NICKEL ZINC FERRITE MATERIALS FOR PULSED APPLICATIONS IN ACCELERATORS

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Abstract

Nickel Zinc ferrite materials are now finding increased applications in pulse magnetic devices of accelerators & laser subsystems. The magnetization rates are involved are up to about 5T/μs & magnetization reverses in order of 100 ns. Switching losses for fast magnetic devices have been measured for sub-microsecond magnetization times for Ni-Zn ferrites & amorphous magnetic materials. A simple domain model of flux reversal in ferrites has been used to describe fast magnetization studies in Ni-Zn ferrites. The magnetic materials were experimentally compared for their usefulness in high–speed magnetic field applications. This particular application is a high-speed kicker magnet for injection of 700 MeV electrons into 2.5 GeV storage ring (Indus-2), that is being built in Indore, India & magnetic switches for pulse power systems.

INTRODUCTION

Magnetic materials are the limiting factor in many pulse power systems & in high frequency switched mode power supplies. Magnetic switches are becoming an increasingly important part of high power laser & accelerator systems.

The basic principles underlying magnetic switches involve using a saturable magnetic core as an inductor in a resonant circuit. The circuit is designed to allow the core of the next stage to saturate before a significant fraction of the energy stored in capacitor of the previous stage is transferred. This nonlinear saturation phenomenon shifts the resonant frequency of this resonant circuit by the square root of the permeability shift as the core saturates. The application of magnetic current amplification switching technique to generation of precise high & fast current pulse for switching magnets of accelerators & to drive excimer lasers. To perform satisfactorily switch operation, it is required a wide flux swings in the magnetic material which must allows transfer of energy between saturated & unsaturated states produces a correspondingly fast rise time for switch. Losses & rounding of transition into saturation are dependent on the domain walls in the material [1].

Requirements for reliable, high energy pulsed power systems for lasers & accelerators have rapidly increased. Amorphous magnetic alloys & Ni-Zn ferrite materials are used in pulse power transformers & in magnetic pulse compressor network in these systems. Magnetization rates to produce pulses in the order of 100 ns are required. The magnetization rates involved are up to about 5 T/μs. The magnetization behaviour of magnetic materials at dc is entirely different from dynamic/pulsed conditions. Therefore, the dynamic studies of magnetic materials have been taken up to know how the ferrite behaves when its magnetization reverses in the order of 100 ns. In this paper, characterization & utilization of Ni-Zn ferrites for pulsed magnetic devices are described.

MAGNETIC MATERIALS

High magnetization rates in magnetic materials are associated with magnetic losses due to induced eddy current in magnetic alloys & spin relaxation-damping loss in ferrites. Losses not only reduce efficiency, but also result in increase in core temperature, which ultimately limit the maximum frequency or repetition rate at which magnetic materials are used[1].

Ni-Zn Ferrite Materials

Isoperm NiZnCo ferrites in large toroids are required for development of high power, high repetition rates & high-speed magnetic switches.

The ferrites needed to produce magnetic rates of magnetization (5 T/μs) in NiZn ferrites are considerably greater than the dc coercivity. The dc coercvity NiZnCo ferrite used in accelerator is about 0.20 °e, whereas the field required to magnetize a small toroidal sample from a dc reset state to 100 ns is of the order of 3 Oe. Under this condition, the dominant magnetization mechanism is assumed to domain wall motion limited by spin relaxation damping.

The properties of ferrites at high rates of magnetization & with substantial magnetization are required to design high-speed magnets for injection of 700 MeV electrons into 2.5 GeV storage ring (Indus-2) at CAT.

PULSE MAGNETIZATION

Pulse power magnetic devices utilizes high rate of magnetization dB/dt of upto 5 T/μs & time in order of 100 ns. Therefore, it is necessary to understand the behavior of magnetic materials when its magnetization reverses in the order of 100 ns.

In the present studies, we have investigated & developed NiZnCo ferrite materials for use in pulsed magnetic devices at CAT [4].

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A Domain Model of Flux Reversal in Ferrites

The design of pulsed magnets for accelerators & magnetic pulsed compressors for lasers requires an accurate description of the electrical behaviour of ferrites. A simple model has been used to describe fast flux reversal in NiZnCo ferrite cores. The ferrite material is represented by an effective spherical "grain" whose size, shape, & orientation of crystal axes are assumed to represent over many grains.

A magnetization mechanism considered is the collapse of the effective spherical domains within the effective grain. A magnetization equation is derived for the field needed to drive the collapsing domain wall against the viscous force of spin relaxation damping. The model described here was therefore applied to provide a ferrite magnetization equation capable of predicting experimental data taken on ferrite toroidal cores.

PULSE CORE TESTER

A high voltage pulsed tester (50 Ω characteristic impedance) was constructed to measure the fast response of the ferrite at high magnetic amplitudes (Bpeak : 200-250 mT). These test results can be reasonably & directly

applied to the design of the kicker magnet. The ferrite ring samples were subject to pulse tests with a drive level of 6 KV from a 50-ohm source where the induced voltage & current were measured.

A high level field is applied so that ferrite is driven into saturation. The flux density & field strength for ferrite samples at both unmagnetised state & a remnant state are measured. The data is presented in a field versus which is shown in Figure 1.

