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New magnetic material for proton synchrotron RF cavity

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Abstract

We have measured the characteristics of the high permeability magnetic materials, auch as ferrites, amorphous and FINEMET. The measurements have showed that the FINEMET is the most excellent material for the RF cavity of high intensity proton synchrotrons.

1 Introduction

The RF cavity of proton synchrotrons requires high permeability magnetic materials for tuning the resonant frequency. We have been seeking the best materials for the RF cavity of the JHF proton synchrotrons [1] so far. Among the samples, we were interested in new magnetic material, 'FINEMET', which is stable against the high RF magnetic field and high temperature[2][3]. The FINEMET core is not a Fe-based soft magnetic alloy composed of amorphous and ultra-fine grain.

We have measured several types of FINEMET cores in detail. In this paper, we report the results of these measurements.

2 Experimental Apparatus

In order to measure the impedance of magnetic material, we fabricated a resonant test cavity with the variable capacitors. The impedance of the materials is obtained by measuring the waveform of the voltage and the current in the cavity. The test cavity is shown in Fig 1. A magnetic core was put between two cooling plates of the cylindrical cavity. The RF power was introduced into the cavity via RF feeder.

The input RF power was limitted to 1kW by the power amplifier. Azimuthal bias magnetic field for frequency tuning was applied by a bias current generator which supplies DC current up to 1000A.

The measurements have been done for three ferrites, an amorphous and eight FINEMET cores. The FINEMET cores we measured were listed in Table 1. Three of them has a practical size and the rests are small. The code name in the table shows the material type(number) and the magnetic anisotropy(alphabet). The FT-1 series has an extremely lower magnetostriction constant compared with that of FT-3 series whose are about 2.3. The anisotropy index describes the direction in which the external magnetic field was applied at heat process, i.e. axial(L), azimuthal(H) or no direction(M). All of the cores except #7 has a SiO_2 coating on the surface.

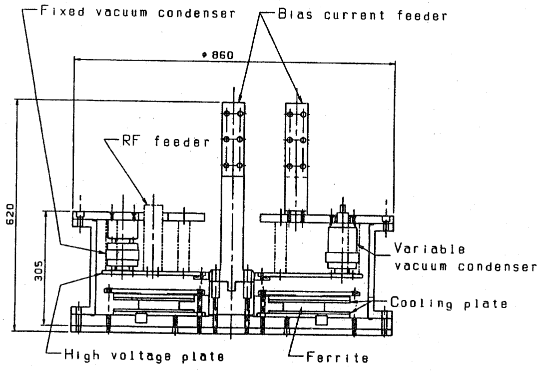

Figure 1: Cross section of the test bench.

no.	code name	O.D.	I.D.	th.
1	FT-3M	579.0	320.0	25.3
2	FT-1H	70.0	32.0	25.0
3	FT-1L	70.0	32.0	25.0
4	FT-3H	70.0	32.0	25.0
5	FT-3M	70.0	32.0	25.0
6	FT-3L	70.0	32.0	25.0
7	FT-3M(epoxy)	340.0	140.0	25.0
8	FT-3M	340.0	140.0	25.0

Table 1: List of FINEMET samples. Each column shows the material code name, outer diameter, inner diameter and thickness in the unit of mm.

3 Results

3.1 The dependence on the RF field strength

The dependence of impedance on the RF flux density for two FT-3M samples is shown in Fig 2. For comparison, the characteristics of ferrite materials; Ni-Zn and Ni-

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Zn-Co are also shown. The $\mu_p Qf$ means the product of the permeability, quality factor and RF frequency. It is a size independent parameter propotional to shunt impedance, that is,

$$R_p = 2\pi\alpha \times \mu_p Qf,$$

where

$$\alpha = \frac{\mu_0 t}{2\pi}\ln(\frac{O.D}{I.D}).$$

The maximum RF flux in this measurement was limited by the power amplifier. We found that μQf was constant even at the high RF magnetic field strength up to 2000 G. This is one of the most interesting characteristics of the FINEMET cores.

