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MEASURING SOFT FERRITE CORE PROPERTIES

George G. Orenchak

Ferrite International Company
Wadsworth, IL 60083

ABSTRACT

Methods used to measure various electromagnetic properties of soft ferrite cores are presented. Needed formulas, calculations, equipment and circuits are examined.

INTRODUCTION

Soft ferrites are ceramic electromagnetic (magnetically soft) material primarily used as cores for high frequency inductors and transformers. The cores are wound with turns of wire or assembled around coils of wire to make inductors or transformers. Soft ferrite materials have many important electromagnetic properties that need to be measured and/or calculated.

INDUCTANCE

Inductance is the circuit property that opposes any change in current. Soft ferrite manufacturers for each core size publish inductance index (AL), which is inductance per squared turn. Users test cores by measuring inductance and dividing by the squared turns on their coil. The inductance index (AL) of a given core is dependent on the material permeability and the core dimensions and shape. Permeability is the ability of a material to conduct magnetic flux relative to the ability of air to conduct magnetic flux. The core dimensions and shape determine the cores' effective cross sectional area (Ae) and its effective magnetic path length (Le). An air core inductance (Lair) can be calculated as follows:

$$\text{Lair} = (0.004\,\Pi\,\text{Ae}\,10^{-6})/\text{Le in Henries}/N^2$$

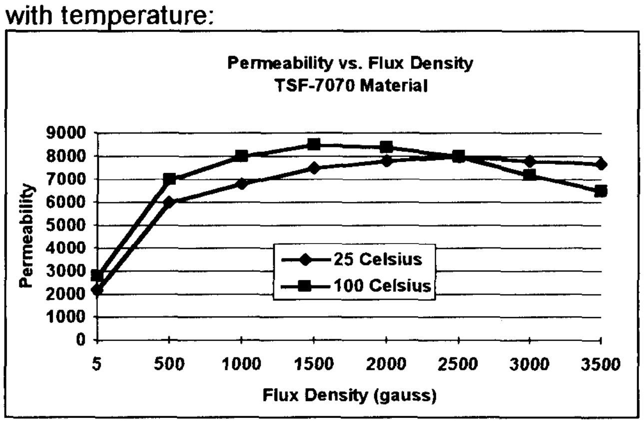
Ae = effective cross sectional area in cm^2
Le = effective magnetic path length in cm
N = number of turns on coil

Permeability can be calculated as follows:

μ = AL / Lair
μ = Permeability
AL = inductance index in $^{nH}/N^2$
Lair = air core inductance in $^{nH}/N^2$

Inductance is a relatively simple property to measure. It can be measured on all shapes and size cores with or without air gaps. Typically, it is measured at low flux densities ($\leq$ 5 gauss) using an LCR meter with variable voltage and frequency such as an HP4275 or equivalent. Wayne Kerr model 3245/F inductance analyzer with a 3210/3211 AC extension or a General Radio 1630 bridge can be used to measure inductance at high flux densities and Wayne Kerr model 3245 with 3220 DC bias unit or equivalent can be used to measure inductance with a DC bias.

Figure 1 shows permeability versus flux density with temperature:



Permeability varies with flux density and temperature, hence the measured inductance also changes with changes in flux density and temperature. Therefore, the flux density and temperature must be controlled. To calculate the test voltage for a given flux density, the following formula is used:

$E = 4.44\ f\ N\ B\ Ae\ 10^{-8}$
f = frequency in Hz
N = number of turns
B = flux density in gauss
Ae = effective core area in cm^2

Typically, inductance measurements are made at room temperature. Occasionally, in production plants that are not air conditioned, or if product is measured too soon after being stored in cool areas before it is allowed to warm to room temperature, the inductance measurements can falsely appear to be out of specification. Temperature chambers can be used to assure measurements are made at consistent temperatures. Temperature chambers are also used to measure permeability versus temperature up to the curie temperature where the material becomes paramagnetic (non-magnetic).

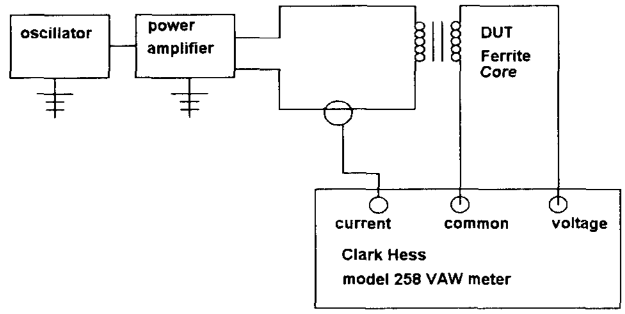
Because ferrite materials are magnetostrictive, mechanical stresses affect changes in their magnetic parameters. At Ferrite International, we have found that clamping pressure of 5 pounds per square inch of mating surface is ideal. Too little pressure results in an undesirable air gap between mating surfaces while too much pressure causes the permeability to drop because of the magnetostriction.

