Incoming Inspection Testing on Soft Ferrite Cores

A Practical Guide

By Gary Van Schaick

Ferrite Applications Engineer

Over the past 30 – 40 years, the applications for soft ferrite and the technology of the soft ferrite has changed considerably. In the 1970s, we were more concerned with ferrites for touch tone telephones, tuned filters and ferrite applications requiring controlled inductance over various temperature ranges. Switch mode power supplies were not well known and ferrites designed for switch mode power supplies were not yet developed. Switching frequencies as they were rarely exceeded 50KHz. Controlling power losses as a function of core temperature was not known. Today, most soft ferrites are used in some power variation of power application and ferrite is being developed to run at 1 – 3 MHz.

And in all this time, the requirement and procedures for incoming inspection has not changed. Paperwork has changed and become more involved, we have seen x-bar control charts, 6-sigma inspections and Cpk calculations. But the actual inspection has not changed. In the 1980s, I was responsible for setting up the incoming inspection for many ferrite users. So, this practical guide is based on these years of involvement. I will try to stay away from minute detail but will discuss primarily test conditions including:

- A_l Value
- Core preparation
- Inductance meter- Lead length on the test coil
- Test coil preparation
- Number of turns on the test coil
- Test Voltage/current
- Test frequency
- Core pressure

Ferrites can be characterized into two (2) classifications for testing purposes, toroids and cut cores, cut cores being any core that two pieces to be placed together to complete the magnetic path. Toroids and cut cores react slightly different to test conditions because the toroids have no air gap and the cut cores have what sometimes is referred to as residual air gap, that air gap that remains after the mating surfaces have been ground. There is a difference in the grinding of the mating surface depending on the permeability of the core and the application. High perm cut cores, 5K perm and above usually need a polished mating surface to achieve the related inductance. Power material does not, usually, need the polished mating surface and in some applications, benefits from the small air gap. The actual air gaps of these two grinds are:

- Polished mating surface ~ 1 µM ~1600 grit polishing wheel
- Standard mating surface ~ 10µM ~400 grit grinding wheel

There are usually only two (2) tests done at incoming inspection, a physical inspection for chips and cracks and the electrical test for inductance / A_ℓ value. Chips and cracks are allowable and there are specifications for the size and number of chips and cracks. This article will look more at the electrical test.

Permeability, Al value and inductance – Permeability is defined, as simply and practically as possible, as the ease at which flux flows. Of course, there are much more scientific definitions including throwing in permeability of free space and relative permeability. Permeability is interpreted for our purposes as initial permeability μ_i and is the slope of the β*H curve measured on the initial curve (often stated as virgin curve) at β~0.1mT. A_ℓ can be interpreted as the representation of the permeability and again measured under very low flux levels. A_ℓ value is an index with the units of nH/N^2. For the A_ℓ, low β levels are then defined as <0.5mT or <0.25mT, depending on the ferrite manufacturer. There is no standard used. And this starts one of the first problems I find with incoming inspections. Some companies want to establish incoming inspection values at higher β levels that the manufacturer establishes, this is not considered as an A_ℓ value but better relates to Amplitude Permeability.

I am giving the formula here, which probably all engineers know, but I have found many incoming inspectors in China and in the U.S., do not.

- $L = A_\ell * N^2$

To directly relate the μ_i to the A_ℓ, we have the following formula:

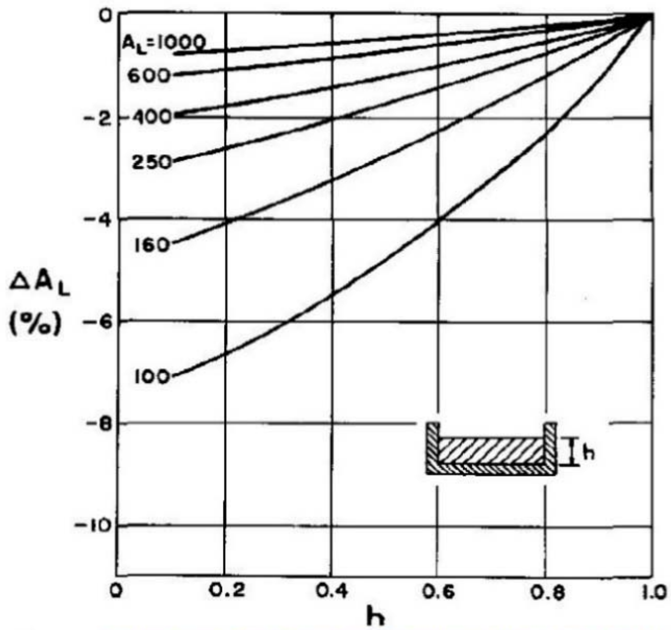
- $L = 0.4\, \pi\, \mu_i\, N^2\, 10^{-8}/C_1$