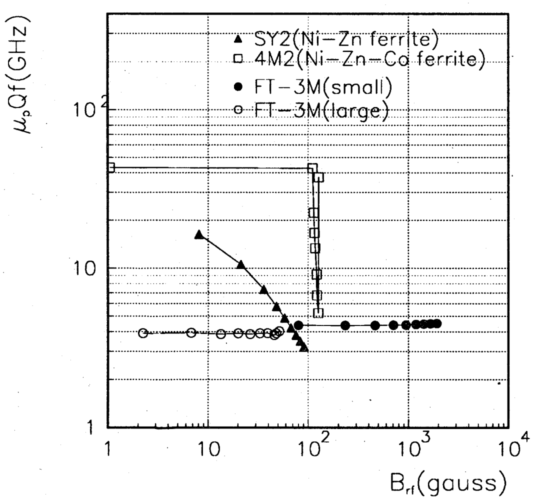

Figure 2: Shunt impedance of FT-3M vs RF flux density.

3.2 Bias field dependence

The bias field dependence was measured at a low RF voltage, ~5V. It has been proved by the previous measurement that such a low RF voltage does not affect the impedance. Fig 3 shows the bias field dependence of permeability for the FT-3M large core at the frequency of 3.0 and 4.0MHz. The relative permeability was calculated by the following eq.

$$Z = i\omega\alpha\mu_r.$$

Fig 3 tells that the permeability of FINEMET can be varied more easily than that of ferrite. However, the tuning is not necessary for the FINEMET cavity because the FINEMET has a broad band impedance curve [5].

3.3 comparison of FINEMET types

We measured the impedance as a function of frequency for all of the FINEMET cores we had. The RF voltage we chose here was 5V. Figure 4 shows the results for the five small samples. The 'H' type material has a small shunt impedance (or $\mu_p Qf$ product), thus it is not useful for the RF cavity. We think that the FT-3L is the best for the JHF synchrotrons because; (1)it has the highest shunt impedance, and (2)its quality factor ($Q \sim 1$) is not too low compared with the other types of FINEMET cores.

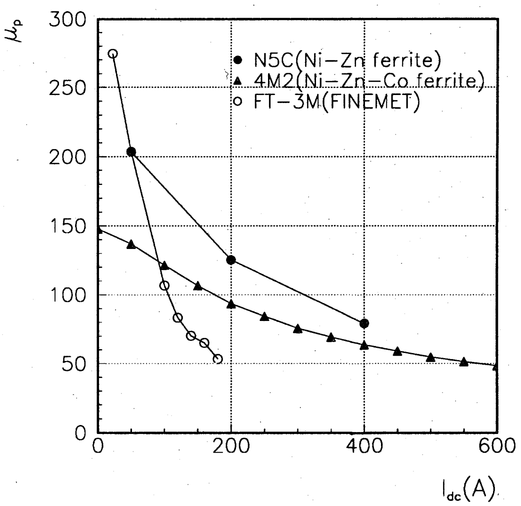

Figure 3: Bias field dependence of FT-3M.

3.4 comparison of insulation material

Fig 5 compares the impedance of a SiO_2 insulated core and an epoxy insulated core, which was measured with a LCR meter. We can found little difference in μQf and no difference in μ.

3.5 Temperature dependence

Temperature dependence of an amorphous core 'metglas' and FT-3M was measured with a thermocouple which is placed on the inner edge of the core. Temperature was raised up to 140 ℃ when high RF was introduced. The shunt impedance of metglas rose 45%. However, there were no variation in characteristics of FT-3M. It is reasonable because the Curie temperature of FINEMET, 570 ℃, is higher than that of metglas, 410 ℃.

4 Summary

We have measured the characteristics of FINEMET cores and compared with the ferrite materials. The FINEMET cores showed the high shunt impedance at a few MHz frequency and both their μ and Q value were extremely stable under the high RF magnetic field strength and high temperature. And, the FINEMET cavity can damp the coupled bunch instability[4], because of its low quality factor (Q~1). The characteristics of the FINEMET is similar to those of soft magnetic materials as metglas. The metglas has temperature dependence, because of its relative low Curie temperature, however, the FINEMET does not have at the temperature of 150 ℃.

