EVALUATION OF MAGNETIC ALLOYS FOR JHF RF CAVITY

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Abstract

A new type of rf accelerating cavity using a high permeability magnetic alloy (MA) has been developed for the high intensity JHF proton synchrotrons. Compared with ordinary ferrites, the MA cores are very stable at high rf magnetic field and thus very high accelerating gradient (=accelerating voltage per cavity length) is available. We have measured several magnetic alloys in order to find a proper material for the cavity. In this paper, the test results are summarized and the evaluation of these materials is presented.

1 INTRODUCTION

In general, magnetic alloys have high permeability and low quality factor (Q value). An rf cavity loaded with the MA cores for high intensity proton synchrotron has many advantages [1]. Because the MA cores are stable up to the high rf magnetic field and have high Curie temperature, they can be used in high gradient operation [2]. Another advantage is to suppress the coupled bunch instability due to its low Q value [3]. If the Q value decreases from 30 to 1, the growth rate reduces by factor of 10. Furthermore, the MA core can make the cavity impedance broad. The MA loaded broad-band cavity does not need biasing circuit which sometimes causes the parasitic resonance.

Two materials were selected as the candidate of the cavity core. One is called FINEMET which is a Fe-based soft magnetic alloy composed of amorphous and ultra-fine grain [4,5]. Another one is an amorphous soft magnetic alloy.

We have measured the rf characteristics of these cores to find a suitable material for the JHF. This paper presents the results of the measurements and evaluation.

2 MEASURING METHOD

2.1 Fundamental Relations

The parallel complex permeability (suffix p) defined in equation (2) is adopted instead of the series expression (suffix s) in equation (1).

$$\mu=\mu_s'-j\mu_s'' \quad (1)$$

$$1/\mu=1/\mu_p'-1/j\mu_p'' \quad (2)$$

Using the parallel expression, the inductance (L_p) and the shunt resistance (R_p) are expressed as; [6]

$$L_p=\mu_0/2\pi\times t\times\mu_p'\times\ln(b/a) \quad (3)$$

$$R_p=\mu_0/2\pi\times\omega\times t\times\mu_p''\times\ln(b/a)=\mu_0\times t\times\ln(b/a)\times(\mu_p'Qf) \quad (4)$$

$$Q=R_p/\omega L_p=\mu_p''/\mu_p' \quad (5)$$

where, a is an inner diameter, b is an outer diameter and t is a thickness of the core, respectively. The quality Factor (Q) is the same in both expressions.

The relation between μ_s' and μ_p' is shown in equation (6).

$$\mu_p'=\mu_s'(1+1/Q^2) \quad (6)$$

It should be noted from equation (6) that in the case of high Q, μ_s' is nearly equal to μ_p' but in the case of low Q, both expressions are different. Therefore, we should give attention for evaluating the MA cores using the parallel complex permeability.

2.2 Test Bench

A test bench to measure L_p, R_p and Q of MA cores and ferrites, is shown in Figure 1 [7]. The test bench is a coaxial cavity composed of an inductance (MA) and a capacitance (vacuum capacitors). It can accept from large-sized core (diameter of 700mm) to small sample core (inner diameter of 30mm). The maximum rf power of 1kW is supplied from the rf feeder and the maximum bias current of 1000A is fed from the bias current feeders.

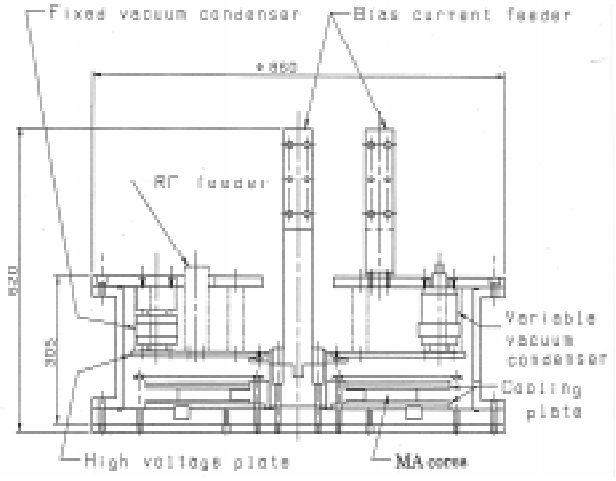

Figure 1. Cross section of the test bench for MA cores

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*3 : also Hitachi Corporation *4 : also The Japan Steel Works Ltd.
*5 : also CNS, Univ. of Tokyo *6 : also RCNP, Osaka Univ.
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3 MEASUREMENT RESULTS

Several FINEMETs and amorphous magnetic alloys listed in Table 1 have been tested.

