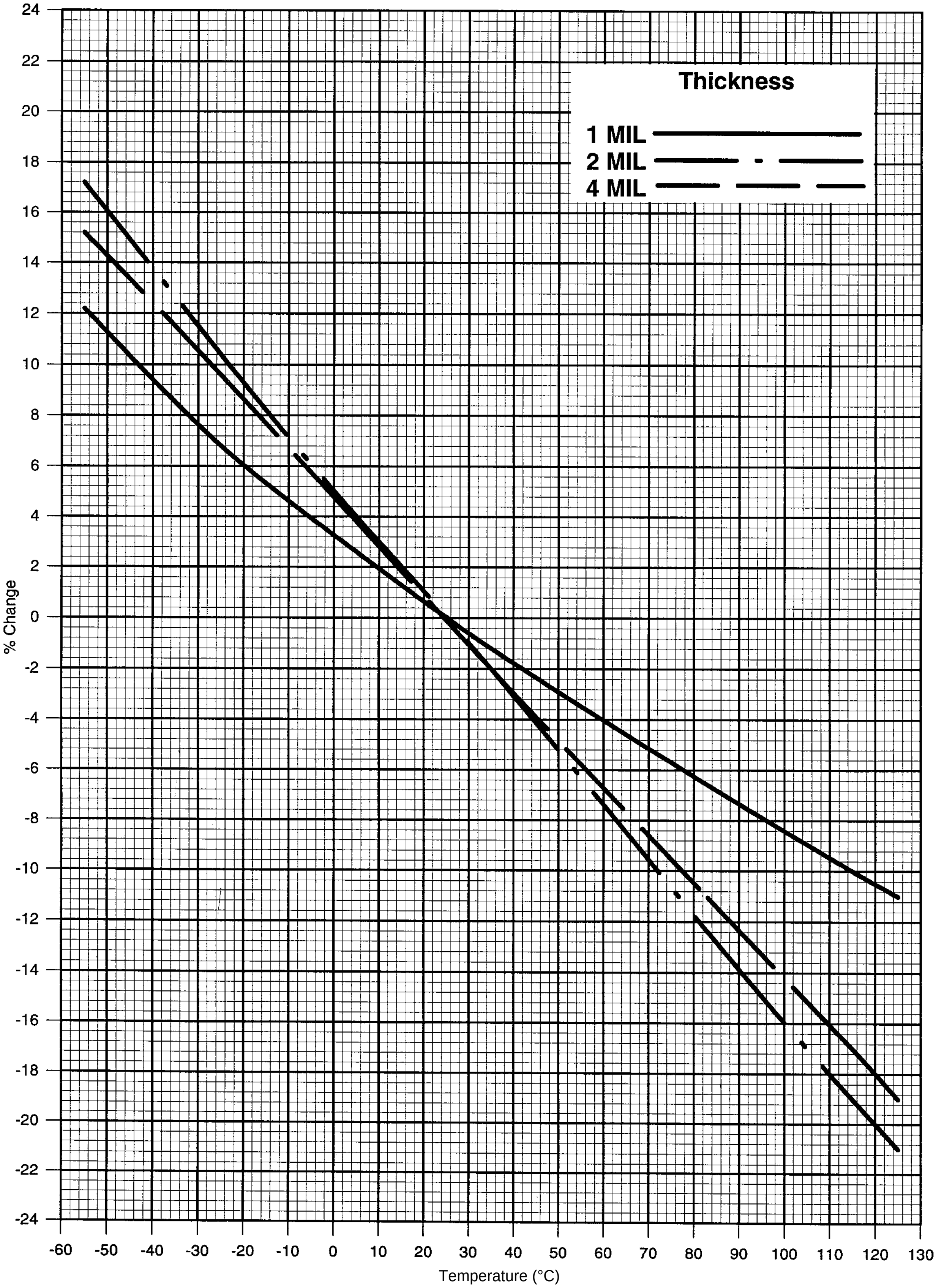
Curve #1: Variation of B_M of Orthonol with temperature

