Evaluation of Several Factors Affecting Inductance Measurements of Ferrite Components

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Introduction

Making inductance measurements on wound components is basically a rather straightforward procedure. However, we often have found that there are several factors which can influence inductance measurements that are not always recognized.

In accessing these parameters, we will pay particular attention to their relationship upon ferrite components. As will become clear, some of these conditions will apply to all magnetic components, while others are peculiarly applicable to wound ferrite components.

In our discussion, we will emphasize the power applications of ferrite components such as in switched-mode power supplies.

'nductance Factor (A_L) and Permeability

It has been common practice for years to quote for ferrite components the inductance factor A_L[1]. This specifies for a particular ferrite core or core set and ferrite material, the inductance in nanohenries per turn[2].

$$L = A_L N^2 \text{ where L is in nanohenries or}$$
$$L = A_L N^2 10^{-9} H \quad (1)$$

Another formula to calculate the inductance of a magnetic component is:

$$L = \frac{.4\pi\mu N^2 10^{-8}}{C_1} \ H \quad (2)$$

C_1 core constant in cm^{-1}

In formula 2, the permeability μ can have different interpretations. In ferrite components this nearly always refers to initial permeability μ_i, which per definition is the permeability at low levels of exitation $B \approx 1$ gauss.

The A_L value also is tested for the same test condition as for initial permeability, low flux density. In situations where the inductance factor requires test conditions well above ≈ 1 gauss, the test conditions would have to be defined as part of the procedure.

The permeability of a ferrite material when tested at flux density levels above 1 gauss are referred to as amplitude permeability μ_a.

Figure 1 shows a typical relationship of amplitude permeability versus flux density with temperature as the parameter for 3C8, a power ferrite material. It is clear that temperature and flux density will change the permeability ɔf a ferrite material, hence change the inductance meaɜured.

The first parameter to control in the inductance measurement of a ferrite component is the flux density. To calculate the flux density or to determine the test voltage this formula can be used:

$$E = 4.44 f N B A_e 10^{-8} \text{ Vrms} \quad (3)$$

f = Freq in Hz
N = Number of turns
B = Flux density in gauss
A_e = Effective core area in cm^2

To check the inductance of a wound ferrite component based upon specified A_L value and number of turns, it is necessary that the test voltage is of such magnitude that it results in the proper flux of ≈ 1 gauss. It also is evident from figure 1 that temperature can influence inductance measurements. For most power applications, inductance measurements will be performed at room temperature. Any deviations from testing at room temperature and at ≈ 1 gauss will require careful definition of the test parameters, temperature, and flux density.

Pressure Versus Inductance

Ferrite materials are magnetostrictive. Because of this characteristic, mechanical stresses upon the ferrite can affect changes in its magnetic parameters such as initial permeability. This phenomena is known as the Villari effect.

Figure 2 shows the percentage change in initial permeability μ_i as a function of applied pressure. The ferrite material is a MnZn 3B7 and is constructed without any

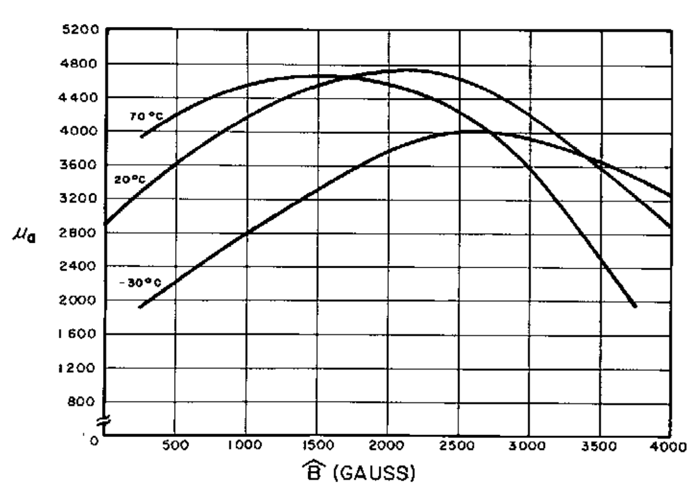

Figure 1, amplitude permeability as a function of peak flux density with temperature as parameter. Material: 3C8.

