

CHARACTERIZATION OF AMORPHOUS MAGNETIC MATERIAL WITH MULTIPLE PULSE EXCITATION

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Abstract

The magnetic characteristics of an amorphous magnetic material have been studied by applying multiple square voltage pulses to an inductor containing the magnetic material. The pulser is a 20 kV, 200 ns, 20 Ω source which drives the core of dimension 160/240/25 mm. Effect of the number of turns and the magnitude of the exciting voltage pulse on the saturation behaviour of the material are presented.

INTRODUCTION

The use of amorphous magnetic material in magnetic switches and induction cells has received widespread attention in the development of pulse power systems of high average power and high repetition rate. The physical dimension of these devices depend on the flux swing offered by the material when driven from remanence to saturation. [1,2]. It is well-known that the magnetic properties of amorphous material are influenced by several factors such as annealing, heat treatment, surface coating, rate of flux change dB/dt, toroidal radius and applied input power etc [3,4]. We are using the material 30 KCP obtained from Russia in the development of a 200 keV, 5 kA, 100 pps Induction Linac. Therefore, we studied the magnetic properties of cores available in standard sizes in the intended frequency regime of operation before designing the switches and induction cells

To emphasize the need for our investigation, we cite here a few problems which one may encounter while using a magnetic core as a switch. For example, when the input capacitor of a magnetic switch is getting charged, the magnetic switch is supposed to have practically infinite impedance. However, there is always a leakage current due to finite impedance, which charges the output capacitor to some extent. A crude design based upon only the flux swing data ignores this fact and one may start worrying why the input capacitor did not get charged to the estimated value.

Similarly the transition from high impedance to low impedance is not an instantaneous affair as one would like to have. Complete saturation means that the relative

permeability of the material approaches the value in air. Depending on the material, this approach, say from $\mu_r = 10$ to $\mu_r = 1$ can be slow or fast. The charging time of the output capacitor of a switch is generally calculated by using $\mu = 1$ in the saturated state of the switch. It is likely that the switch remains in the quasi-saturated state for quite sometime. Unless one knows this charging time, it will be difficult to design the switch for the next compression stage.

Besides this, the magnetic data provided by the manufacturers are obtained by experimenting with continuous sinusoidal power sources. The characteristics of the magnetic material differ considerably from the above situation when they are used as core material in switches and induction cavities. It is imperative to know the pulse characteristics of the material while designing these devices.

Thus, more insight into these limitations are needed for almost perfect designs of pulse transformers, magnetic pulse compression chain and induction cavities in Linear Induction Accelerators.

EXPERIMENTAL SET-UP

The amorphous core material used in our experiment was supplied to us by M/S Tukson Inc., Moscow, Russia, under the trade name 30KCP[5]. The chemical composition of the material is Fe(63.95%), Co(30%), Cr(3%), B(3%) and C(0.05%). The core is made from 25 μm thick tapes with SiO_2 insulation between layers and annealed in longitudinal field. The magnetic characteristics, provided by the manufacturer at 50 Hz, indicates that the core material has a flux swing around 3T ($-B_{\text{max}}$ to $-B_{\text{max}}$) and coercive field of 12A/m. The toroidal test core is taken to be of the same size as that to be used in the actual system i.e. inner diameter 160 mm, outer diameter 240 mm and height 25 mm.. Before using the core, it was cleaned with alcohol and then two layers of 2 mil semi-cured kapton tape were wound on it to prevent incursion of outside dirt and any damage during handling the material.

