A 20 MHz FERRITE INDUCTIVE ISOLATION LOSS STUDY*

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Abstract

This paper presents data on ferrite core samples that were tested with an applied 20 kilovolt, 25 ns unipolar pulse. The intent of this study was to identify ferrite materials that had superior blocking characteristics at this frequency. The 15 samples are toroidal cores with a 7.6 cm outside diameter, a 3.8 cm inside diameter and a 1.27 cm thickness. The sample cores acted as blocking inductors in the test circuit. When pulsed, the excitation current and induced voltage were recorded and presented in graphical form. The principal data evaluated in this study were power loss and maximum delta B swing. Four samples were tested from Phillips Corp. (Holland): 4M2, 4L2, 8C11, and 8C12. Five samples were tested from TDK Corp. (Japan): PE11B, PE11BB, PE14, Q5B, and MD9. Six samples were tested from Ceramic Magnetics Corp. (USA): CMD5005, CN20, C2003, C2010, C2025 and C2050. The results of this study identify four materials that have pulsed relative permeability (>400) and a total magnetic induction swing (ΔB) greater than 0.6 Tesla at this frequency.

Introduction

Linear Induction Accelerators (LIA) have used ferromagnetic material as their inductive isolation medium since their inception.[1] To provide efficient energy transfer to the load in a LIA , three criteria must be satisfied: (1) the volt-second product of the ferromagnetic material must be sufficient to support the driving pulse, (2) the material's permeability must be high enough that the load impedance is small compared to the impedance of the inductive cavity, and (3) the driving source impedance should be equal to the effective cavity impedance which is the parallel sum of the load and the cavity impedance. To design a high frequency (20 MHz) LIA for maximum efficiency and minimum size, inductive isolation materials must be identified that maintain a maximum level of pulsed permeability and a maximum magnetic induction swing.

The permeability of a given ferromagnetic material changes as a function of frequency (Fig. 1). A material typically has a permeability that remains constant out to a certain frequency (break frequency). As the frequency increases, the loss tangent rises sharply while the permeability remains constant or rises slightly.[2] The loss tangent reaches a maximum at the frequency where the permeability starts decreasing with a constant slope. If the frequency is increased further, the relative permeability asymptotically approaches unity and the loss tangent decreases.

For this study the pulse permeability and magnetic flux swing were analyzed. The break frequencies of the tested materials were below, on and above 20 MHz.

This research program was initiated to establish benchmark data for high frequency ferrite materials. Many samples of the same size were procured from three manufacturers. The experiment was to provide a known pulse into a device which would (1) hold a variable number of test cores in a blocking geometry, (2) provide a direct measurement of excitation current, and (3) provide a direct measurement of core voltage (Fig. 2). This is accomplished by using a 20 kV power supply to charge a 5 meter long 50 Ω coaxial cable. When the cable is charged, a SF_6 gas switch is depressurized until it breaks electrically and charges a second 50 Ω coaxial cable. The pulse reaches the experimental test chamber loaded with blocking cores. The loaded chamber's impedance is high and approximately equal to 250 Ω. The high voltage is maintained until the cores saturate. Then the voltage goes to zero while the current increases to the maximum value of the source (Figs. 3 and 4). The saturation of the core is necessary to determine the maximum ΔB swing ($=B_s - B_r$) of the particular sample. During the unsaturated portion of the pulse, the pulsed permeability and impedance may be characterized. The diagnostics on the experiment consisted of a 0.049 Ω current viewing resistor used to measure the current flowing through the cores and a 1:1 transformer connected to a 2000 Ω resistive monitor used to measure the voltage being blocked by the cores ($\dot{\Phi}$). The resistive monitor and transformer represent a parasitic load on the cavity. The inductance of the single-turn winding and the capacitance of the high-impedance monitor resonate during the initial 5 ns of the pulse. When the voltage monitor is removed, the oscillations are not present and the true excitation current alone is observed. However, the excitation current alone is not enough information to calculate the parameters in question. Work is continuing in order to improve the voltage monitor and eliminate the current oscillations. The compiled data has been corrected for the current drawn by the voltage monitor (V/R), but the oscillations remain (Fig. 4). To ensure a proper reset of the sample cores, a negative polarity 120 Amp critically-damped reset circuit is used to drive the cores to their negative remnant point ($-B_r$). The reset plunger is manually lowered to touch the center conducting rod. The reset current waveform is measured using the existing CVR to ensure that the negative critical magnetic field intensity ($-H_c$) has been reached.

