RF ACCELERATION CAVITY FOR TARN II

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ABSTRACT

An RF acceleration cavity for heavy ion beam synchrotron TARN II is designed. Design procedure and some results of numerical calculations are presented. A ferrite measurement experiment is prepared.

INTRODUCTION

At Institute for Nuclear Study, University of Tokyo, a synchrotron TARN II* has been designed to accelerate heavy ion beams.

A single-gap RF accelelation cavity, based on two quater-wave ferrite-loade coaxial lines excited in push-pull mode, is designed for the synchrotron. One RF feed is used to supply RF power. Tight coupling between two halves of the cavity is ensured by figure-of-eight loops which carry the ferrite bias current.

Table 1 shows the basic parameters of the RF cavity.

Table 1

Revolution frequency	0.38 - 3.75	MHz
Acceleration frequency	0.76 - 7.50	MHz
Harmonic number h	2	
Maximum RF voltage	6	kV

DESIGN PROCEDURE

As the acceleration frequency must be changed at least by a factor of ten, we study the cavity using TDK ferrite SY6, which has a large remanent permiability.

A beam aperture at RF cavity has been designed to be 200 mm. Adding the lengths of the spaces for beam pipe, heat insulation for vacuum baking, high voltage isolation and bus bars for ferrite bias current, an inner diameter of ferrite ring becomes 320 mm. We study the RF cavity using ferrite rings with dimensions 500x320x25 mm^3.

We design the cavity considering one half of the cavity structure including a gap capacitance Cg which is twice the capacitance between the acceleration gap. Because the two coaxial lines operate in push-pull mode, the voltage across the gap capacitance Cg will be equal to that at the open end of the line and the gap capacitance may be considered to be in pararel with the line.

An RF power is fed to a ferrite-tuned cavity to induce an RF voltage across the gap. When the RF voltage exceeds a certain threshold, an instability known as Q-loss effect occurs. The RF voltage V is given by

$$V = 2\pi f B_{rf} \ell R ,$$

where f frequency, Brf peak RF flux density, ℓ total length of ferrite rings in half cavity, R difference between outer and inner radii (r3= 0.25 m, r2= 0.16 m , R = 0.09 m) of ferrite rings.

We assume that RF induction Brf in ferrite must be less than 10 mT·MHz to avoid the instability due to the Q-loss effect. Then the total length of the ferrite rings must be larger than 0.53 m to induce RF voltage V= 3 kV (for half cavity).

Overall half cavity length L, consisting of a stack of n ferrite rings with inserted cooling-plates, acceleration gap and end flange, is

$$L = 0.025n + 0.007(n + 1) + 0.51$$
$$= 0.032n + 0.517 \text{ meters.}$$

n	L (m)	ℓ (m)
22	1.221	0.550
23	1.253	0.575
24	1.285	0.600
25	1.317	0.625

As an available space 2L for the cavity in straight section of the synchrotron is limited to 2.5 m, number of ferrite rings in the half cavity is set to 23, and ℓ = 0.575 m.

We have inner and outer radii of ferrite ring r3= 0.25 m, r2= 0.16 m and radius of inner conductor r1= 0.10 m. With a ferrite filling factor x, we have effective permitivity and permiability,

$$x = (\ln r3/r2)/(\ln r3/r1) = 0.4871,$$

$$\varepsilon_{eff} = \varepsilon / (x + (1 - x)\varepsilon) = 1.764 ,$$

$$\mu_{eff} = 1 + x (\mu - 1) \approx \mu x = 0.4871\mu.$$

Inductance and capacitance of ferrite loaded coaxial line of length ℓ are

$$Ld = \frac{1}{2\pi} \mu_{eff}\mu_0 \ell \ln(r3/r1)$$
$$= \frac{1}{2\pi} \mu\mu_0 \ell \ln(r3/r2),$$

$$Cd = 2\pi\varepsilon_{eff}\varepsilon_0 \ell / \ln(r3/r1) .$$

We have characteristic impedance for the line

$$Zc = Rc = (Ld/Cd)^{1/2}$$
$$= 60 (\mu_{eff} / \varepsilon_{eff})^{1/2} \ln(r3/r1)$$
$$= 28.9\mu^{1/2} .$$