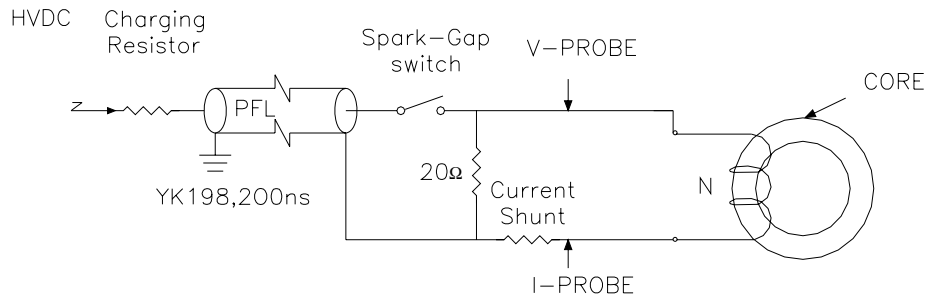


Fig.1 : Experimental set-up to study core characteristics

The core under test is connected in shunt with the matched load of a pulsed voltage source. The pulser consists of a YK198 cable of suitable length which is charged from a D.C supply through a resistor. At the other end, it is terminated through a spark gap switch to the matched resistive load (20Ω) of copper sulphate solution and a pulse of 200 ns duration is realized when the spark gap fires. The experimental arrangement is shown in Fig. 1. Resetting is done before applying a series of pulses to the core. For resetting, 10 A D.C was passed through the turns of the core using a power supply of M/S Aplab make (Model 7317). The Voltage (V) across the core is measured by Tektronix voltage probe P6015A and current (I) through the turns of the core by a $10\text{m}\Omega$ current shunt of T&M make (Model no. 8615). These V & I signals are displayed in a digital storage oscilloscope of Lecroy make (Model No.9350A). Voltage signal is captured, stored and integrated in this unit. The flux swing ΔB and the magnetizing field H during the pulse are calculated according to the following equations:

$$\Delta B(t) = \int V(t).dt / (N \cdot A) \quad (1)$$

$$H(t) = N \cdot I(t) / l \quad (2)$$

Here N denotes no. of turns, A the area of cross-section of core in m^2 and l the mean magnetic path length in meters. It has been assumed in the above equations that the magnetic induction is uniform throughout the core cross-section.

RESULTS AND DISCUSSION

While operating as a switch or as an induction cell, the magnetic core is driven from negative saturation to positive saturation by application of a single voltage pulse. In our experiment, we utilize low voltage pulses and observe the saturation after a series of pulses. The effect of number of pulses of peak magnitude (V_{pk}) 17.5 kV on the core with 7.5 turns is shown in Fig.2. When the first pulse was applied, voltage wave-shape showed no reversal as shown in Fig.2(A). In the 2nd pulse, reversal is

seen along with a voltage droop in the earlier flat-top portion. The effect of exciting voltage (V_{pk}) on the performance of the core was studied in the following manner. First, $\Delta B(t)$ was evaluated for a pulse at different times during the pulse using Eqn 1. At first, $\Delta B(t)$ rises with time and then remains steady, if the voltage pulse has no reversal. If it has reversal, it starts falling down from the peak value. For every pulse, $\Delta B(t)$ was evaluated and found to decrease after a few pulses. The test core has not been reset in between these shots. Resetting has been done in the beginning of each set of data. Effect of excitation level has been observed by changing the input charging voltage of the cable. The applied voltage to the core V_{pk} is varied from 7.5 kV to 17.5 kV and a range of dB/dt from $2.5\text{T}/\mu\text{s}$ to $6.5\text{T}/\mu\text{s}$ is obtained. As expected from equation 1, higher input voltage results in larger total flux swing ΔB . Also when pulses have been applied repeatedly without in-between resetting, the core moves closer and closer towards saturation and its impedance continually reduces. From Fig.4, it is observed that, for the same charging voltage, more current passes through the turns of the core in subsequent pulses. The value of the relative permeability μ_r , defined by $\Delta B / (H \cdot \mu_0)$ can be estimated from the voltage and current pulse and one finds that it reduces from 1700 to less than 100 during this process. At lower excitation level, variation in ΔB is smooth but at higher excitation or near the saturation point, changes are drastic.

The effect of successive pulses on ΔB has been shown in Fig.4, for various number of turns keeping excitation voltage constant. As the no. of turns increases, ΔB decreases for the same charging voltage of the cable. When it approaches saturation, ΔB becomes minimum. At this point, the core will be at the knee of typical B-H loop. It has been observed that the core withstood large number of pulses (n) for more number of turns. This can be attributed to smaller flux value at each pulse as can be seen from eq.(1) i.e. ΔB will decrease with increase in N for fixed values of V, t and A.