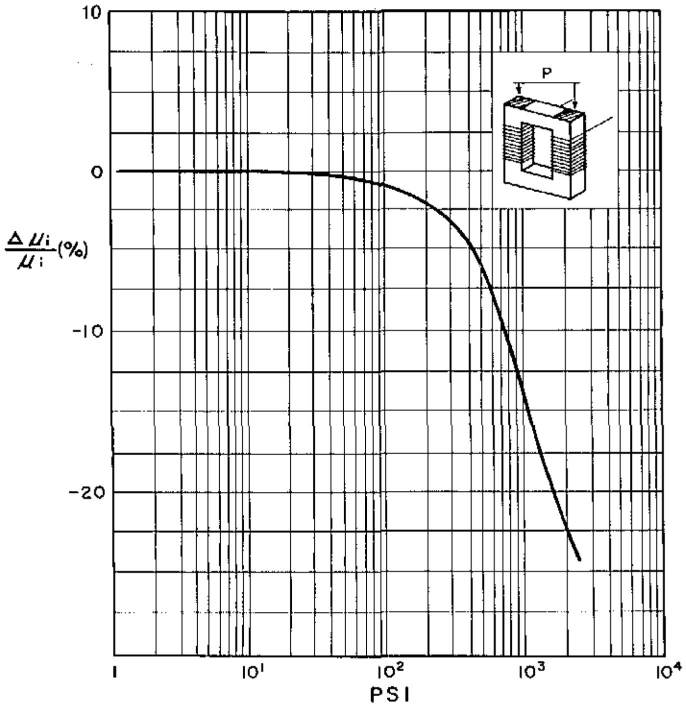

Figure 2, change in initial permeability as a function of applied pressure. Material: 3B7.

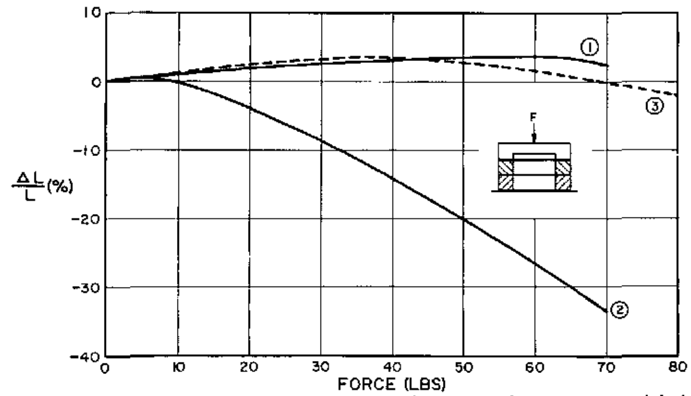

Figure 4, measured inductance changes in two toroidal cores, 846T250-3E2A.

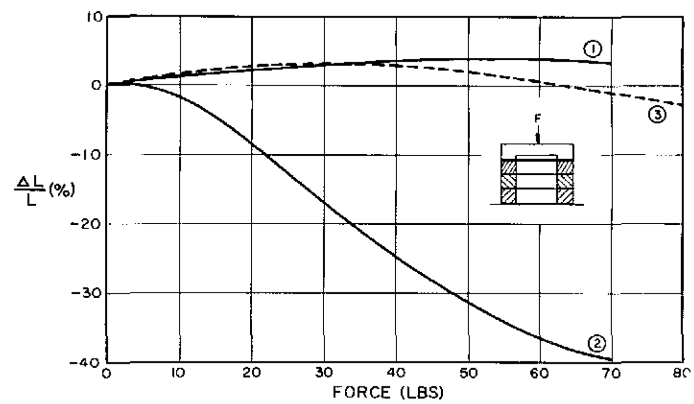

Figure 5, measured inductance changes in three toroidal cores, 846T250-3E2A.