C_1 = Core Constant in cm^{-1}, these values are given in manufacturers catalogs.

CORE PREPARATION: Ferrite cores are washed at the factory and then packed and moved to the warehouse. The cores are shipped via boat or aircraft, go through incoming inspection and then into a storage warehouse. No matter how good cores are packed, there is always the possibility for ferrite dust to accumulate on the mating surface of a core. And there is the everpresent air pollutants and people handling the cores where finger prints get on the mating surface. Cleaning the cores prior to testing is appropriate. The recommended method of cleaning the mating surfaces is very simple. I have seen ultrasonic cleaners and other chemical wipes used however these methods can adversely affect the core performance. The simple method to clean the mating surface is to dry wipe the mating surfaces on a clean, white bond (copier) paper. Next is to place the test coil into the two halves of the cut core. Upon placing the test coil into the two halves, twist the two cores together effectively rubbing the mating surfaces together in a circular or elliptic arc. This is called “wringing in” the cores. Then it is necessary that before clamping/putting the pressure on the cores, that the mating surfaces be perfectly aligned. The mating surfaces out of alignment can drop the testing values.

INDUCTANCE METER: The requirements are relatively simple for the inductance meter. The inductance meter needs to have variable voltage/current and frequency capabilities. The usual meter is the HP4274A – HP4284A or equivalent. Some meters rely only on variable voltage but these can be used. In today’s configurations, having a test frequency up to 1 MHz may be required. An item that is critical is the ability to “zero” out the effects of the meter’s circuitry and external test leads so that the only inductance the meter is displaying is the inductance of the test core. The 4274A has an open circuit and short circuit “zero” that needs to be done at the start of every test action. The short circuit “zero” becomes more critical when the test leads from the core under test are long. Every wire carrying an AC signal has an electromagnetic field which can affect the display of the inductance of the test core. If the leads to the test core are long, the wire during the “short circuit zero” also must be just as long. An understanding of the internal test circuit is also a must. Test equipment has series resistance and parallel resistance that it uses in its automatic testing, varying the resistance to keep measurements within prescribed limits.

TEST COIL: There are some points to keep in mind when producing test coils. There should be multiple test coils made however those test coils need to be compared to make sure the test coils are all the same. The ideal test coil will have a 100% fill however 80% fill of the winding area is considered good. I have though seen many ferrite users, machine shops and even ferrite manufacturers use something closer to a 50% fill. In most cases, there is no problem. However, if the requirement is a gapped core to a +/-3% tolerance, the construction of the coil could easily become critical. There are charts on the internet showing the effect of a partially filled window area, one such graph is below. You can imagine that at some point it could be extremely critical that the manufacturer or machine shop uses the same test coil as the ferrite user. Therefore, many machine shops grinding ferrite and ferrite manufacturers are requiring customer coils for critical gapping of the ferrite cores.



Inductance Deviation as a function of Winding Height

NUMBER OF TURNS-FREQUENCY-VOLTAGE/CURRENT: Varying the number of turns, the test frequency and the test voltage/current has the ultimate effect of changing the flux which changes the inductance. The usual formula given is:

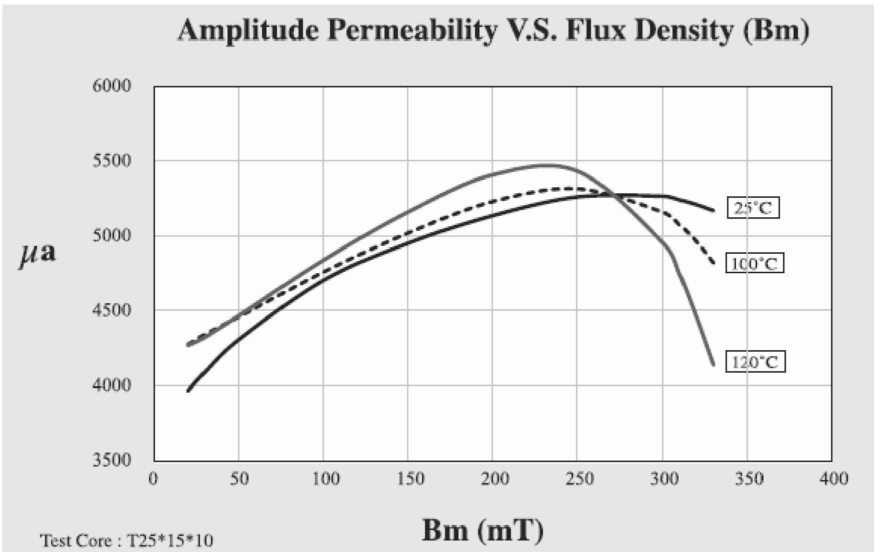
$$L = N\frac{\Phi}{I}$$

Some ferrite manufacturers establish their standard for inductance based on the current to be used to measure inductance, usually 0.5mA. The original theory was that by establishing a current for the standard for measuring inductance, the flux pattern is well established and stabilized throughout all the manufacturing process and over all the different shapes and sizes of ferrite cores. Other standards, employed by most machine shops and ferrite users establish a test voltage as a standard. There are few LCR meters on the market that have the capability of using a current as the test signal but all LCR meters have the capability to establish a voltage as a test signal. The formula when using voltage as the test signal is:

- $E = 4.44\ f\ N\ \beta\ A_e\ 10^{-6}$

f = frequency (KHz): N = Number of turns: B = Flux density (mT): A_e = Effective core area (cm^2)

A difficulty in this formula is the β, flux density. With the definition of A_ℓ value, it is required that the β be low, < 0.5mT or <0.25mT. By keeping the β at a fixed number, this would require the voltage to change as the frequency, number of turns or A_e changes. However, in practice, companies establish a fixed test voltage so we would have to solve the equation for β to see how the β would change. And then we must understand and account for the changing β resulting in a change to the inductance. When the flux level rises above the "LOW" value, the definition changes from Initial Permeability to amplitude permeability and the resulting inductance levels change accordingly.



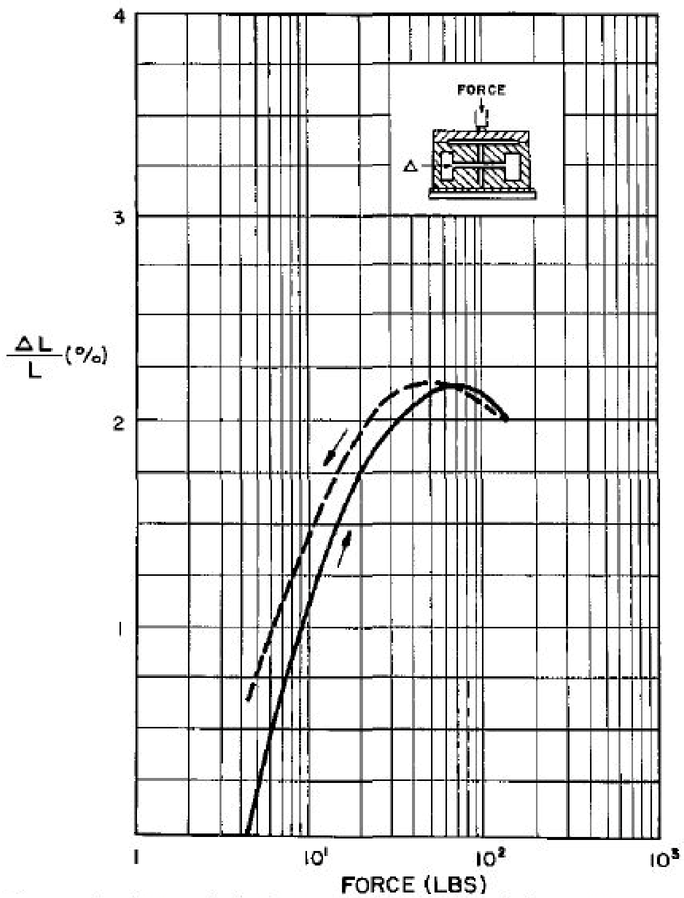
Here is a graph of the ACME P45 wide and power material that demonstrates the increasing flux density.