Table 1. Test Samples of Magnetic Alloys (MA)

Material	Name	Comments
FINEMET	FT3M	Heat process without magne- tic field, 18μm*
	FT3L	Heat process with axial magnetic field, 18μm*
	FT3H	Heat process with azimuthal magnetic field, 18μm*
	FT1H	Extremely low magneto-striction but low $\mu_p'Qf$.
	FT1L	
Amorph-ous soft magnetic alloys	MET GLAS	Fe-based, 23μm*.
	Fe-Ni	Fe-Ni based , 16μm*
	Co	Co-based, low $\mu_p'Qf$.

*: tape thickness

These cores have an inner diameter of 32mm, an outer diameter of 70mm and a thickness of 25mm. Promising four cores, FT3M, FT3L, METGLAS and Fe-Ni based core, are reported in this paper.

3.1 Dependence of $\mu_p'Qf$ on RF Magnetic Flux Density

The $\mu_p'Qf$ dependence on rf magnetic flux density (B_{rf}) at 2MHz is shown in Figure 2. The B_{rf} is obtained from,

$$B_{rf}=V_{rf}/\omega S \qquad (7)$$

where V_{rf} and S mean the induced rf voltage and the cross sectional area of a core, respectively.

It is clear from Figure 2 that the $\mu_p'Qf$ of ferrites (Ni-Zn) is higher than that of FT3M and amorphous cores

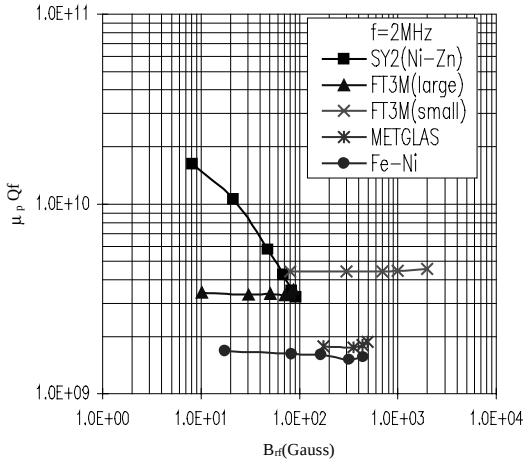

Figure 2. $\mu_p'Qf$ vs. B_{rf} for MA cores and ferrite

under low B_{rf}, but the $\mu_p'Qf$ of FT3M becomes higher over 100Gauss because it remains flat up to 2000Gauss.

The $\mu_p'Qf$ of the amorphous cores is about 1/3 of that of FT3M and nearly flat up to 500Gauss. Because in this case, the maximum B_{rf} is limited by the capacity of rf power source, there is a possibility that the amorphous cores can be used over 500Gauss.

3.2 RF Characteristics of Magnetic Alloys

As shown in Figure 3, the μ_p' becomes low gradually as the frequency increases. The μ_p' of FINEMET (FT3M and FT3L) is several 1000 around 2MHz and about 10 times higher than that of amorphous cores (METGLAS and Fe-Ni based core).

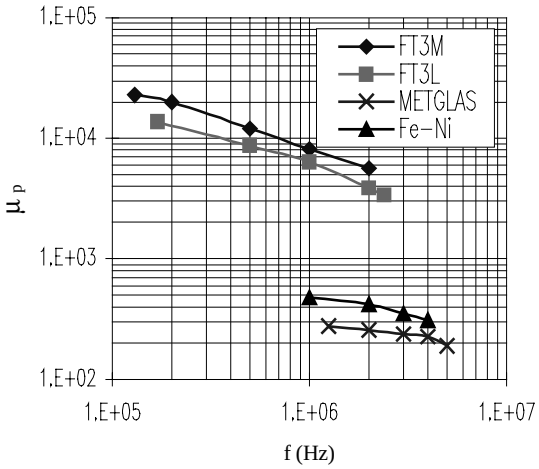

Figure 3. Comparison of parallel permeability (μ_p') for four MA cores (2MHz)