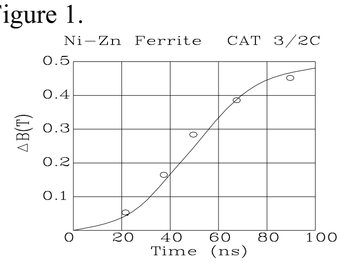

Figure 1: Pulsed Field Vs. Time. This clearly shows the different time regimes during the pulse.

HIGH FREQUENCY CHARACTERISTICS

Saturable inductors & pulse transformers are main component parts of a magnetic pulse compressor (MPC) to drive excimer laser & large ferromagnetic toroidal cores (100 mm dia) are magnetized by high frequency. (KHz-MHz) voltage pulse. This is very important to obtain high frequency magnetic properties of ferrites for designing a pulsed magnets & a magnetic pulse compressor. A conventional AC excitation method requires a high power source (MW) to measure a full B-H curve of large ferrite toroids at 1 MHz excitation. It is difficult & expensive also, so we have developed a pulse excitation method to get high frequency magnetic properties of large ferrite toroidal cores (150 mm dia).

Basic Principles of Pulse Excitation Method

The ferrite cores under test are excited by a sinusoidal voltage pulse of waveform like f (t) = Vo (1-cos (2πft)) up to magnetic saturation occurs at the peak voltage Vo. The excitation frequency f is decided by a charge transfer circuit composed of a capacitors & inductors. The change in the magnetic flux density ΔB & magnetic field strength force are calculated by the induced voltage V (t) = Vo (1-cos(2πft)) of a search coil & magnetizing current through the sample.

ΔB-H characteristics of large ferrite toroidal cores (150 mm OD) were measured by a 500 MHz digitizer. Figure 2 shows measured V & I waveforms & calculated ΔB–H characteristics.

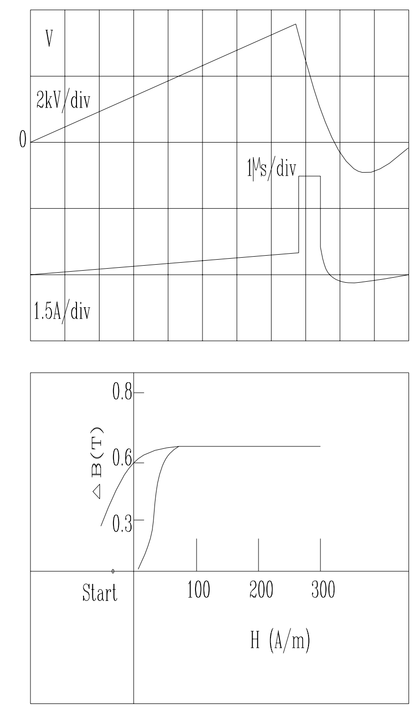

Figure 2: Pulse Waveforms & ΔB–H characteristics.

Core Loss Results

The effect of an excitation frequency upon the core loss calculated from ΔB–H characteristics have been made at various magnetization times for each magnetic material. It is found that all the materials show loss inversely proportional to magnetization time. Figure 3 shows the results, expressed as loss per unit volume of magnetic materials for a flux swing, from remanence to saturation.

From this result, it is clearly found that NiZn ferrite has the advantage of low core loss in applying to MPC & high-speed magnets.

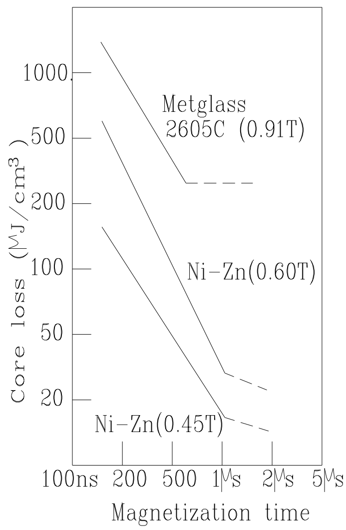

Figure 3: Core loss density for pulsed magnetization from remanence to saturation versus magnetization time, using a (1-cosωt) voltage waveform.

ORDER OF MAGNETIC MATERIALS

The lower power density in NiZn ferrite, combined with good thermal conductivity & monolithic structure, allows efficient cooling throughout the volume of quite large cores through convection from the surface. Loosely wound metallic ribbon cores in insulating enclosures have poor heat conduction properties, & the high power density of core losses in amorphous metals is difficult to handle by conduction. The performance of magnetic switches is mainly governed by large flux ΔB & low losses. The larger ΔB of metallic ribbons metal gives a core volume which is little, but practically difficult to get large ΔB due to large fill factor. Ni-Zn ferrite has Flux swing ΔB - 0.74 T & low core losses as compared with amorphous metals. Ferrite has clear advantages over amorphous metals, because switching properties of NiZn ferrite is excellent as compared with amorphous ribbons.

CONCLUSIONS

A pulse-testing fixture was developed & pulse response of different ferrite materials was examined. CAT-3/2 C (Ni-Zn-Co ferrite) has lowest losses, high value of knee of magnetization (> 0.32 T), low coercivity (0.20 Oe). Also the flux density for kicker operation is 0.20 T & is within even repetitive flux density excursion. Therefore, CAT-3/2C ferrite materials, which was investigated & developed in-house for Indus 2 pulsed kicker magnets at CAT. CAT-3/2C ferrite materials have large flux swing ΔB (> 0.74 T) on large toroidal shape. This material has been chosen for magnetic pulse compression applications for pulse power supplies. A domain model described for simulation of dynamic magnetization in ferrites at 100 ns pulses, which has good agreement with experimental results.

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