Data Reduction

The two pieces of information that are recorded are the ferrite cores excitation current and the blocking voltage ($\dot{\Phi}$). The current drawn by voltage monitor is estimated by dividing the blocking voltage (V) by the monitor's resistance (R = 2000 Ω). This current is subtracted from the total current waveform (I-V/R). This is the excitation current used in the analysis. The power absorbed by the cores is the product of the current and the voltage waveforms (Fig. 5). The time integration of the voltage waveform provides the ΔB waveform ($\Delta B = \int \dot{\Phi} dt/A$) where A is the cross sectional area of the cores (Fig. 6). The magnetic field intensity (H) plot vs time is obtained by dividing the excitation current by the mean flux path length around the core (Fig. 7). The spurious oscillations caused the relative permeability (μ_r) to appear negative at the beginning of the B vs H plot (Fig. 8). The relative permeability is the ratio of B over H divided by the permeability of free space (Fig. 9). The upward tail in the relative permeability curve is caused by the current limited source. With a lower impedance source μ_r would return to unity as expected. The μ_r vs H plot is shown in Fig. 10. The B vs H plot is shown in Fig. 11.

The compiled four-core data is presented in Table I. The power loss data is not the only representation of the blocking characteristics. With the 50 Ω source providing the pulse, a material with a large excitation current would block less voltage than a material with a small excitation current (V = 20 kV - (50 x I)). Another measure of the blocking characteristics of the cores would be an equivalent impedance (V/I -50 ≈ Z). The impedance, which appears resistive, is calculated in the unsaturated region of the current and voltage waveforms.

Conclusion

Fifteen toroidal ferrite cores have been tested with a known voltage pulse. This data has been studied and four materials (C2010, C2003, PE11BB, and PE14) have been identified that would operate efficiently and with a minimal cross sectional area at 20 MHz. They have ΔB swings of greater than 0.6 Tesla and pulsed relative permeabilities larger than 400. For this frequency the impedance of these ferrites, to a first approximation, appears resistive with a value between 200 and 300 ohms.

1. N. Christofilos et al., Rev. Sci Instruments 35, 886 (1964).

2. R. Tebble, Magnetic Materials, London: Wiley-Interscience, 1969, pp. 600-603.

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Supplier Material Type	*Power Loss (MW)	†ΔB (Tesla)	μ_r (Pulsed)	Equivalent Impedance (Ω)
Ceramic Magnetics				
C2003	1.25	0.67	580	240
C2010	1.20	0.68	600	250
C2025	1.40	0.46	390	223
C2050	NA	0.22	105	NA
CMD5005	1.40	0.47	460	280
CN20	1.20	0.60	540	280
Phillips				
4M2	NA	0.24	130	NA
4L2	NA	0.28	175	NA
8C11	1.50	0.43	390	330
8C12	NA	0.30	240	NA
TDK				
M9D	NA	0.16	50	NA
PE11BB	1.10	0.68	650	265
PE11BL	1.45	0.45	395	275
PE14	1.15	0.67	610	215
Q5B	1.35	0.40	150	52