Gapped ferrite structures exhibit a winding dependency due to fringing flux intersecting the coil. Inductance index measured on the same gapped core set, but with different coil constructions or different number of turns, might exhibit differences of more than 20%. It is important that manufacturers and customers of gapped cores measure the inductance on coils of the same construction and turns.

CORE LOSS

Core loss is a measure of the efficiency of a material at high levels of magnetizing force. Core loss is dissipated electrical power which turns into heat inside a core when a magnetic field which varies with time is applied on the core.

Figure 2 shows a circuit for measuring core loss:



The equipment list is as follows:

Function Generator - HP 3225B or equivalent
Power Amplifier - ENI 2100L or equivalent
VAW Meter - Clark Hess model 258
286 PC for automation control and data collection

PROCEDURE

1. Set Oscillator frequency 10 KHz to 1 MHz.
2. Increase the oscillator amplitude until the desired voltage ($E = 4.44\ F\ N\ B\ Ae\ 10^{-8}$) is measured on the VAW meter.
3. Switch and read power in watts from the VAW meter.

Core loss is typically measured under sine wave conditions because sine wave is the worst case resulting in the highest core losses when compared with square wave measurements.

The VAW meter internally calculates power by multiplying $E\ I\ COS\ \theta$ and displays power in watts on its digital display. If sufficient wire size is used, the losses of the winding are insignificant and the voltage can be measured across the primary. The secondary, in the circuit in Figure 2, can then be eliminated.

Samples must be ungapped, because it requires too much power to drive gapped cores. A gap also causes higher winding losses and therefore the measurement of the power loss of the gapped transformer is high. The loss due to the winding is not easily separated from the loss due to the core.

Figure 3 shows core loss versus flux density:

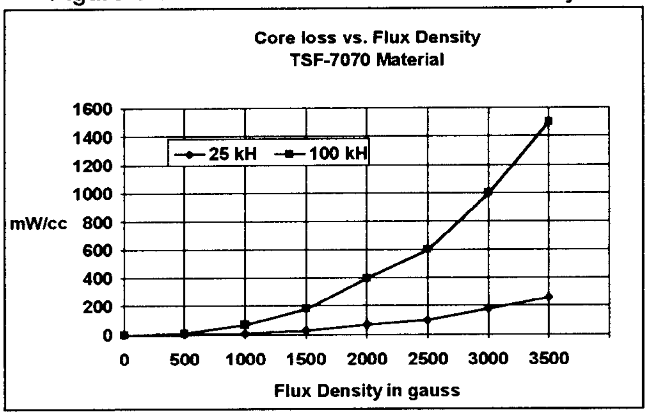


Figure 4 shows core loss versus frequency:

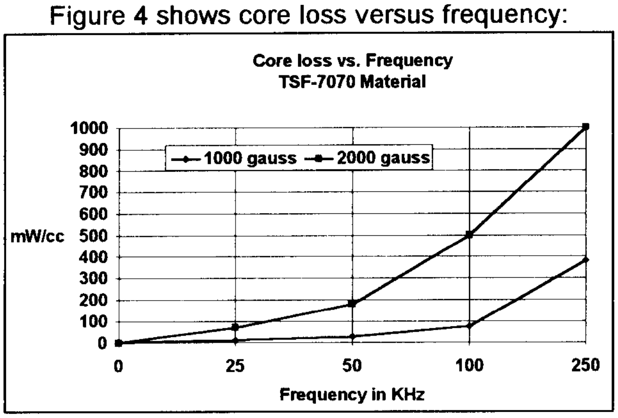
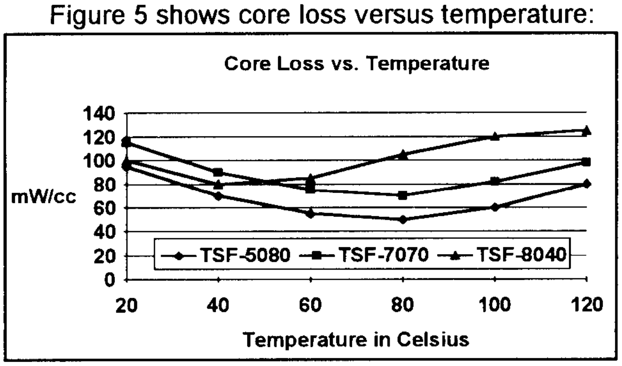


Figure 5 shows core loss versus temperature:



Core loss varies exponentially with changes in flux density. Therefore, samples must have uniform cross sectional areas throughout their magnetic path lengths. Measuring core loss on cores with non-uniform cross sectional areas is not accurate no matter if effective cross sectional areas are used or minimum cross sectional areas are used, because the flux density throughout the path length is not controlled.