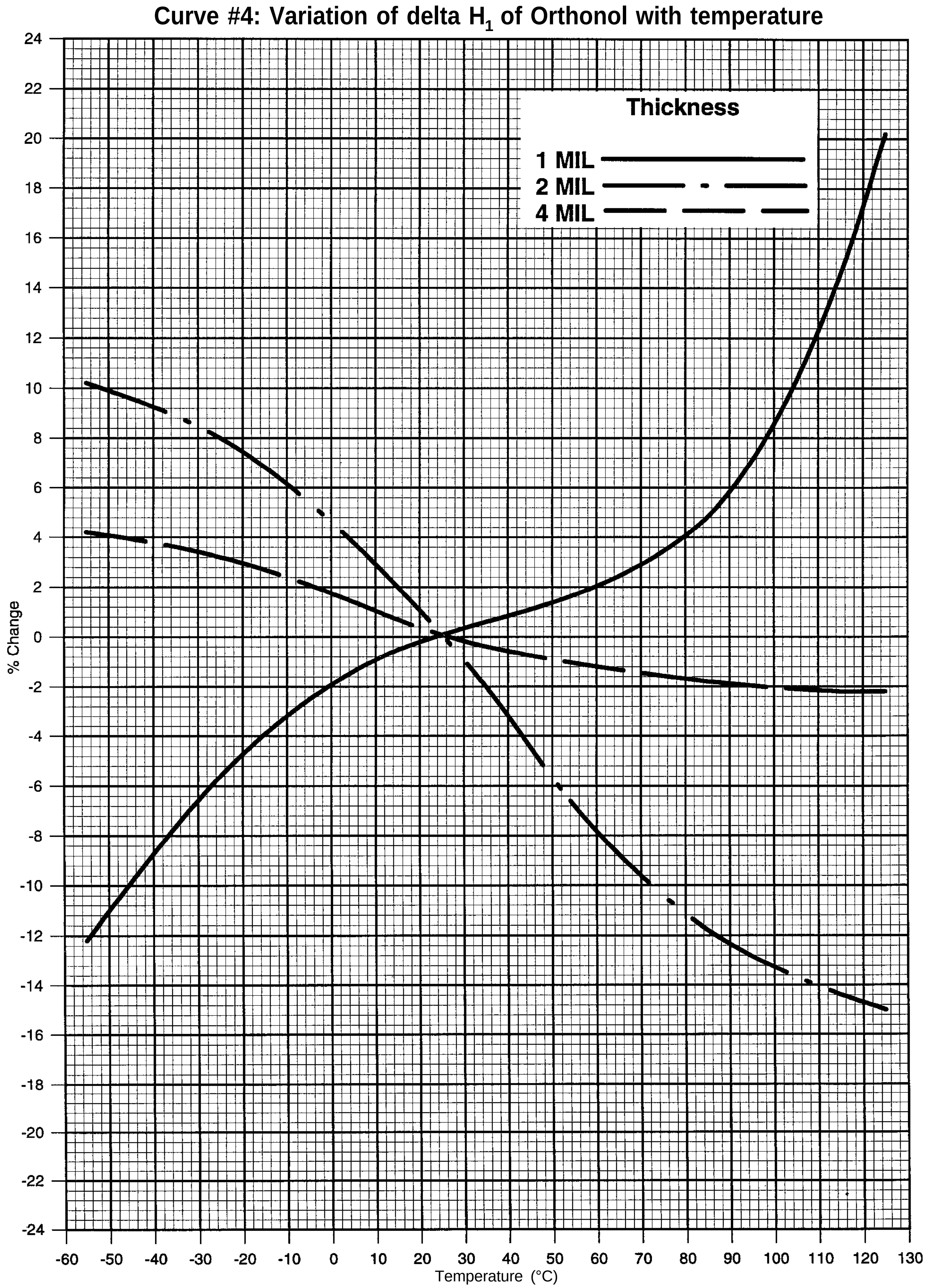


Curve #2: Variation of B_R/B_M of Orthonol with temperature

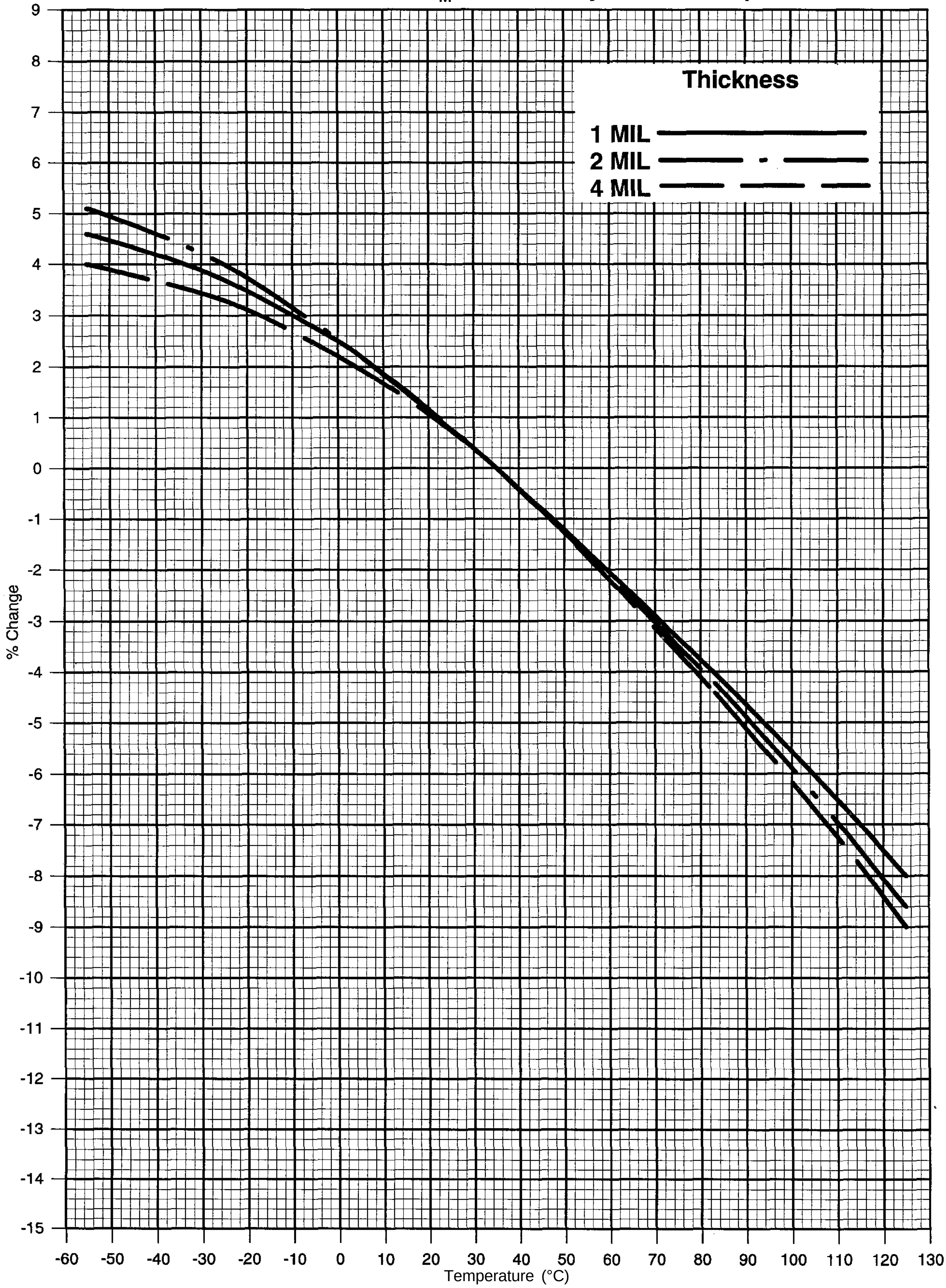


Curve #3: Variation of H_1 of Orthonol with temperature

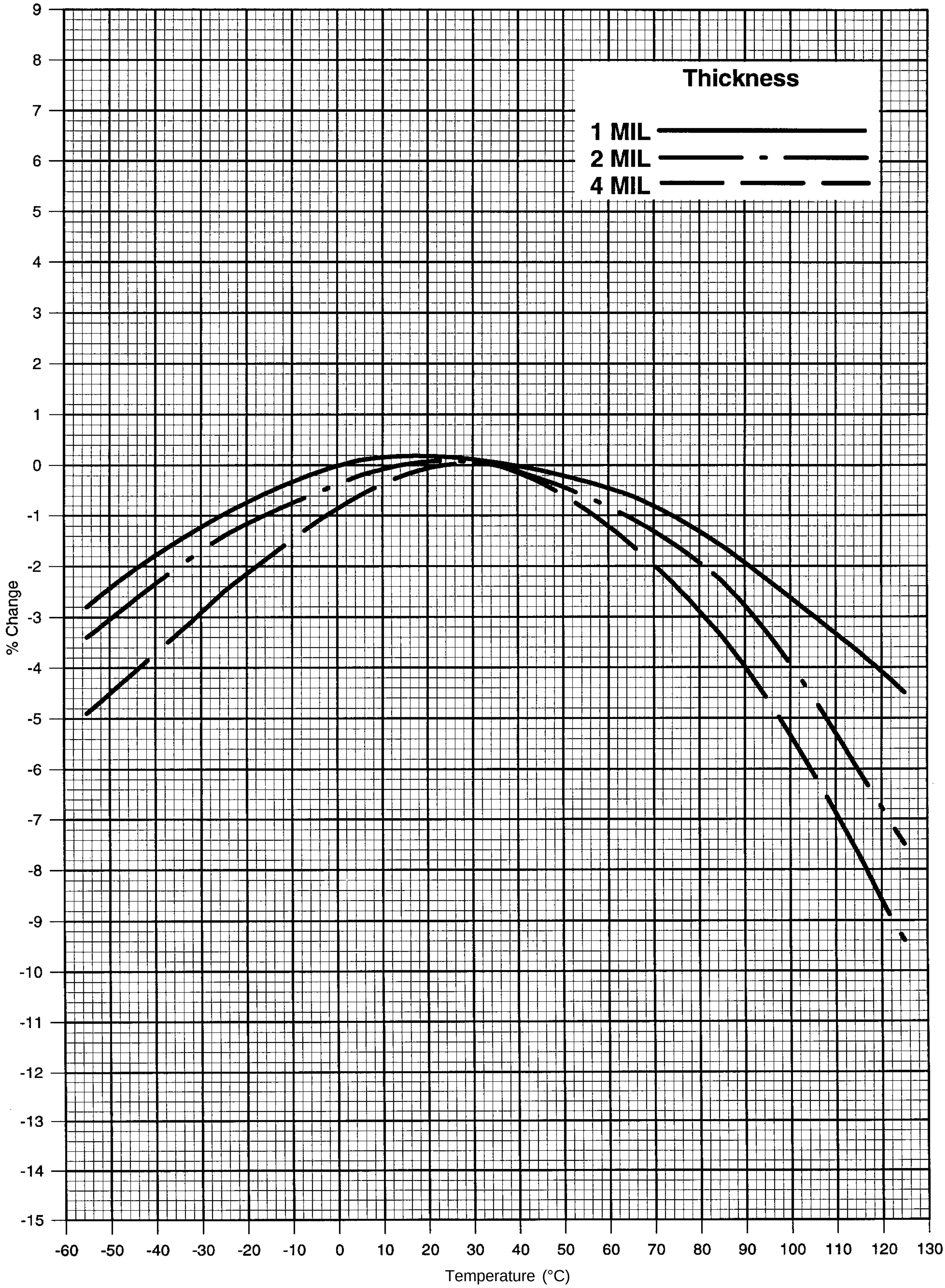



Curve #4: Variation of delta H_1 of Orthonol with temperature
Thickness
1 MIL
2 MIL
4 MIL
% Change
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-22
-24
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
130
Temperature (°C)

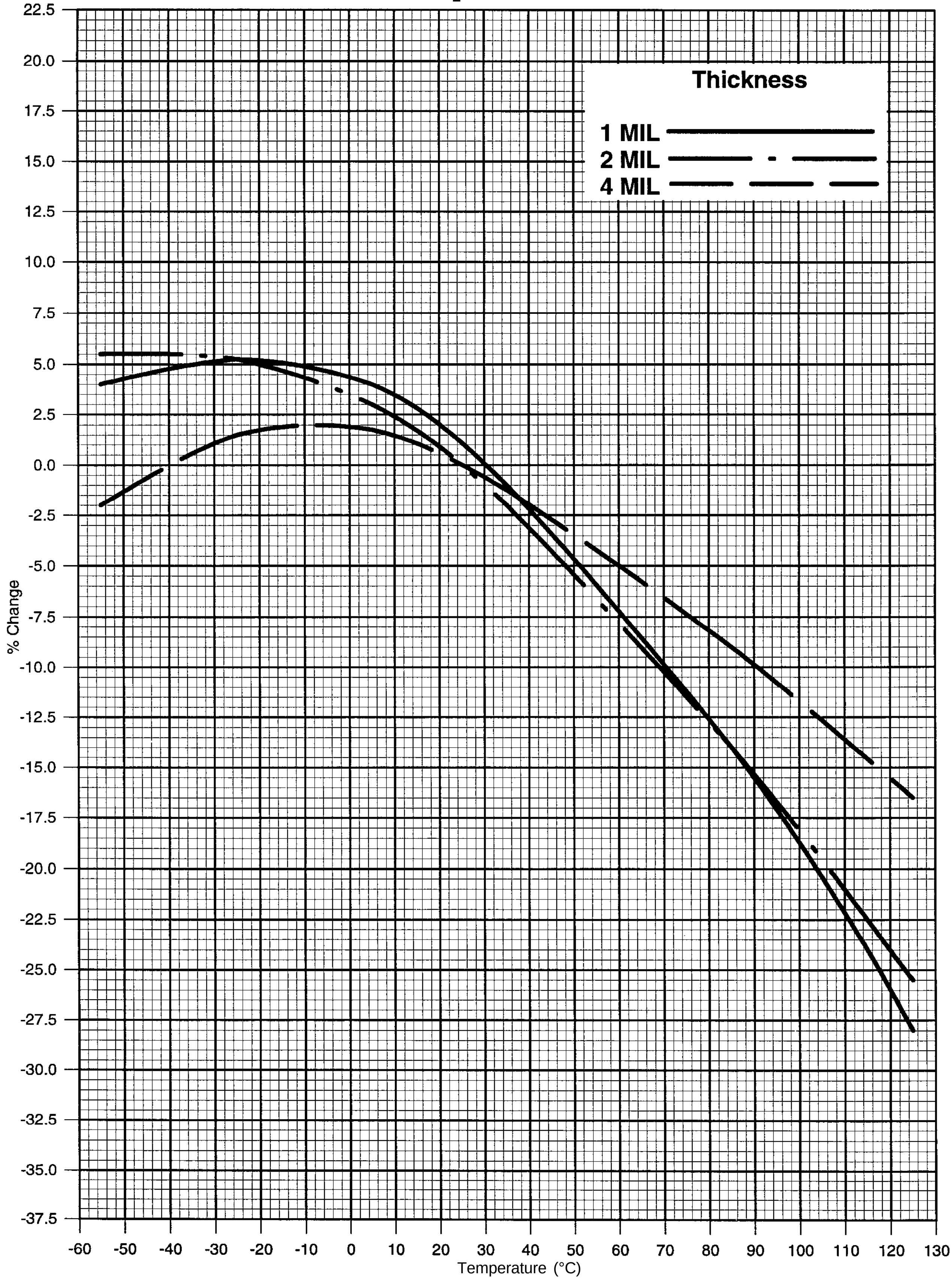
Curve #5: Variation of B_M of Permalloy 80 with temperature