NA - The Volt-Second Product was Insufficient to Support the Pulse

*** Instantaneous Power Loss at 25 ns**
† ΔB is $-B_r$ to $+B_s$

Table 1. Experimental Results of the 20 MHz Power Loss Study with 4 Cores

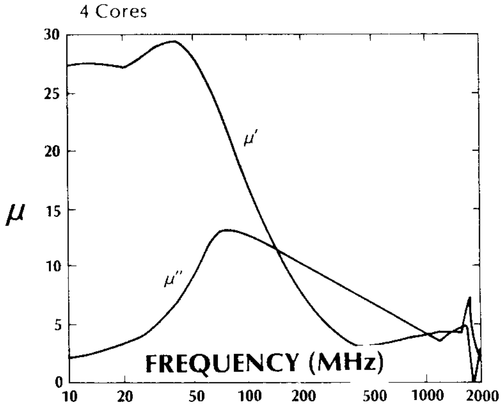

Figure 1. Relative Permeability (μ') and Loss Tangent (μ'') vs Frequency

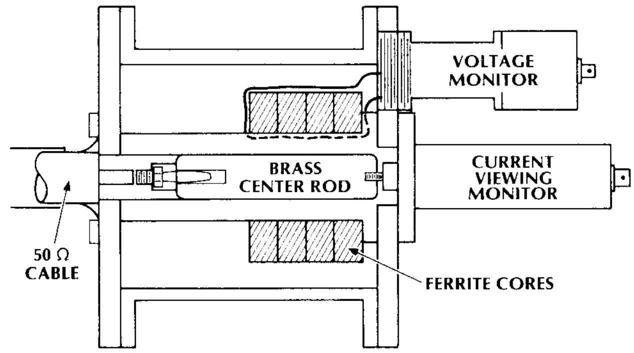

Figure 2. 20 kV Ferrite Core Testing Fixture

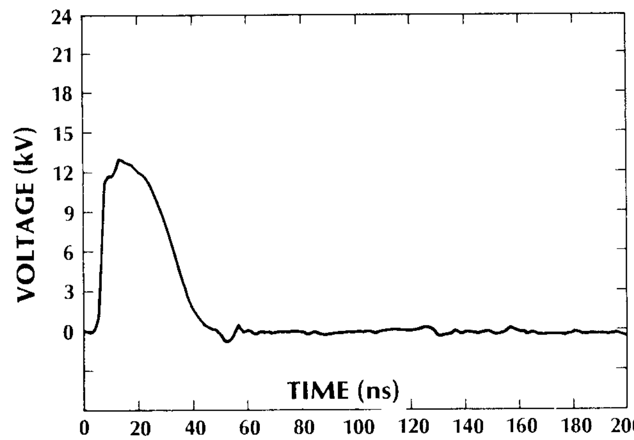

Figure 3. Voltage vs Time