PRESSURE - MAGNETOSTRICTION - VILLARI: The last element to consider in this paper is the pressure on the core including mounting pressure, winding pressure and coating pressure. The pressure is a major issue as you will see in the simple tests. However, we must first discuss pressure to understand how pressure can affect the inductance. Ferrite is Magnetostrictive. This means that ferrite cores can change their shape or dimensions during the magnetization process. The ferrite core can expand. Because of this characteristic, mechanical stresses on the ferrite can affect changes in the magnetic parameters including the initial permeability. This change to the magnetic parameters is known as the Villari effect. But where do the stresses come from? Stresses likely to cause problems come from a few potential sources.

- Mounting clips pressure and location of the pressure
- Winding pressure of the windings on a toroid
- Stacked toroids with no cushioning between the cores
- Varnish or potting compounds on the ferrite cores

The stresses in the cores does not come from the mechanical changes of the core but come from the pressure source constricting the cores, preventing the cores from changing even localized area of the cores. A varnish or potting compound that shrinks onto the core puts pressure on most of the volume of the core where as a particularly tight winding on a toroid puts pressure on a localized area of the core but the net effect is the comparable.

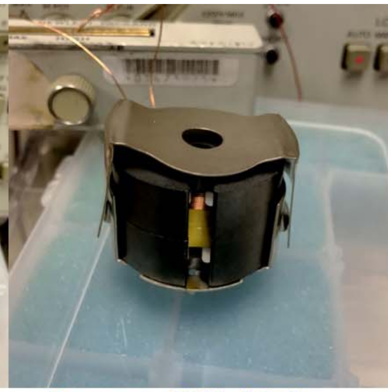
Taking an example of the mounting pressure of a P36/22 in a power material, we see a graph such as the below graph readily available on the internet.



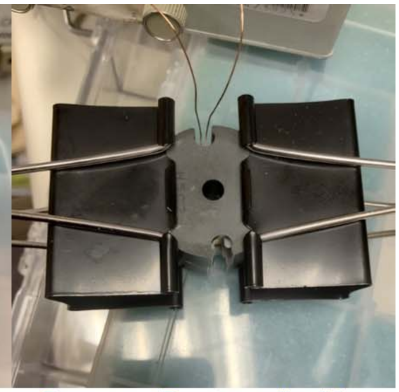
Change in Inductance verses Change in Mounting Pressure in P36/22

The interpretation of the graph is that the inductance of the test will increase as the mounting pressure increases, but up to a point. There is some point where if the mounting pressure increases too much, the inductance will decrease quickly. I have made some quick measurements using a couple of the common pressure devices for testing.

Pressure 1Kgm Weight
100 turns
0.5mA @ 1KHz
L = 333mH



Pressure TDK -6Cclip
100 turns
0.5mA @ 1KHz
L = 391mH



Pressure Boston clip #4
100 turns
0.5mA @ 1KHz
L = 436mH

The specification of the H5C2P36/22Z-52H is 390mH with 100 turns @ 0.5mA and 1KHz. I used the Boston #4 paperclip because I find many ferrite users that love using these clips. This clips are quick to mount and unmount. But as you can see, they can put an increased amount of pressure on the core beyond the normal pressure.

One other item when considering mounting pressure of the cut core comes in to play when there is a gapped core (center leg gap). If the mounting pressure of the clip is centered too much on the center leg, the pressure can deflect the center leg, causing the air gap to be reduced and of course giving a false inductance reading.

In a couple of months, I will be releasing one more basic paper concerning gapping of ferrite cores, mechanical verses electrical tolerances, factory machining verses grounding house machining and other areas of interest. Any comments, let me know.

Gary Van Schaick worked as Soft Ferrite Product Manager at Ferroxcube Division of Amperex in Saugerties, NY from 1981 – 1985. He has worked at the Ferrite Division of MH&W International since 1985 in the positions of Applications Engineer, Product Manager, Regional Sales Manager, Vice President of Sales and Engineering and Vice President of Engineering. His email address is garyv@mhw-intl.com