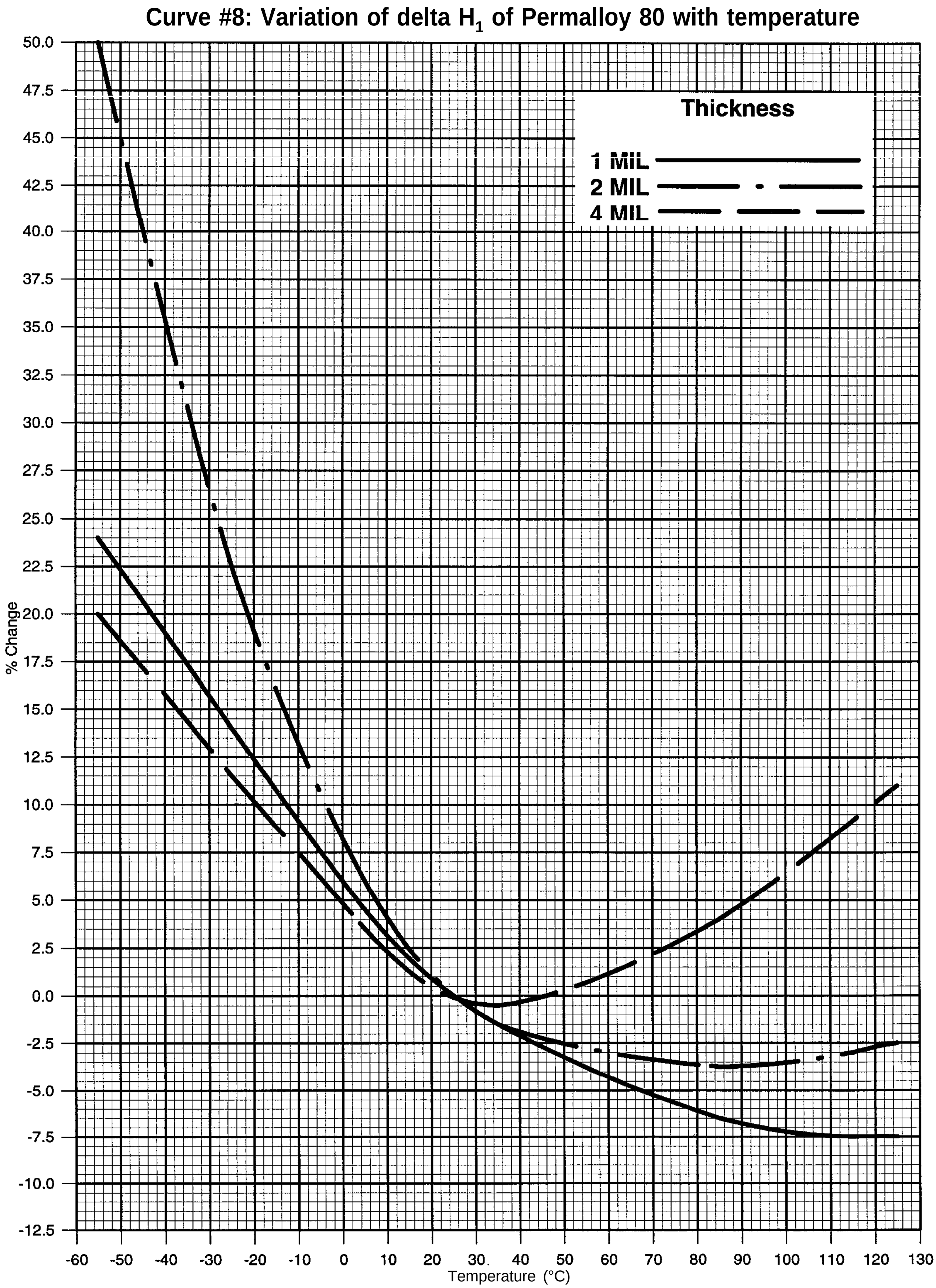


Curve #6: Variation of B_R/B_M of Permalloy 80 with temperature



Curve #7: Variation of H_1 of Permalloy 80 with temperature





Curve #8: Variation of delta H_1 of Permalloy 80 with temperature
Thickness
1 MIL
2 MIL
4 MIL
% Change
Temperature (°C)
50.0
47.5
45.0
42.5
40.0
37.5
35.0
32.5
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
-2.5
-5.0
-7.5
-10.0
-12.5
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
130

IV. Environmental Effects on Magnetic Characteristics of Tape Wound Toroidal Cores

General Comments on Environmental Testing

The study of environmental effects on tape wound cores must include references to the methods used to perform the tests. The evaluation presented here refers to the most applicable Military Specifications for Environmental Testing and describes the parts of those specifications which could apply to cores. Additional information required to investigate the possible effect on core performance is discussed.

The military test specifications referred to are:

1. MIL-STD-446A - Military Standard Environments for Electronic Parts, Tubes and Solid State Devices.
2. MIL-STD-202B - Military Standard Test Methods for Electronic and Electrical Component Parts.
3. MIL-T-5422E(ASG) - Military Specification Testing, Environmental, Aircraft Electronic Equipment.
4. MIL-E-5272C(ASG) - Military Specification Environmental Testing, Aeronautical and Associated Equipment.

In evaluating the types of environmental tests to be performed on a tape wound toroidal core, analysis of the core structure and its use in a circuit must first be made. For example, a core cannot be used alone; it must be wound with copper wire, taped, potted or impregnated, and in many cases, sealed in a metal case (or can) before it is a usable magnetic device. Therefore, many of the environmental tests need not be performed on a core because the core itself will never be subjected to that exposure in actual practice. Conditions of this type are:

1. Salt Spray (corrosion)	4. Moisture resistance
2. Humidity (steady state)	5. Explosion
3. Immersion	6. Sand and Dust

Other environmental conditions, however, possibly could change the characteristics of a core in a magnetic circuit and should be completely analyzed and evaluated for any effects on the core and circuit performance. These conditions are:

1. Life	5. Vibration
2. Temperature Cycling	6. Mechanical Shock
3. Pressure	7. Nuclear Radiation Damage
4. Thermal Shock	

In MIL-E-5272C(ASG), failure is defined as “Deterioration or change in performance of any components which could in any manner prevent the equipment from meeting functional, maintenance and service requirements during service life shall provide reason to consider the equipment as having failed to comply with the conditions of the test to which it was subjected." MIL-T-5422E(ASG) defines failure as "Variations of operational and performance characteristics outside of the limits permitted by the detail equipment specification are reason to consider the equipment having failed the test. Deterioration and material failure of any part or material which could in any manner prevent the equipment from meeting operational, performance, and reliability requirements during service life shall provide reason to consider the equipment as having failed the test."

From these definitions, it must be determined if the device being tested will meet all requirements of the "detail specification" for that part not only after the environmental test being performed, but in many cases during the test. A complete evaluation of each environmental test required, relative to the part "detail specification", must be made to satisfy the full requirement and meaning of the specifications referred to. For example, a "detail specification" which includes a note requiring MIL-STD-202B be met, doesn't contain sufficient information by which the MIL-STD-202B may be applied. Therefore, in testing a tape wound toroidal core for its acceptance under various environmental conditions, each test method and test condition must be referred to or specified to prevent confusion in the interpretation of the test. Equally important, the characteristics defined in the "detail specification" **must be compatible** with the variations expected (if any may exist) when the component is tested to MIL-STD-202B, Method 108 (Life) test condition D at a temperature of 125°C. In addition, a "detail specification" for the part requires that it must also meet some tight electrical specification without reference to temperature. Method 108 states that the test is performed "for the purpose of determining the effects on electrical and mechanical characteristics of a part, resulting from exposure of the part to an elevated ambient temperature for a specified length of time, while the part is performing its operational function." Because of these limitations, or from lack of clarity in the "detail specifications", cores cannot be produced to simultaneously meet all of the above requirements. This is due to the normal temperature variation of core properties, which prevent the core from meeting the specified magnetic tolerances. Clarification of the "detail specification" must therefore be made either to alter the core requirements, to take exception, or change the temperature requirements given by method 108.

To state that a component, especially a tape wound toroidal core, will meet the requirements of specific Mil Specs for environment is somewhat meaningless, unless specific and detailed information is also included. Although "failure" is well defined in a Mil Spec, the allowable variation of properties which determine a failure are given in the "detail specification." Hence, a complete and correct "detail specification" is much more important in determining the acceptability of a component than just stating that the part shall meet the requirement of a particular Mil Spec.

The Meaning and Scope of Mil Specs Covering Environmental Testing

1. MIL-STD-446A - The purpose of this specification is to establish uniform environmental design requirements for use in planning of research and development programs and to provide a guide for use in the preparation of military specifications and standards involving electronic parts, tubes, and solid state devices.

It divides the application of basic electronic parts into eight environmental groups which contain the requirements of the Three Military Departments. Environmental characteristics which may effect core performance, and therefore should be covered under this specification are:

a. **Temperature** - All of **MAGNETICS** tape wound toroidal cores meet the requirements of Group III calling for an operating temperature range of -65°C to +125°C, without physical damage to the core or its protective case or cover. Plus, **MAGNETICS** aluminum boxed (51000 or 52000 series) cores meet the requirements of Group V, while the uncased Magnesil® cores (53000 series) meet the requirements of Group VIII.

b. **Vibration** - The mass of the core determines the maximum amplitude of vibration to which it can be operated. For cores weighing less than 200 grams, all **MAGNETICS** core sizes and types can be operated per Group VIII. For cores weighing more than 200 grams, Group VII can be maintained.

c. **Pressure** - Pressure is an important consideration, especially in a hermetic seal requirement, only during the potting or impregnation process after the winding of copper wire on the core. After potting and subsequent sealing of the case, very little if any external pressures will be transmitted to the core because of the rigidity of the potted structure and the core case construction. In addition, the damping compound with some air space inside the cased core will absorb any small variations of internal pressures if any could occur.

d. **Life - MAGNETICS** cores will withstand the operating and storage life requirements as associated with each environmental group, as described above under Temperature, for each core type. (See table I for description of requirement of MIL-STD-446A.)

Table I - Environmental Requirements
MIL-STD-446A

Environmental Characteristics	Group I	Group II	Group III	Group V	Group VII	Group VIII
Temperature (ºC)						
Operating	-55 +55	-65 +55	-65 +125	-65 +200	-65 +350	-65 +500
Storage	-65 +71	-65 +85	-65 +85	-65 +85	-65 +85	-65 +85
Thermal Shock	NA	-65 +85	-65 +125	-65 +200	-65 +350	-65 +500
Vibration:						
Cycles / second	10 - 55	10-2000	10-2000	10-2000	10-2000	10 - 3000
Accel. (g)	NA	10	10	15	20	40
Shock:						
Accel. (g)	50	50	50	50	50	50
Time in msec.	7	11±1	11±1	11±1	11±1	11±1
Life (hr):						
Operating	30k	30k	30 k	20k	2 k	10k

2. MIL-STD-202B - This standard establishes uniform methods for testing electronic and electrical component parts, including basic environmental tests. The important parts of this specification which may effect core performance are:

a. Temperature Cycling (Method 102A) or Thermal Shock (Method 107A)

This test is conducted for the purpose of determining the resistance of a part to the shock of repeated surface exposures to extremes of high and low temperatures for comparatively short periods of time. Effects of temperature cycling include cracking and delamination of finishes, embedding compounds, and other materials, opening of terminal seals and case seams, and changes in electrical characteristics.