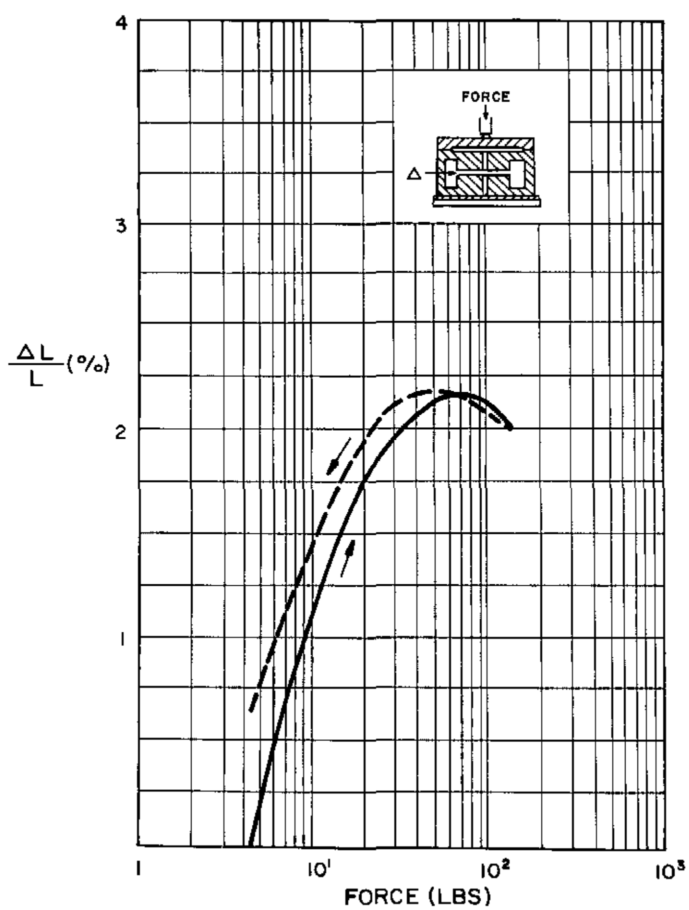

Figure 3, change in inductance in a gapped 3622 pot core as a function of the clamping force.

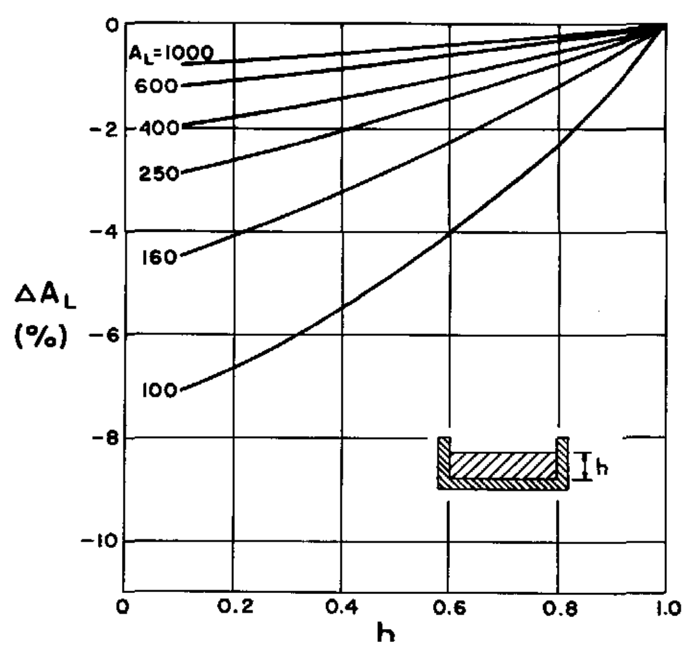

Figure 6, inductance factor deviation as a function of winding height for the 2616 pot core.