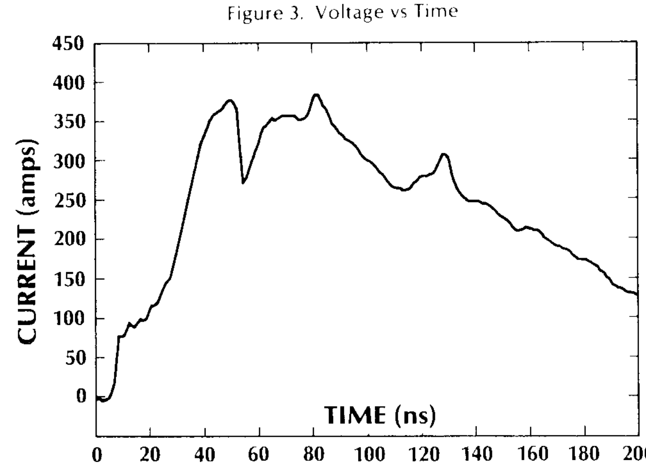

Figure 4. Current vs Time

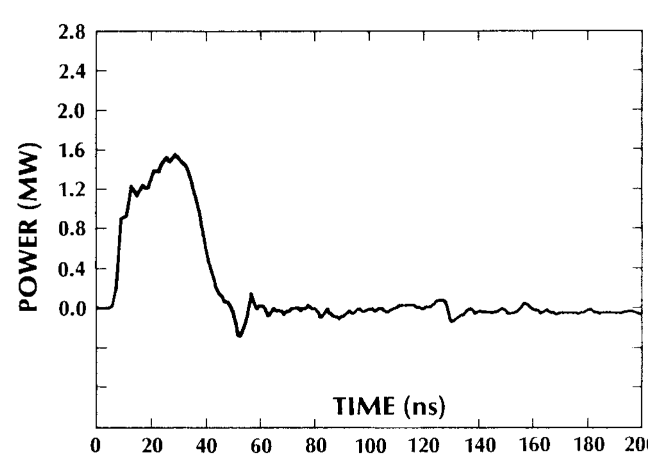

Figure 5. Power vs Time

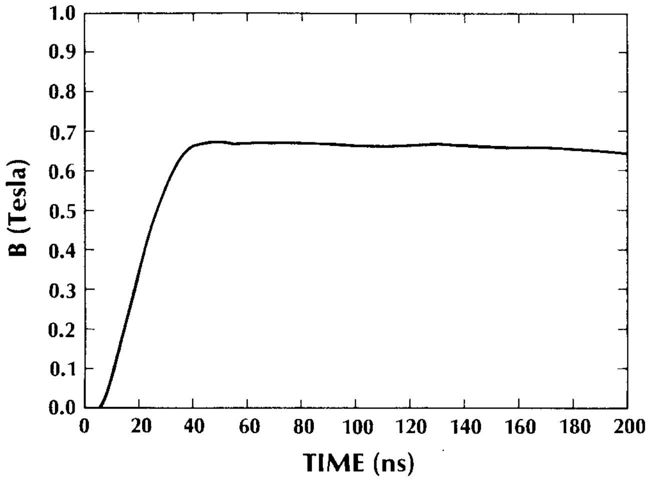

Figure 6. ΔB vs Time

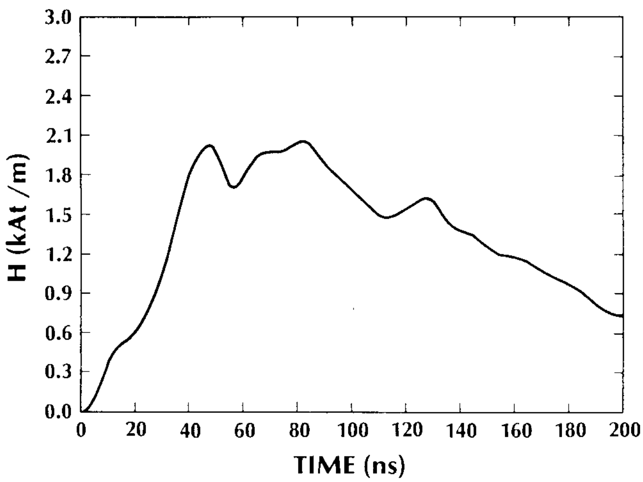

Figure 7. H vs Time

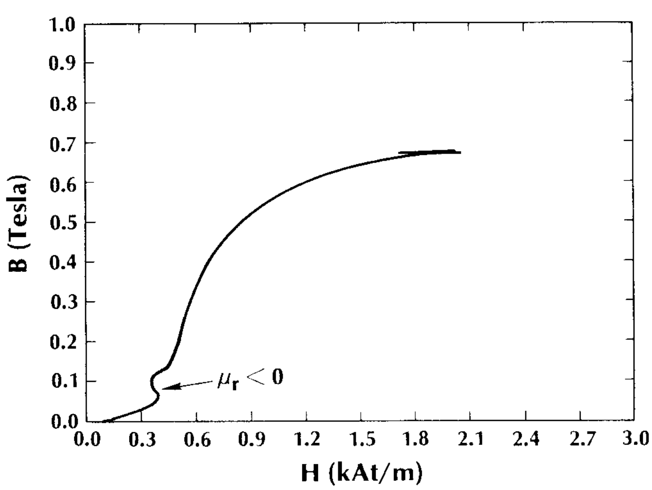

Figure 8. B vs H (unsmoothed)

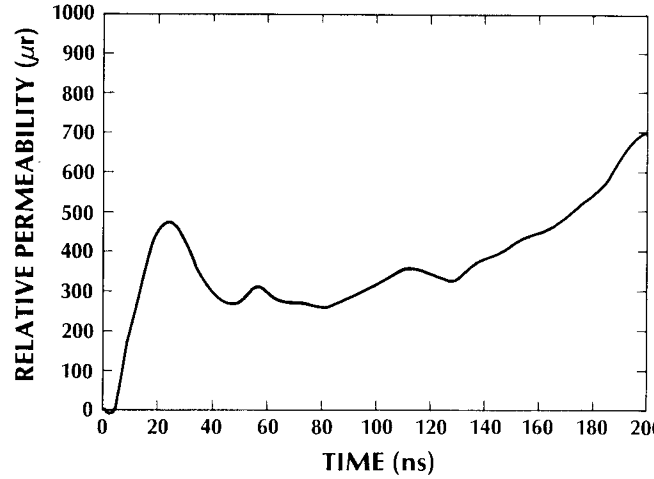

Figure 9. μ_r vs Time

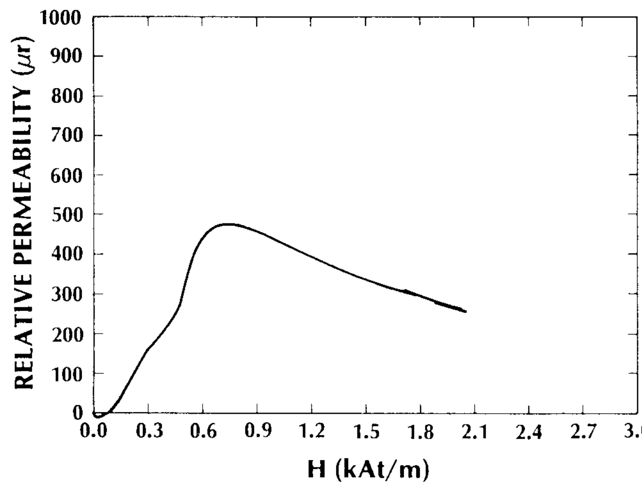

Figure 10. μ_r vs H

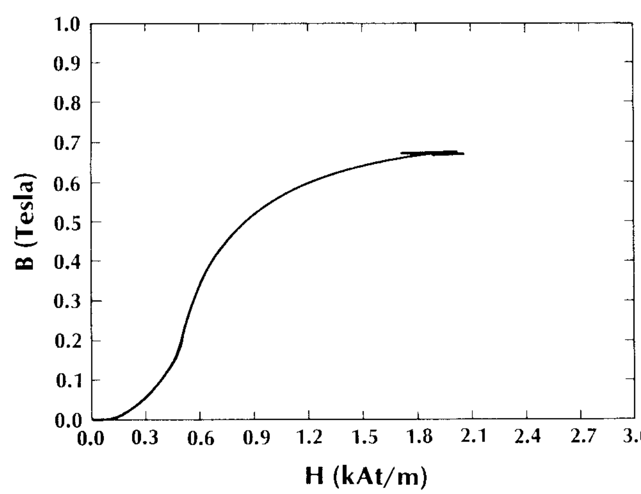

Figure 11. B vs H