The preferred tests are 5 cycles of one of the programs listed in table two.

Table II

Test Condition (a)		Test Condition (b)		Test Condition (c)	
1. -55°C	30 mins.	1. -65°C	30 mins.	1. -65°C	30 mins.
2. +25ºC	5 mins. max.	2. +25ºC	10-15	2. +25ºC	5 mins. max.
3. +85ºC	30 mins.			3. +200ºC	30 mins.
4. +25ºC	5 mins. max.			4. +25ºC	5 mins. max.

Test Condition (d)		Test Condition (e)	
1. -65°C	30 mins.	1. -65°C	30 mins.
2. +25ºC	5 mins. max.	2. +25ºC	5 mins. max.
3. +350ºC	30 mins.	3. +500ºC	30 mins.
4. +25º C	5 mins. max.	4. +25ºC	5 mins. max.

For parts weighing more than 0.3 pounds, the exposure time at the temperature extremes shall be measured according to the following table:

Table III

Weight of Specimen	Minimum Time For Steps 1 & 3 (Table II)
Above 0.3 to 3 pounds	1 hour
Above 3.0 to 30 pounds	2 hours
Above 30 to 300 pounds	4 hours
Above 300 pounds	8 hours

Specified measurements shall be made prior to the first cycle and upon completion of the final cycle. Failures shall be based on measurements made after the specimen has returned to thermal stability at room ambient temperature following the final cycle. All **MAGNETICS** tape wound cores will meet the requirements of Test Conditions B while the aluminum boxed (51000 and 52000 series) cores meet Test Condition C also. Uncased Magnesil cores will meet all requirements including Test Condition E of Table II.

b. **Life** (Method 108) (at elevated ambient temperature) - The test is conducted for the purpose of determining the effects on electrical and mechanical characteristics, resulting from exposure of the part to an elevated ambient temperature for a specified period while the part is performing its operational function.

Specified measurements shall be made prior to, during, or after exposure as required.

Test samples shall be subjected to one of the following temperature conditions, as specified:

Table IV	
ºC	ºF
55º	131º
70º	158º
85º	185º
125º	257º
200º	392º
350º	662º
500º	932º

The length of test at the specified temperature shall be as follows:

Table IV	
Test Condition	Length of Test (Hours)
A	96
B	250
C	500
D	1000
E	1500
F	2000
G	3000
H	5000

c. **Vibration** (Method 201A) - This test is used to determine the effects of vibration within the predominant frequency ranges and magnitudes that may be encountered during field service. Each part to be tested is subjected to a simple harmonic motion having a 0.06” total excursion with the frequency varied uniformly between 10 and 55 cycles. The entire cycle shall be traversed in one minute for a period of two hours in each of three mutually perpendicular directions.

All **MAGNETICS** cores meet and exceed these requirements. Cores weighing less than 200 grams can be safely operated to 50 G amplitude while cores weighing greater than 200 grams can be operated to 30 G within this frequency range.

Specified measurements shall be made **during** and **after** vibration.

d. **Vibration** (Method 204A) - This test extends the frequency of vibration to 2000 Hz. The worst condition encountered is equivalent to 20 G and **MAGNETICS** cores will withstand this requirement.

See Vibration Nomogram for more information.

3. MIL-T-5422E(ASG) - This specification is similar in nature to the above MIL-STD-202B except for the following conditions:

   a. **Temperature Cycling or Thermal Shock**

Class	Temperature Operating	Temperature Non-operating
1	-54°C to +55°C	-62°C to +85°C
2	-54°C to +71°C	-62°C to +95°C
3	-54°C to +95°C	-62°C to +150°C
4	-54°C to +125°C	-62°C to +260°C

   b. **Vibration** - From 5 to 500 cycles at a maximum amplitude of 10 G.

4. MIL-E-5272C(ASG) - This specification is similar to the others, with these exceptions:

   a. **High Temperature Test** - The device being tested shall be raised to 71 °C and held at that temperature for 48 hours unless otherwise specified. At the end of the exposure period, and while still at the test temperature, it shall be tested to the detail specification. The device shall be returned to +25 °C and again tested.

   b. **Low Temperature Test** (Procedure 1) - The device shall be cooled to a temperature of -54 °C and stabilized at that temperature. While at that temperature it shall be tested to the detail specifications. The device shall be returned to +25 °C and again tested. (Procedure II) - The device shall be cooled to a temperature of -62 °C for 72 hours. The temperature shall then be raised to -54 °C and maintained for an additional 24 hour period. At the end of this period, while at -54 °C, the device shall be tested in accordance with the detail specification. The device shall then be returned to +25 °C and again tested.

   c. **Temperature Shock** - This test calls for 3 cycles from +85 °C to -40 °C, holding at the specified temperature for 4 hours minimum with a transfer time of 5 minutes maximum, unless otherwise specified. After the third cycle, the device shall be returned to +25 °C and tested within 1 hour after reaching this temperature.

d. **Vibration -** The worst condition specified is an amplitude of 20 G over a frequency range of 5 to 2000 Hz for periods of 15 minutes duration.

e. In the event the temperatures specified under (a) are considered inadequate and temperature requirements are not specified in the “detail specification”, one of the following test temperatures may be used:

The temperature selected should be closest to the maximum service temperature of the equipment.

°C	°F
95°	199°
125°	257°
150°	302°
200°	392°
250°	482°

5. No attempt has been made to evaluate cores under mechanical shock conditions. One of the reasons for this is that a shock test is intended to determine the suitability of a part for use in equipment which may be subjected to mechanical shocks as a result of suddenly applied forces, or abrupt changes in motion produced by rough handling, transportation, or field operation. Shocks of this type may cause damage similar to that resulting from excessive vibration, particularly if the shock pulses are repetitive. Therefore, a severe vibration test placed on the specimen is equivalent to testing it under mechanical shock conditions. When required to meet Mil Specs, **MAGNETICS** cores weighing up to 200 grams are vibrated up to 50 g amplitude to determine their acceptability in shock and vibration environments.

6. Nuclear Radiation Damage has been explored and investigated by various groups under contract with the government. These studies have been assembled in report form and because of their nature will not be discussed here. However, listed below are references covering this subject:

1. “Effect of Neutron Bombardment on the Magnetic Properties of Iron and Nickel of Very High Permeability, III, “Biorci, Ferro and Montelenti, Final Report 3b, Contract AF61(514)-1331, Office of Scientific Research, ARDC, February 1960.

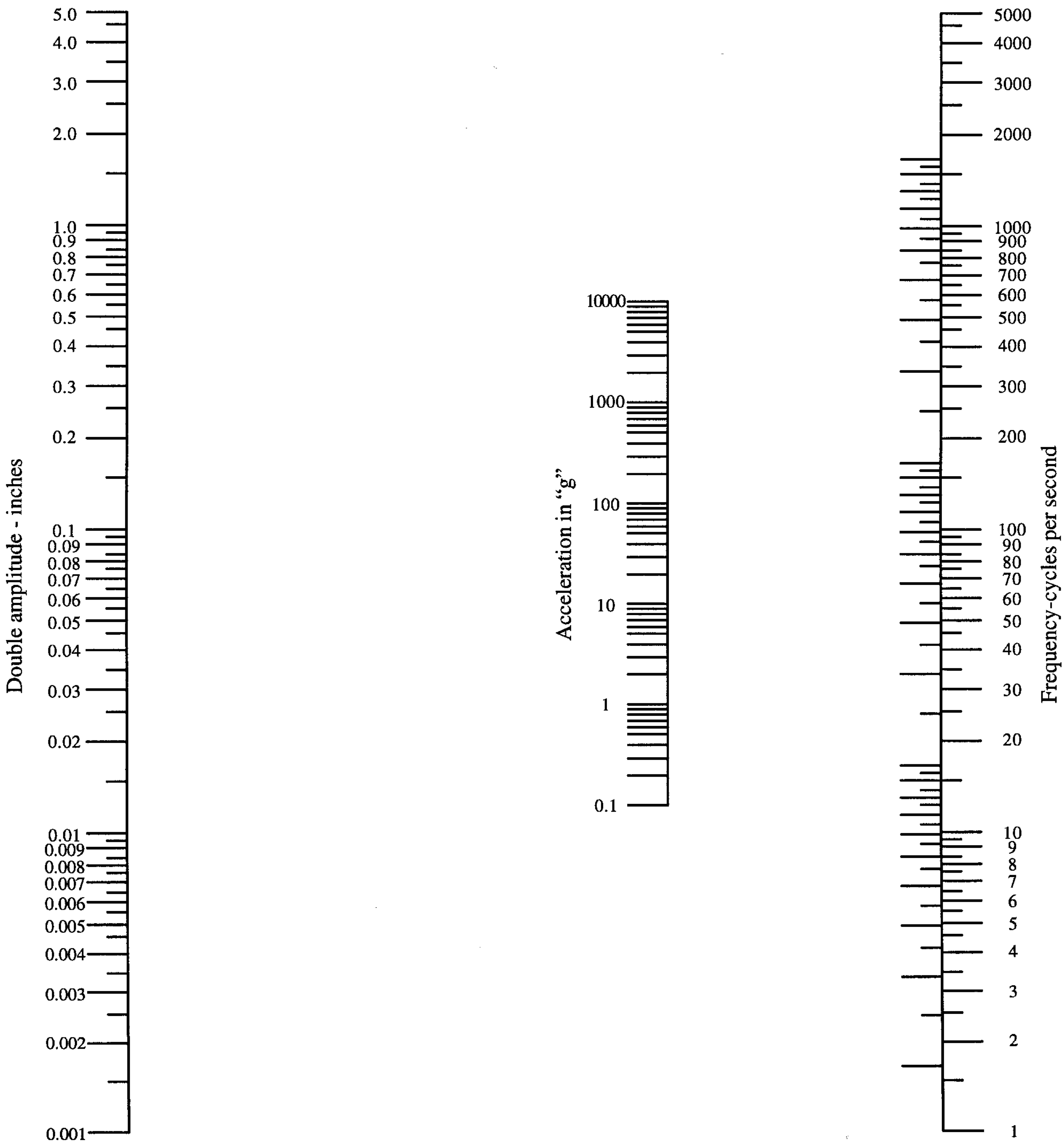
2. “Nuclear Irradiation Effects on Soft Magnetic Materials,” R. S. Sery and D. I. Gordon, Bull. Am. Phys. Soc. (Series II-3), 117 (1958).