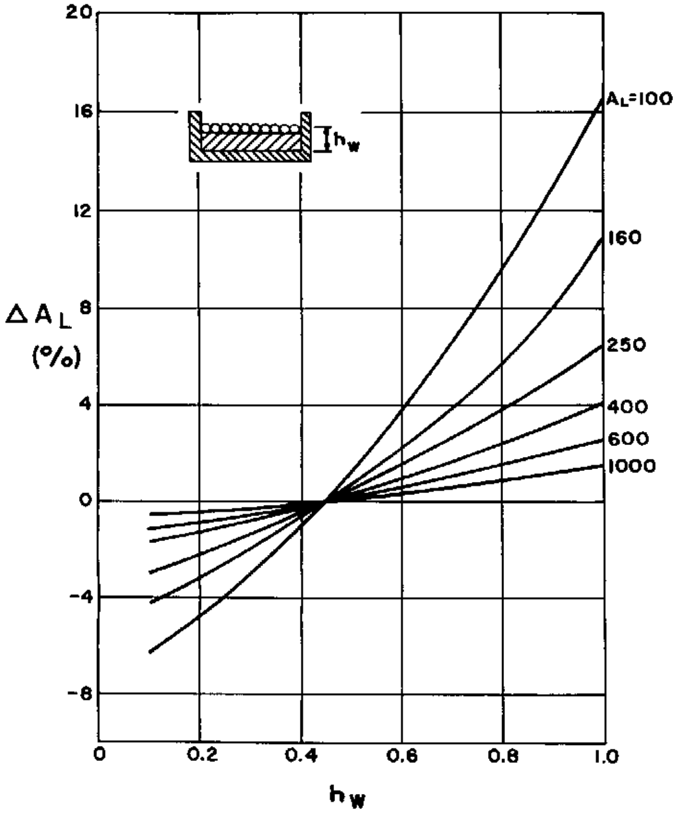

Figure 7, inductance factor deviation as a function of the location of a single-layer winding in the 2616 pot core.

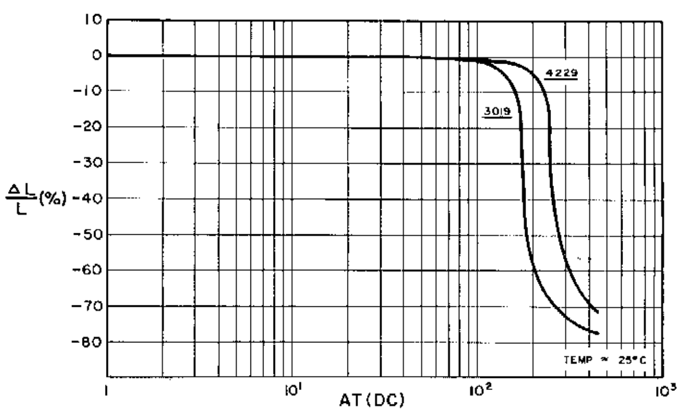

Figure 8, inductance change as a function of DC ampere-turns. Pot cores 3019 and 4229 gapped to μ_e = 75.

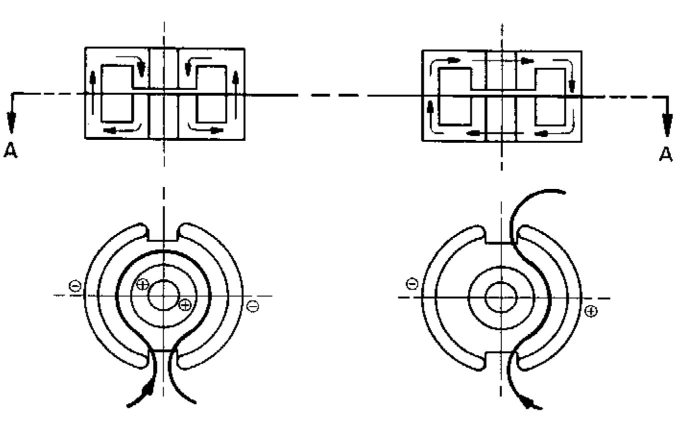

Figure 9, flux paths in a gapped pot core for integral turns (A) and fractional turns (B).

air gap in the magnetic circuit[2]. If an air gap is present in the magnetic circuit, and this will always be the case when two cores are used to form the magnetic circuit, we can observe an increase in inductance at relatively low clamping pressures.

Figure 3 gives the increase in inductance as a function of the clamping force for a 3622 pot core with an μ_e = 500[2]. The change in inductance is due to a reduction of the length of the air gap. The proper clamping force for a gapped 3622 pot core is approximately 50 lbs. or ≈ 150 PSI.