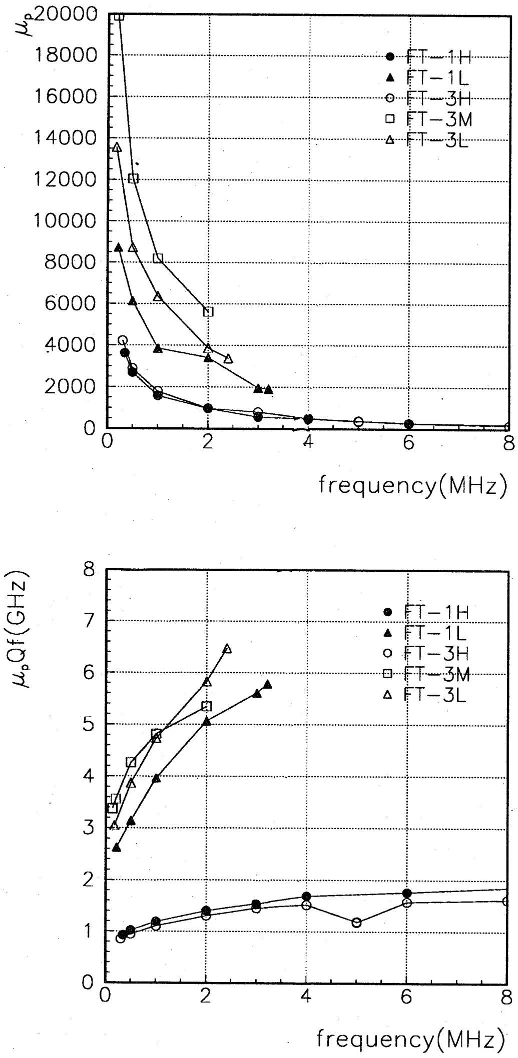

Figure 4: Comparison of FINEMET cores.

References

[1] Y. Mori *et al.*, The Japanese Hadron Facility, Proceedings of 1997 Particle Accelerator Conference, Vancouver, B.C., Canada 1997.

[2] T. Uesugi *et al.*, Summary of the measurement of magnetic materials for JHF RF cavity(1), JHP-31, Internal Report of JHF(only in Japanese).

[3] M. Fujieda *et al.*, Studies of Magnetic Cores for JHF Synchrotrons, Proceedings of 1997 Particle Accelerator Conference, Vancouver, B.C., Canada 1997.

[4] T. Uesugi *et al.*, Longitudinal Coupled Bunch Instability in the JHF 50GeV Main Ring, Proceedings of 1997 Particle Accelerator Conference, Vancouver, B.C., Canada 1997.

[5] C. Ohmori *et al.*, A Broad Band RF Cavity for JHF Synchrotrons, Proceedings of 1997 Particle Accelerator Conference, Vancouver, B.C., Canada 1997.

[6] M. Fujieda *et al.*, A Broad Band RF Cavity for JHF Synchrotrons, these proceedings.

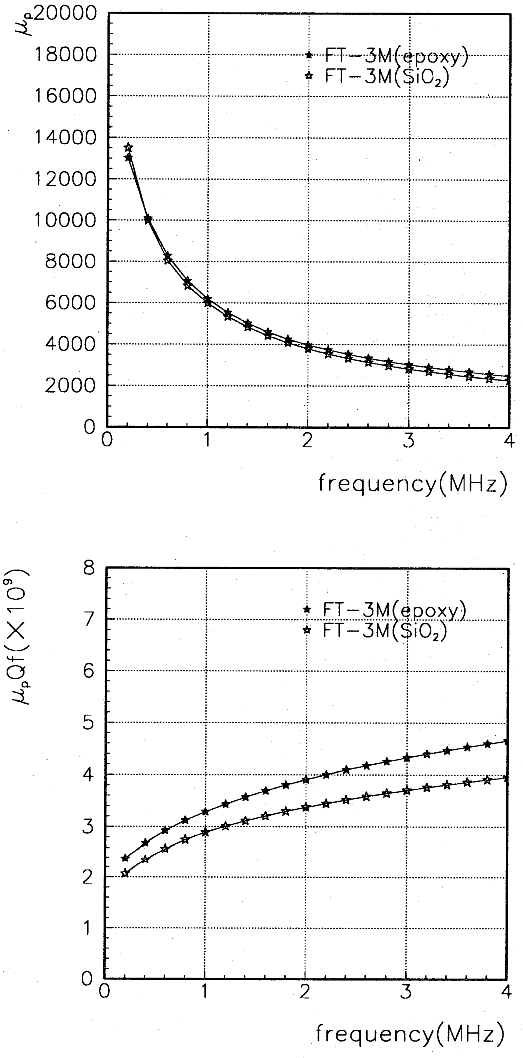

Figure 5: Comparison of insulation material.