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## Development of High Frequency Large Ferrite Toroids for Accelerators

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**Abstract:** Large soft ferrite toroids & slabs in various Ni-Zn compositions were developed for high frequency switching magnets (kickers) & fast rise time current monitors of 450 MeV Electron Accelerator. The electric & magnetic properties of large ferrite ring cores were obtained using a special sintering process. These magnetic properties include a high saturation flux density, high initial permeability, low coercivity, large  $\mu Q$  products (at  $\hat{B}$ : 100 mT,  $f$  = 20 MHz) & low loss rf characteristics at high magnetic amplitudes.

### 1. INTRODUCTION

Synchrotron radiation facility of CAT consists of 20 MeV microtron, 700 MeV Booster Synchrotron & 450 MeV storage ring. Very fast kickers are needed in accelerator beam transport lines to transfer the beam into & out of storage & damping rings. It is essential to use a kicker magnet having a very short rise time & a stable switching characteristics [1].

Ni-Zn-Co ferrites are widely used in high frequency ( $> 1$  MHz) & fast pulsed field applications for their unique combination of high flux swing ( $\Delta B$ ), low coercivity, high electrical resistivity & low loss rf characteristics at high rf magnetic amplitudes [1].

Ni-Zn-Co ferrite slabs & toroids were developed by sintering at low temperature (1180 °C) with long sintering time 20 hrs. Low loss rf characteristics were obtained [2].

This paper presents the electric & magnetic characteristics of large ferrite slabs & toroids & high power rf measurements.

### 2. EXPERIMENTAL

Toroidal ferrite samples were prepared with a chemical compositions of  $(\text{Ni}_{35}\text{Zn}_{65})\text{Fe}_2\text{O}_4$  &  $(\text{Ni}_{40}\text{Zn}_{60})\text{Fe}_2\text{O}_4$  by ceramic techniques. Microstructure of the sintered samples were observed by SEM.

Complex permeability ( $\mu'$ ,  $\mu''$ ) & loss factor as a function of frequency (1-100 MHz) were measured by RF impedance analyser. Fast pulse B-H measurements & core losses at high magnetic amplitudes were carried out using a high voltage (6KV) testing fixture constructed inhouse for this purpose [3].

### 3. PULSE MEASUREMENTS & RESULTS

We made magnetic hysteresis loop measurements with a pulse core tester in addition to the measurements done at 60 Hz. Fig. 1 shows variation of the flux with field obtained with a pulse magnetizer. Energy loss of the core is determined by integrating the product of the voltage & current for the pulse duration. We found this value varies widely depending on the rise time of the pulse, bias field strength & other experimental conditions. Complex permeability spectrum ( $\mu'$ ,  $\mu''$ ) of a NiZnCo ferrite system is shown in fig. 2. It is observed that there are very low losses in low frequency range ( $< 5$  MHz).

Magnetic permeability ( $\mu'$ ) is almost independent of frequency within application frequency ranges from 0.5 to 60 MHz. This suppresses the loss contributions from gyromagnetic & dielectric influences. These are desirable characteristics of ferrites useful in high speed kickers (30 ns rise time) of Accelerators.

RF field dependence of Ni-Zn-Co ferrite toroids at high magnetic amplitudes ( $B$ : 100 mT, 20 MHz) is studied and shown in fig. 3. It is observed the RF losses increases with  $B_{rf}$  & further becomes unstable at high rf voltages. This phenomenon is high power instability. At low rf levels, non linearity in ferrites is weak & loss of the ferrite is caused mainly by relaxation between uniform mode & lattice. At high power levels non linearity increases in the ferrites, & the coupling between the uniform mode & the spin wave modes becomes stronger [3].

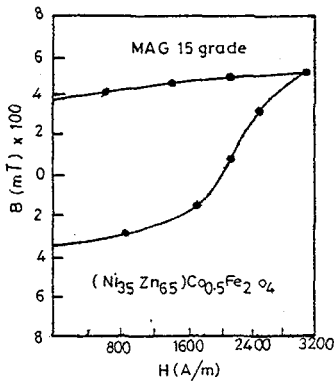


Fig.1. Variation of  $B$  (mT) as a function of applied field for Ni-Zn-Co ferrites

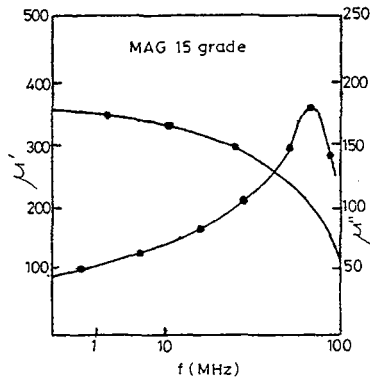


Fig.2. Complex  $\mu$  as a function of frequency (MHz)

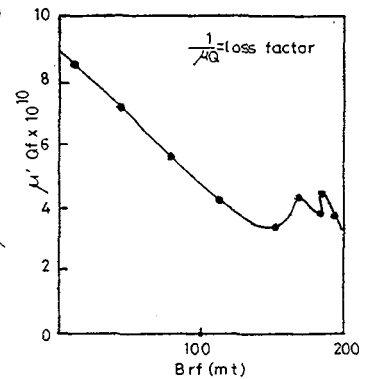


Fig.3. Plot of  $\mu'Qf$  against  $B_{rf}$

#### 4. CONCLUSIONS

A pulse test stand was constructed & the pulse response of Ni-Zn-Co ferrite materials was examined. Ni-Zn-Co (MAG - 15 grade) have low losses at high rf magnetic fields & larger pulse permeability under dynamic conditions. Also they have small non linear effect over the kicker's operating frequency range. Ni-Zn-Co (Grade MAG-15) material was chosen for 30 ns, switching kickers & fast current monitors. Kickers & current monitors have been developed using MAG-15 grade slabs (120 x 100 x 20 mm) & toroids (120 mm OD x 90 mm ID x 20 mm Ht). These magnetic devices are working entirely satisfactorily during accelerator operations since a year & found most efficient & reliable.

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