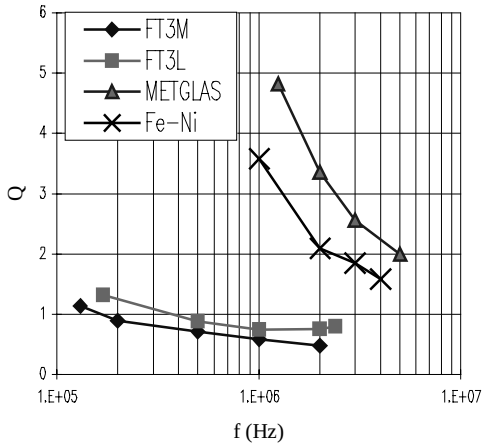

Figure 4. Comparison of Quality factor (Q) for four MA cores (2MHz)

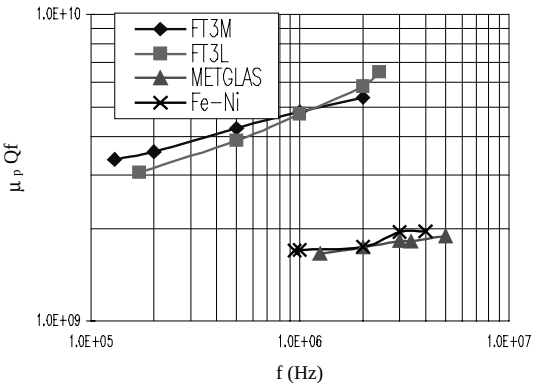

Figure 5. Comparison of μp′Qf for four MA cores (2MHz)

The comparison of quality factor (Q) is presented in Figure 4. The Q values of FINEMET are below 1 and those of amorphous cores are from 2 to 3 around 2MHz.

Figure 5 shows the comparison of μp′Qf. Both μp′ and Q value become low at higher frequency as known from Figure 3 and Figure 4, but the product, μp′Qf, becomes high as the frequency increases. The μp′Qf of both FINEMET cores is about 3 times high compared with the amorphous cores because of their high permeability (μp′).

3.3 Dependence of permeability and Q on Bias Field

Figure 6 shows the dependence of the μp′ on the DC bias magnetic field at 2MHz. FINEMETs are very sensitive to the bias field and therefore we can easily change the resonant frequency of rf cavity, if necessary. On the other hand, the amorphous cores are not sensitive to the bias field. For example, the μp′ of METGLAS hardly changes by the bias field.

Figure 7 shows the dependence of the Q value on the DC bias magnetic field at 2MHz. The Q values become large as the bias field increases and the μp′Qf of the amorphous cores increases because the change of their μp′ is small as seen from Figure 6.

4 CONCLUSION

The rf characteristics of the MA cores have been measured and evaluated. Several MA cores are stable even under high rf magnetic flux density and therefore they can be used in high gradient operation. Because FINEMET cores have high μp′Qf, the JHF rf cavities become compact by adopting them. On the other hand, the amorphous cores have high Q value and they will become promising candidate, if higher Q value is required.

Above-mentioned results have been acquired from small samples except FT3M. It is necessary for future study to measure the core of actual size.

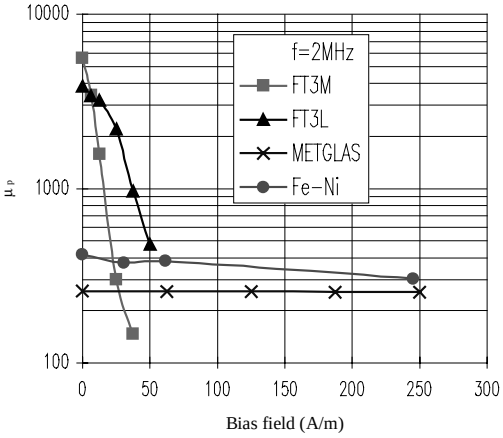

Figure 6. DC bias field dependence of μp′

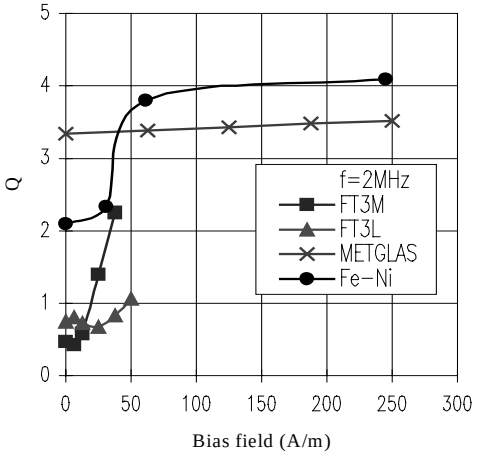

Figure 7. DC bias field dependence of Q

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