3. “Nuclear Radiation Effects in Magnetic Core Materials and Permanent Magnets,” D. I. Gordon, R. S. Sery and R. H. Lundsten, ONR-5, Materials Research in the Navy, Symposium, Philadelphia, 1959 (Office of Naval Research, Washington, 1959) pp. 253-292.

VIBRATION NOMOGRAM

The nomogram represents the equation $g=0.0511 \times D \times f^2$

where g = acceleration
D = double amplitude (inches)
f = frequency (cycles per second)



4. “Effect of Applying a Magnetic Field During Neutron Irradiation on the Magnetic Properties of Fe-Ni alloys,” A. I. Schindler and E. I. Salkovitz, J. Appl. Phys., 31, supplement to No. 5, 245-S (1960).

5. “Some Effects of Pulsed Neutron Radiation on Electronic Components - II,” Radiation Research Group, IBM 447103-9.14 (International Business Machines Corp., Military Products Div., Owego, N.Y.).

6. “Environmental Evaluation of Magnetic Materials,” Electre-Technology, Vol. 67, No. 1, Page 118, January 1961.

General Effects of Exposing Tape Wound Cores to Extreme Environments

Tape wound toroidal cores are designed to withstand severe environmental conditions. However, due to their basic construction, their limits of operation are able to be defined. The reliability of a component must be built into it. The “detail specification” of that part will determine how effectively that reliability can be determined. A Mil Spec on Environmental Testing can be used as a guide to determine the types of tests and how they are performed, but the individual detail specification must define the performance of each part when subjected to those environments.

Cores will withstand the effects of vibration environments as defined in any of the Mil Specs, during and after vibration, only if they are adequately damped in their protective case. Inadequate damping will allow core characteristics to change as much as 30-50% **during** vibration. This change will appear as a modulated change in characteristics, based on the frequency of the vibration. After vibration there will be very little if any permanent change in characteristics, because the material was not stressed beyond its elastic limit during vibration. This is prevented due to the close tolerances between the core and its case, preventing excessive movement of he core during its vibration test even when inadequate damping of the core is in evidence. Therefore, it is necessary to monitor the core performance both **during** and **after** any vibration test to determine acceptable core performance. A well damped core having proper damping compounds will not change characteristics when subjected to vibration environments defined in the Mil Specs referred to.

Thermal shock will not affect tape wound cores as long as the maximum temperature does not exceed the breakdown temperature of the damping compound or the non-metallic parts of the case (fiberglass lid material). For aluminum boxed cores (51000 or 52000 series), the maximum operating temperature is 200 °C. Uncased Magnesil cores, because they are not cased or damped, can be operated safely to 500 °C without permanent changes in core characteristics. Thermal shock or cycling of cores is a method of flexing or aging the core so that temperature hysteresis effects will be negligible when the core is assembled into a finished unit and in operation.

Checking core performance at temperature other than normal room ambient (25 °C), as would be done under life test at elevated ambient temperature (Method 108 MIL-STD-202B), calls for a complete evaluation of core characteristics with temperature changes. Core characteristics vary greatly when operated at temperature extremes; these variations must be anticipated and, if necessary, specified on the detail specification for the part.

In conclusion, a Mil Spec on Environmental Testing is only as good as the part detail specification in which it is mentioned. Unless the “detail spec.” makes full explanation of how the Mil Spec is to be used and the measurements that must be taken, reliability and performance cannot be insured. Careful analysis of the part, its characteristics, and its function in the finished assembly must be made before a useful and complete specification can be written. Reference to a Mil Spec alone does not solve any problems.

References

(Covering Temperature Effects on Magnetic Materials)

1. “Effects of Temperature on Magnetic Core Materials,” M. Pasnak, R. H. Lundsten. ELECTRICAL MANUFACTURING, 64, No. 4, p 119, October 1959.

2. “Effects of Ultra High Temperature on Magnetic Properties of Core Materials,” M. Pasnak and R. Lundsten, AIEE Transactions, Part I (Communication and Electronics), No. 46, 1033 (January 1960).

3. “Magnetic Core Materials for Extreme Environments,” Staff Report, ELECTRICAL MANUFACTURING, 65, No. 5, p 76 (1960).

4. “Effect of Temperature on Magnetic Properties of Silicon-Iron, Cobalt-Iron and Aluminum-Iron Alloys,” J. J. Clark and J. F. Fritz, WADC Tech. Note 59-240 (Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, 1959).

5. Ultra High Temperature (500 °C) Power Transformers and Inductors,” H. B. Harms and J.

V. Shortcuts in Selection of Toroidal Tape Wound Cores

MAGNETICS has developed three sets of curves helpful to engineers designing in the areas of INVERTERS, MAGNETIC AMPLIFIERS, and TRANSFORMERS. There is a characteristic curve for each of the three materials...Magnesil, Orthonol, and Permalloy 80...in each device area. The curves were developed by solving Faraday's Law and using specific basic assumptions in solving this equation.

MAGNETICS core tables (TWC-400) contain a column headed "$W_a A_c$". This column lists the value of the relative power handling capacity of each core. By equating this value against Faraday's law, the following relationships have been obtained:

I - Solving for Saturating Type Inverter Designs

Faraday's Law: $E = 4\, B_m A_c N f \times 10^{-8}$

Solving for $NA_c = \dfrac{E}{4 B_m f \times 10^{-8}}$

However, the Window Utilization Factor

$$K = \frac{NA_w}{W_a} = 0.1$$

$$NA_w = 0.1\, W_a$$

Multiply both sides by A_c and transpose

$$NA_c = \frac{0.1\, W_a A_c}{A_w}$$

Combining and solving for $W_a A_c$

$$0.1\, W_a A_c = \frac{E}{4 \times B_m \times f \times 10^{-8}}$$

$$W_a A_c = \frac{EA_w}{0.4 \times B_m \times f \times 10^{-8}}$$

$$W_a A_c = \frac{2.5 \times EA_w}{B_m \times f \times 10^{-8}}$$

Assume 85% efficiency and 750 cir mils/amp current capacity of wire. However the primary winding has a 50% duty factor, giving a current capacity of 375 cir mils/amp.

The formula then becomes:

$$W_a A_c = \frac{1.1 \times \text{Power Output}}{B_m \times f \times 10^{-11}}$$

Since the inverter is a saturating device,

$B_m = 17000$ (Magnesil)

$B_m = 14500$ (Orthonol)

$B_m = 7000$ (Permalloy 80)

Formulas used for inverter curves are:

$$W_a A_c = \frac{6.5 \times \text{Power Output} \times 10^{6}}{f} \qquad \text{(Magnesil)}$$

$$W_aA_c = \frac{7.6 \times \text{Power Output} \times 10^6}{f} \qquad \text{(Orthonol)}$$

$$W_aA_c = \frac{14.3 \times \text{Power Output} \times 10^6}{f} \qquad \text{(Permalloy 80)}$$

II - Solving for Typical Sine Wave Magnetic Amplifier Designs

Faraday's Law: $E = 4.44\ B_mA_cN\ f \times 10^{-8}$

$$K = 0.3 \text{ and } W_aA_c = \frac{0.75 \times EA_w}{B_m \times f \times 10^{-8}}$$

Assume 94% efficiency and 750 cir mils/amp.

Therefore the formula becomes:

$$W_aA_c = \frac{0.06 \times \text{Power Output}}{B_m \times f \times 10^{-11}}$$

Since magnetic amplifiers are saturating devices, use B_m noted for inverters.

Formulas used for Magnetic Amplifier curves are:

$$W_aA_c = \frac{3.5 \times \text{Power Output} \times 10^6}{f} \qquad \text{(Magnesil)}$$

$$W_aA_c = \frac{4.15 \times \text{Power Output} \times 10^6}{f} \qquad \text{(Orthonol)}$$

$$W_aA_c = \frac{9.35 \times \text{Power output} \times 10^6}{f} \qquad \text{(Permalloy 80)}$$

III - Solving for Typical Transformer Design Where Flux Swing Doesn't Exceed 0.5 B_m

Faraday's Law: $E = 4.44\ B\ A_c\ N\ f \times 10^{-8}$

$$K = 0.2 \text{ and } W_aA_c = \frac{0.89 \times EA_w}{B_m \times f \times 10^{-8}}$$

Assume 95% efficiency and 750 cir mils/amp

The formula becomes:

$$W_aA_c = \frac{0.7 \times \text{Power Output}}{B_m \times f \times 10^{-11}}$$

Since B is only 1/2 of the B_m value for each core material,

B_m = 8500 (Magnesil)

B_m = 7250 (Orthonol)

B_m = 3500 (Permalloy 80)

Formulas used for Transformer curves are:

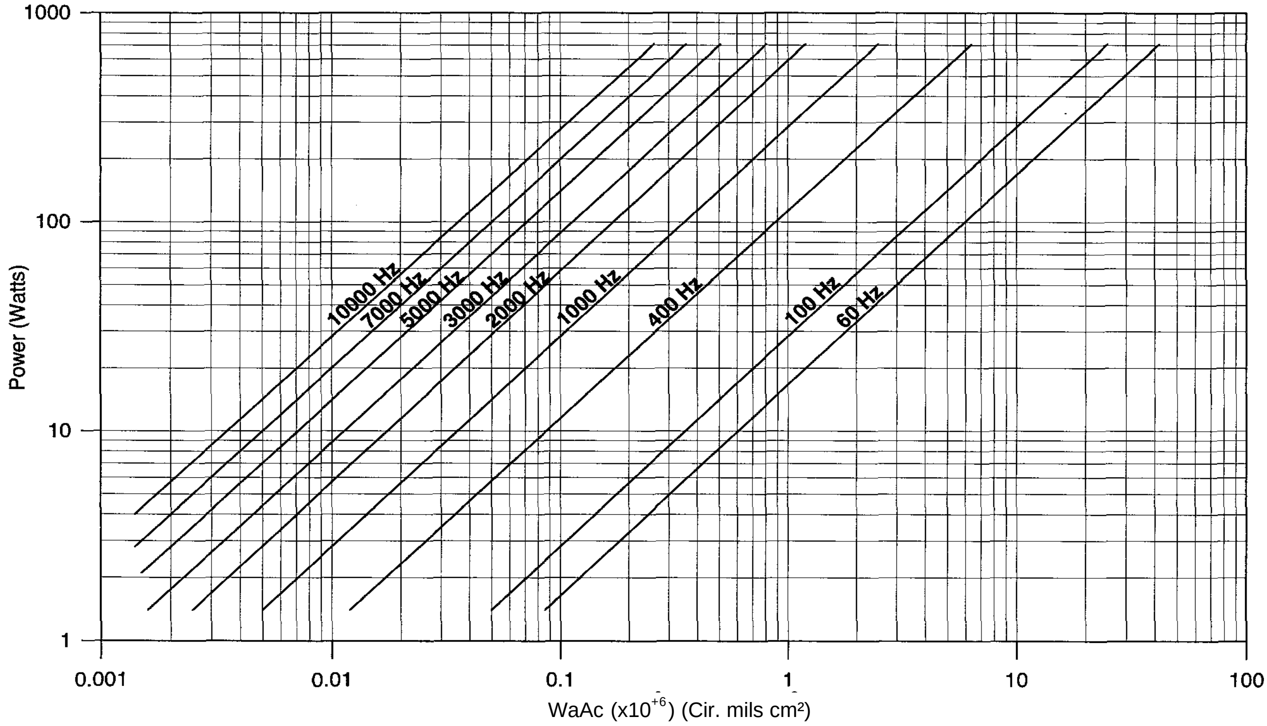
$$W_aA_c = \frac{8.25 \times \text{Power Output} \times 10^6}{f} \qquad \text{(Magnesil)}$$

$$W_aA_c = \frac{9.7 \times \text{Power Output} \times 10^6}{f} \qquad \text{(Orthonol)}$$

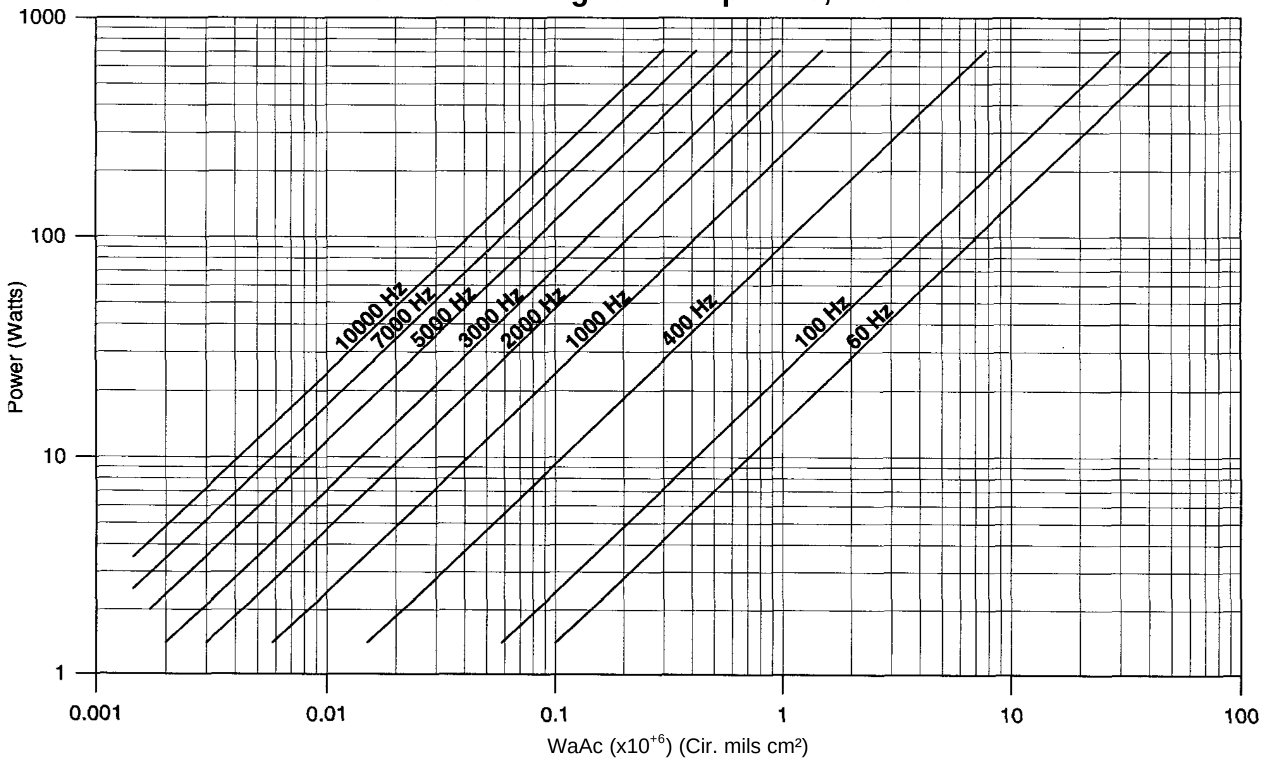
$$W_aA_c = \frac{20 \times \text{Power Output} \times 10^6}{f} \qquad \text{(Permalloy 80)}$$

To use the curves, the output power and operating frequency must be known. Select the proper frequency curve from the family of curves chosen. Read across from the power output to the intercept point on the frequency curve. Read down to the proper W_aA_c value. Refer to TWC-400 for the selection of the proper core by its W_aA_c.

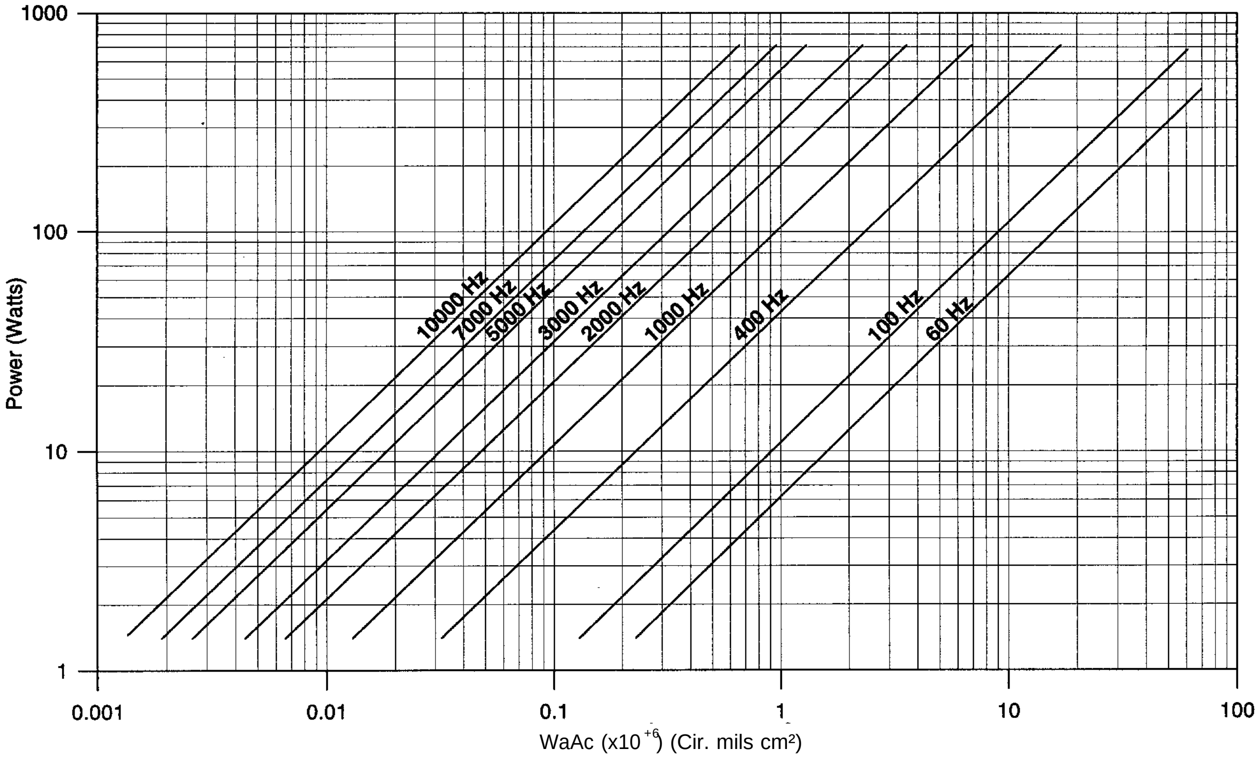
Magnesil - Magnetic Amplifiers, Reactors