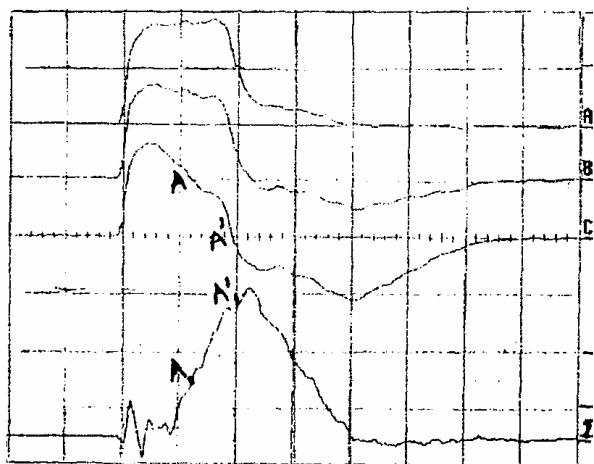


Figure 2 (A,B & C): Three successive pulses
 Figure 2 (D): Current pulse for voltage pulse (C)
 X-axis: 100ns/div, Y-axis:10kV/div, 200A/div.

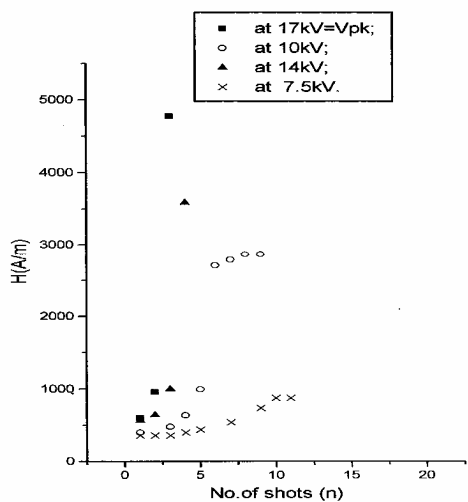


Figure 3: Core current with shot no.

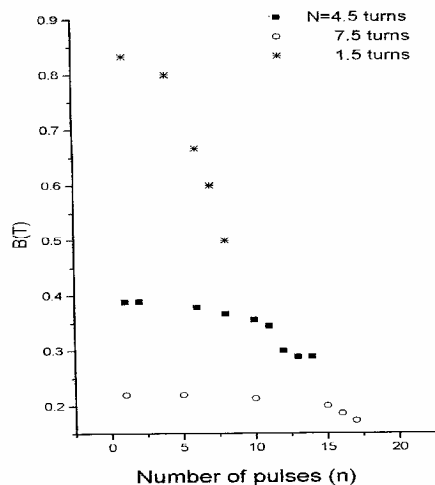


Figure 4: Effect of no. of turns.

Each pulse, of course, shows a departure from the previous one in terms of voltage drooping and the degree of reversal. At higher peak voltage, the difference in magnetic properties between the 1st (low dB/dt) pulse and last (saturated) pulse is significantly larger compared to that at low V_{pk}. Before saturation, H remains almost same irrespective of input excitation voltage, but ΔB is greater in case of higher V_{pk} or faster dB/dt. In the saturated state, H and ΔB increase with input level but μ_r remains almost constant. The relative permeability remained as high as 50 in this state of saturation. Possibly, very large current is necessary to achieve μ_r ≈ 1 and it can be realized in driving system of low impedance.

It is quite clear from the graphs that the core can be used for many pulses without resetting, either when input voltage is low, or the no. of turns are high. Thus an economic and efficient design for a specific application is possible by utilizing the core behavior.

CONCLUSION

These results show that few pulses of low voltage magnitude can be achieved at higher repetition rate, without having to reset the core. These results may be useful in applications such as design of pulse transformers and induction cavities where cores are to be used at multiple pulses without complex synchronized resetting unit. During the burst of pulses, the core will give reproducible results depending on the voltage and the number of turns used.

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