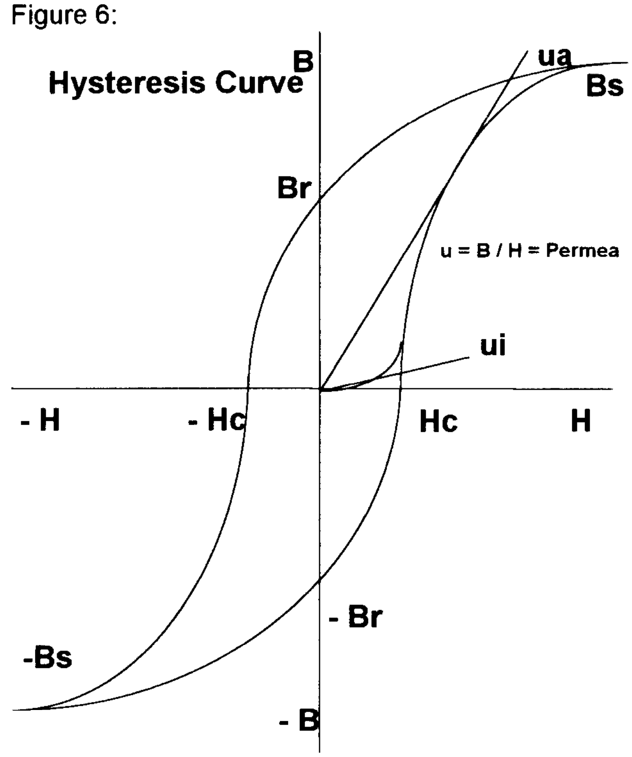
As can be seen from examining Figure 5, core loss varies significantly with changes in temperature. Therefore, temperature chambers are used. Cautions must be taken to assure that the long test leads do not introduce impedance, especially at high frequencies.

Clamping forces affect core loss. Pressures of 5 pounds per square inch of mating surface area is ideal. Too little pressure results in an undesirable air gap between mating surfaces, while too little pressure causes high core losses because of the magnetostriction.

HYSTERESIS CURVES

Hysteresis curves show the relationship between a magnetizing force (H) and the resultant magnetic induction (B)

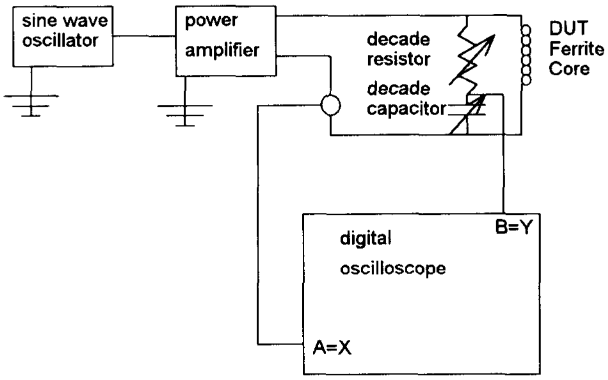
Figure 6:



Saturation flux density (Bs) is a material's maximum magnetic induction. Saturation can be seen in quadrant 1 of the Hysteresis curve. When increases in magnetizing force (H) no longer cause significant increases in magnetic induction (B), the material is said to be saturated.

Residual induction (Br) is the remaining magnetic induction after the magnetizing force (H) has been reduced to zero. Coercive force (Hc) is the magnetizing force required to reduce the magnetic induction in a magnetic structure from Br to zero.

Figure 7 shows the circuit diagram for measuring hysteresis curves:



The equipment list is as follows:

Function generator
Power Amplifier
Digital dual channel storage oscilloscope with current probe

The field strength H is changed by varying the current, which is sensed by the oscilloscope's current probe.

$H = 0.4 \Pi N Ip/Le$ in oersted
N = winding turns
Ip = peak current in amps
Le = effective magnetic path length in cm

The current, due to an alternating sine wave, is continually varying.

The flux density in the core is determined by integrating the secondary voltage.

$B = Vp C R 10^8/N Ae$
Vp = peak voltage
C = capacitor in farads (typically 1.0 μf)
R = resistor in ohms (typically 10.0 kΩ)
N = winding turns
Ae = effective core area in cm^2

The voltage must be integrated, because the voltage wave form distorts as the core saturates. For this an integrating oscilloscope is recommended. If an integrating oscilloscope is unavailable, the integration can be accomplished by using an RC circuit like shown in Figure #7 or an operational amplifier circuit.

IMPEDANCE

Impedance is the total opposition in ohms (resistance and reactance) to the flow of alternating current at a given frequency. Impedance is an important property for components intended to suppress unwanted frequencies. Impedance is a simple property to measure using an Impedance Analyzer such as HP 4191A with test fixtures 1692A and 16093A. Typically, cores are measured with a single turn. Test wires should be kept as short as practical. The Impedance Analyzer will give a direct reading of impedance.

CONCLUSION

The difficulty of measuring the properties of soft ferrites range from simple to impossible, based on the desired property attempting to be measured and the configuration and size of the core sample. Careful attention must be given to clamping forces, flux densities and temperature in order to avoid inaccuracies.