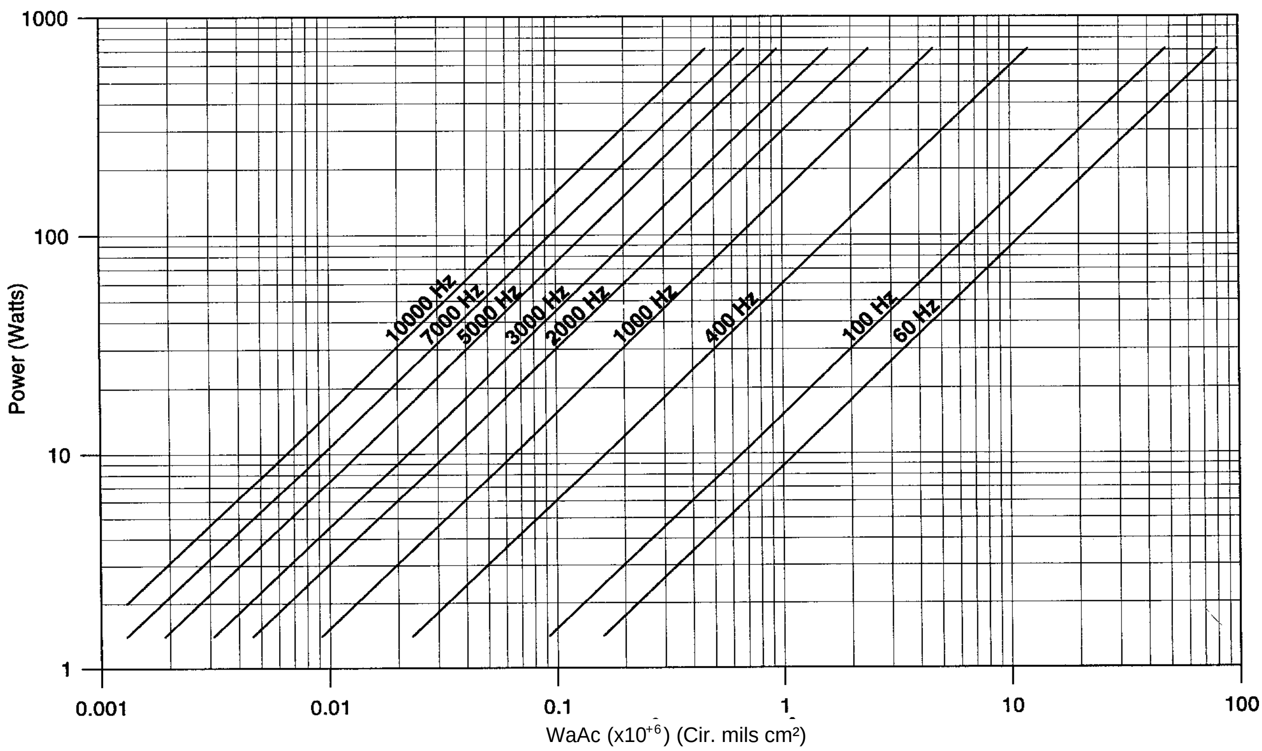
Orthonol - Magnetic Amplifiers, Reactors



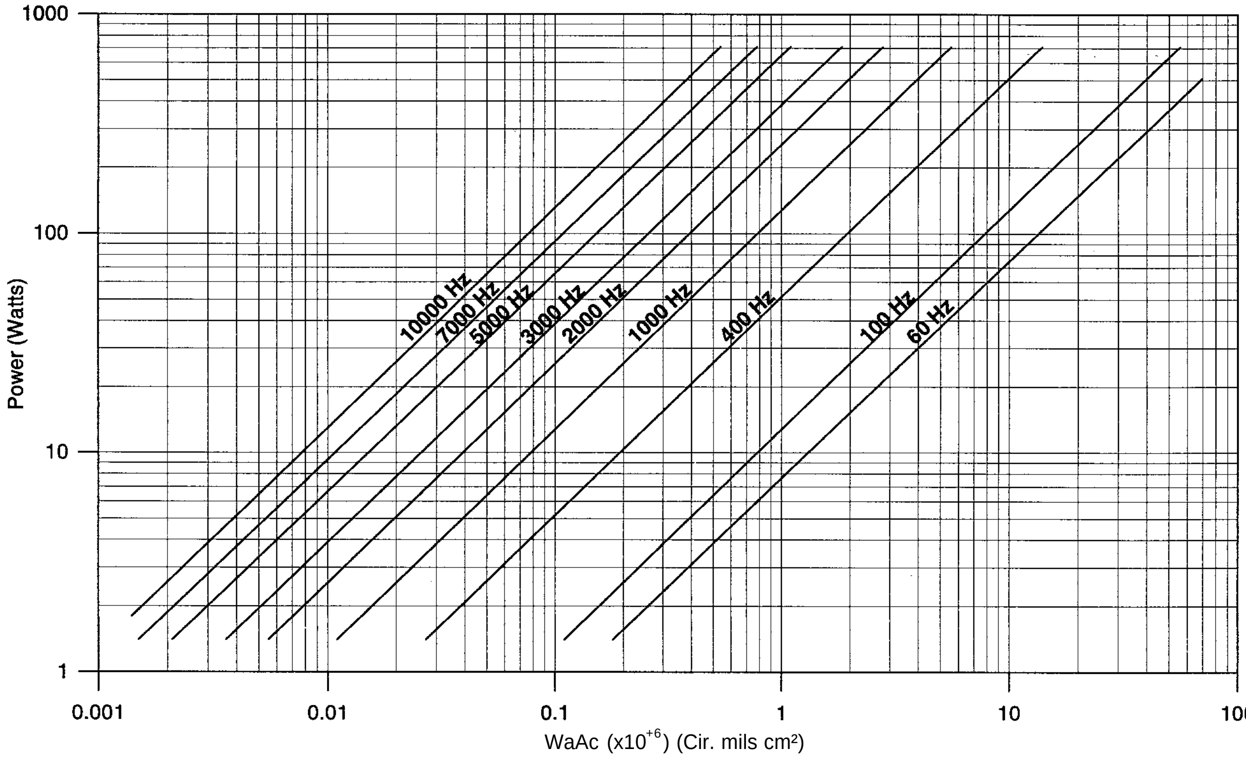
Permalloy 80 - Magnetic Amplifiers, Reactors