Cores that are impregnated or encapsulated can exhibit a significant drop in inductance after potting, which is due to the Villari effect[3]. The pressures involved here, however, are in the order of 1000 PSI or higher.

For certain applications, it is quite normal to use two or even three toroidal cores in parallel. Taping these cores prior to winding is often standard procedure. Yet this seemingly simple operation can cause an unexpected and undesirable decrease of inductance.

Figures 4 and 5 demonstrate what is happening. The toroidal cores used in these experiments are our 846T250-3E2A (OD .870, ID .540, and HT .250; 3E2A μ_i = 5000). Each toroid is clamped between rubber pads and the clamping force is increased while periodic inductance measurements are made. Curve 1 in figures 4 and 5 represents the average value of two and three cores respectively. Now cores 1 and 2 were clamped together and the force was again applied, which resulted in curve 2 of figure 4. The same procedure was followed with three toroids, curve 2 of figure 5. We find large changes in inductance at very modest levels of pressure of ≈ 150-200 PSI. This cannot be explained due to the magnetostriction of the material since this is about a factor 10 lower than the pressures where the Villari effect becomes significant. We felt that this change in inductance which we observed was probably caused by the fact that toroids are not perfectly flat, causing large pressures in localized small areas. To test this theory, we repeated the same tests with the two and three toroids, but we now placed rubber washers between the toroids. Curve 3 in figures 4 and 5 showed the test results for this combination completely restoring the original individual core data.

Winding Dependency

In gapped ferrite components, such as pot cores and E cores, we observe a winding dependency. If a bobbin is wound with a winding that occupies substantially less than the total winding area, the measured inductance will deviate from the expected, calculated inductance[4].

Figures 6 and 7 give, for a 2616 pot core, the magnitude of these deviations. Since the tolerance on low-inductance factors can be as low as ± 1%, the possible deviations are large when compared with this tolerance. This is particularly the case with single-layer windings, where depending upon their location in the bobbin and A_L value, we might find differences of more than 20% in measured inductance values (figure 7).

Inductance and DC Bias

It is a well recognized phenomena that the presence of a DC pre-magnetization in a magnetic component easily can influence measured inductance values. Since ferrites have relatively low saturation flux densities, they are more susceptible to DC bias than some other materials.

Figure 8 shows, for two gapped pot cores, the change in inductance as a function of the DC ampere-turns. Both cores are pre-adjusted for the same effective permeability of 75. The 4229 core, which is larger than the 3019 core, will be able to support larger values of DC ampere-turns.

Fractional Turns

In magnetic designs using E cores or pot cores, it is possible to use fractional turns. When this is done on gapped core structures, some unexpected inductance values may be obtained.

Figure 9 gives a view of the flux path in a gapped pot core, for integral turns (A) and fractional turns (B). It is clear that the inductance value of the half-turn is not determined only by the A_L value of the pot core, but also is influenced by a second magnetic circuit as indicated by the flux path shown in figure 9B.

To measure the effect of half-turns upon the overall inductance of a gapped pot core, we wound a 20 turn winding for a gapped 4229 pot core with an A_L value of 370. We then measured the inductance values by unwinding the bobbin in half-turn steps. Table 1 gives a summary for the calculated and measured inductance values from 20 turns to 10 turns.

Figure 10 shows the measured deviation from the calculated change in inductance values. Curve A represents full-turn readings which are close to the expected decrease in inductance if we change from 20 to 19 turns, 19 to 18, etc.

When we do the same for the half-turns, curve B, we consistently find smaller than expected changes in inductance. If we change from 14 turns to 13½, instead of the calculated 5.1 µH decrease in inductance, we actually measure an inductance increase of .6 µH or a 5.7 µH deviation from the calculated decrease. These fractional turns tend to increase the measured inductance values particularly if relatively few turn windings are used on a gapped pot core or E core.