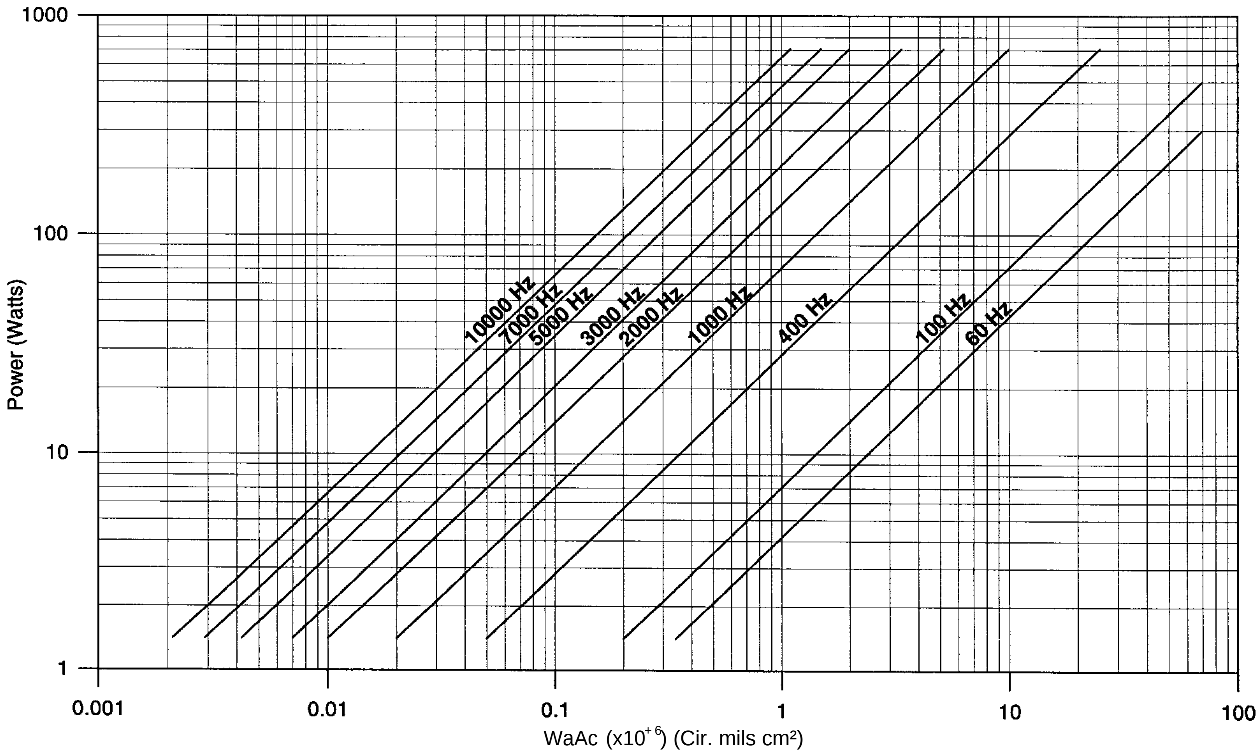
Magnesil - Inverters

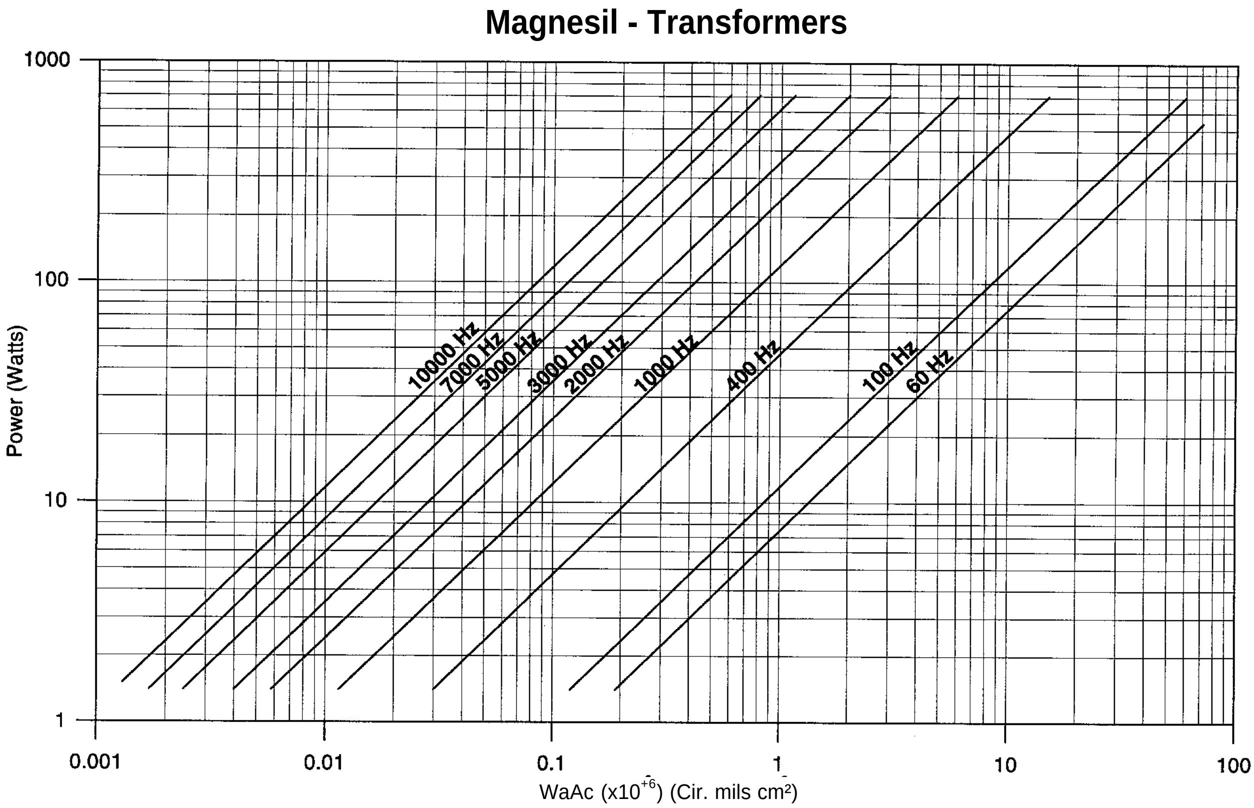


Orthonol - Inverters

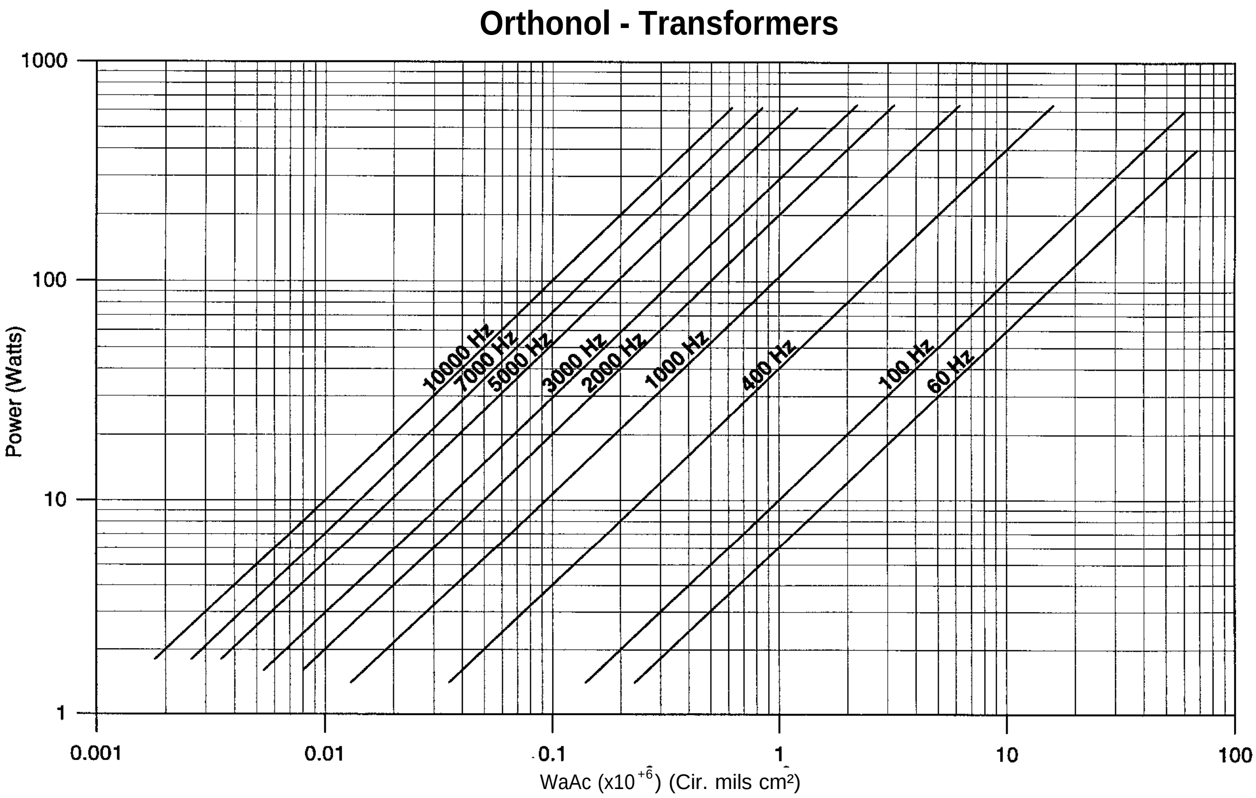


Permalloy 80 - Inverters



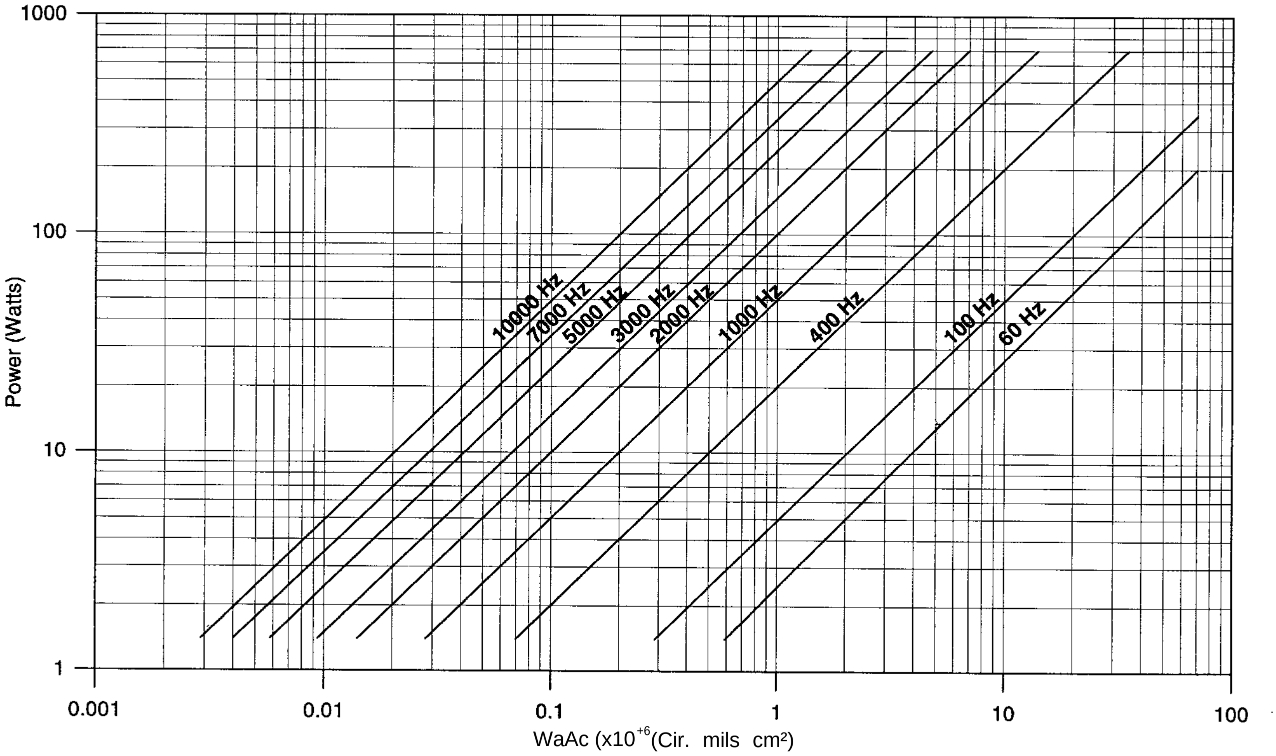


Magnesil - Transformers
1000
100
10
1
Power (Watts)
0.001
0.01
0.1
1
10
100
WaAc (x10+6) (Cir. mils cm2)
10000 Hz
7000 Hz
5000 Hz
3000 Hz
2000 Hz
1000 Hz
400 Hz
100 Hz
60 Hz



Orthonol - Transformers
1000
100
10
1
Power (Watts)
0.001
0.01
0.1
1
10
100
WaAc (x10+6) (Cir. mils cm2)
10000 Hz
7000 Hz
5000 Hz
3000 Hz
2000 Hz
1000 Hz
400 Hz
100 Hz
60 Hz

Permalloy 80 - Transformers



Magnetic Formulas & Conversion Factors

Faraday's Law: $E = N \frac{d\phi}{dt} \times 10^{-8}$

For Sinusoidal Drive $E = 2.22\phi N f \times 10^{-8}$

Where: E = volts
f = total flux change in maxwells
N= turns
f = frequency in Hertz

Relationships of various terms from Faraday's Law

1 Line	-	1 Maxwell
1 Weber	-	10^8 Maxwells
1 Gauss	-	1 Maxwell per sq. cm.
1 Weber per sq. cm. (tesla)	-	10^4 Gauss
1 Maxwell per sq. inch	-	0.155 Gauss
1 Webster	-	1 Volt-Second
1 Volt-Microsecond	-	10^2 Maxwells

Ampere's Law

$$H = \frac{0.4\pi NI}{Ml_1}$$

$$H = \frac{0.495NI}{Ml_2}$$

$$H = \frac{NI}{6.35 \times Md}$$

Where: H = magnetizing force in oersteds
N = turns
I = current in amperes
Ml_1 = mean length of magnetic path in centimeters
Ml_2 = mean length of magnetic path in inches
Md = mean diameter of toroid in inches

Relationship of various terms from Ampere's Law

1 Gilbert	-	0.796 Ampere-turn
1 Ampere-turn	-	1.257 Gilbert
1 Gilbert per centimeter	-	1 Oersted
1 Ampere-turn	-	0.495 Oersted
1 Oersted	-	2.02 Ampere turns per inch
1 Ampere-turn per centimeter	-	0.796 Oersteds
1 Oersted	-	1.257 Ampere-turns per cm.

A Division of Spang & Company

HOME OFFICE AND FACTORY
P.O. Box 391
Butler, PA 16003
FAX: 724-282-6955
Phone: 724-282-8282
1-800-245-3984
e-mail: magnetics@spang.com
www.mag-inc.com

MPP Powder Cores • High Flux Powder Cores

KOOL MU® Powder Cores

Tape Wound Cores • Bobbin Cores

Ferrite Cores

Custom Components

Printed in USA • TWCX-S1 6H