4229PA370-3C8

N	L Calc (µH)	L Measured (µH)
20	148.0	141.2
19½	140.7	140.4
19	133.6	128.0
18½	126.6	126.8
18	119.9	115.7
17½	113.3	114.9
17	106.9	103.8
16½	100.7	102.2
16	94.7	92.2
15½	88.9	91.9
15	83.3	80.9
14½	77.8	80.9*
14	72.5	70.8
13½	67.4	71.4*
13	62.5	61.3
12½	57.8	63.2*
12	53.3	53.3
11½	48.9	53.3*
11	44.8	44.6
10½	40.8	46.8*
10	37.0	37.6

* Inductance values did not decrease when number of turns was reduced by ½ turn. In some cases actually increased.

Table 1, calculated and measured inductance values.

To demonstrate how fractional turns react under DC bias conditions, we used, again, the 4229PA370-3C8 pot core and wound a bobbin with 150 turns and then wound an additional 20 turns as per figure 9B. As for figure 8, we plot the change in inductance as a function of the DC ampere-turns. This curve, shown in figure 11B, is quite different from the curve in 11A. The outer wall without a measurable air gap will cause an early decrease in inductance due to the DC well before saturation occurs in the centerpost. On the other hand, the very sharp drop normally observed in a gapped pot core is modified by avoiding saturation of the centerpost.

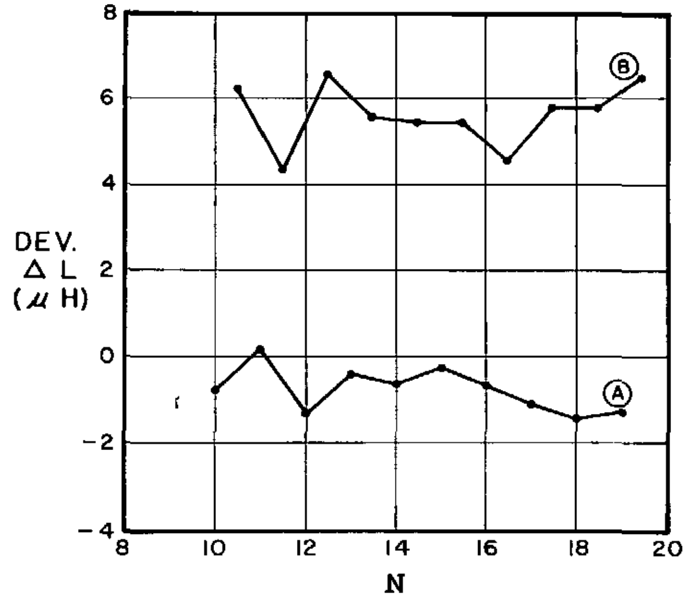

Figure 10, measured deviation from calculated change in inductance as a function of number of turns, core 4229PA370-3C8.

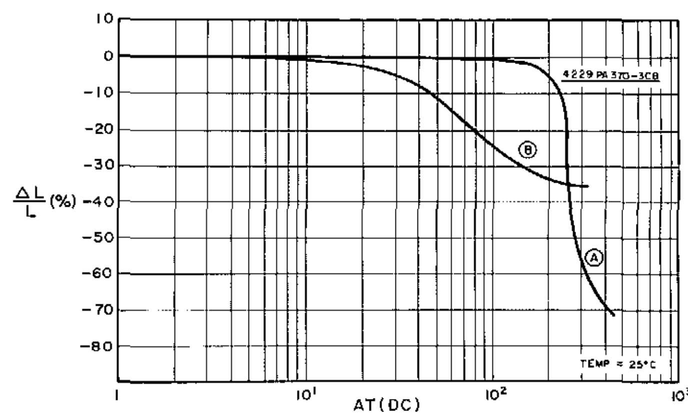

Figure 11, inductance change as a function of DC ampere-turns. Curve A, integral turns; Curve B, combination integral and fractional turns.

Conclusions

Inductance measurements of ferrite inductive components needs careful attention to a number of parameters.

Most obvious and recognized are flux density, temperature, and clamping force. Less well known are the influence of winding configurations, DC bias, and fractional turns upon the inductance measurements. Large mechanical pressures, which can cause significant changes in inductance should be avoided.

References

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2. The Reproducibility of Variability Measurements of Pot Cores. E. Olsen, Intermag 1964, 15-2-1 15-2-8.
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