The voltage across the line at the shorted end is zero and some current exists there. The voltage and current in the standing wave on the line, expressed as a function of distance z from the shorted end, are

$$i(z,t) = i(0,t) \cos(\beta z)$$

$$v(z,t) = j\, i(0,t)Rc \sin(\beta z),$$

where $\beta = 2\pi f/v = 2\pi f/c\, (\varepsilon_{eff}\mu_{eff})^{1/2}$
$= 1.94 \times 10^{-8} f\mu^{1/2}.$

The impedance of the shorted line of length ℓ is

$$Zin = v(\ell ,t)/i(\ell ,t) = jRc\tan(\beta\ell).$$

The line is adjusted in length ℓ and gap capacitance Cg so that the system is resonated at the required frequency,

$$Xgap + Xline = 0 ,$$

then $1 / \omega RcCg = \tan(\beta\ell)$ with $\omega = 2\pi f$.

Shunt impedance of the structure Rs is

$$Rs = 2\pi f L_d Q = \mu Q f \mu_0 \ell \ln(r3/r2)$$
$$= 3.22 \times 10^{-7} \mu Q f \text{ ohms},$$

* Katayama et al., Design Study of TARN II, Sep. 1984.

and the power dissipation in the ferrite is given by

$$P = V^2/2Rs = 13.96/(\mu Qf/10^9)\ kW.$$

NUMERICAL CALCULATIONS

Figure 1 shows a dependence of permiability on DC bias field for TDK ferrite SY6. Figure 2 shows a dependence of μQf product on RF frequency.

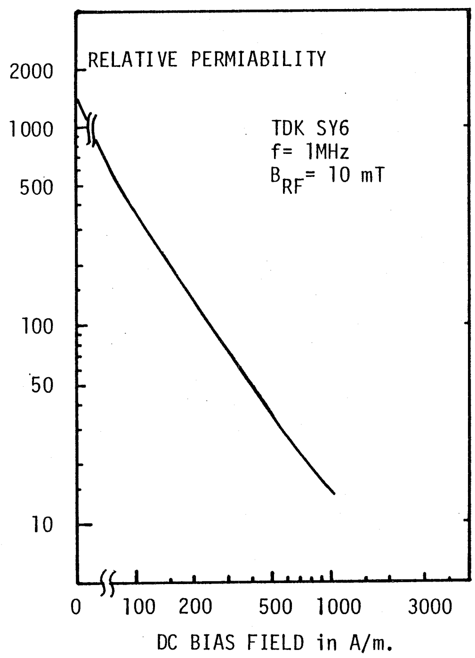

Fig. 1 Dependence of Permiability on DC Bias Field.

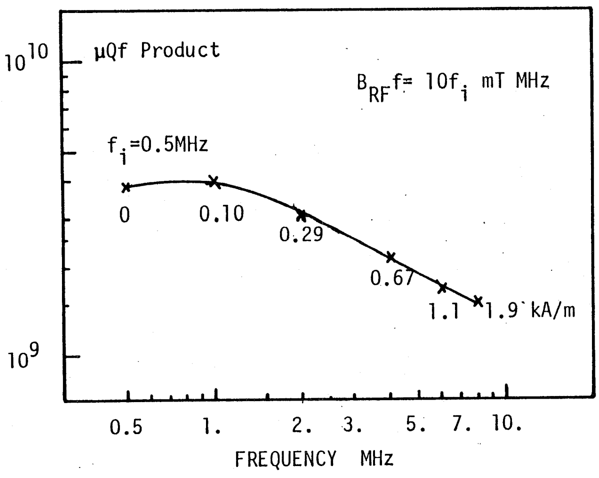

Fig. 2 Dependence of μQf Product on Frequency.

From Fig. 2, we see that at resonance frequency 1 MHz, bias field is 0.10 kA/m. From Fig. 1, permiability at 0.10 kA/m is 360. The resonance condition gives the gap capacitance Cg = 1350 pF.

Shunt impedance and power dissipation are calculated for various resonant frequencies and they are shown in Fig. 3, where we show the values for total cavity (i/e., Rs/2 and 2P).

Average power density dissipated in the ferrite is 160 mW/cm^3 at 8 MHz.

Maximum required magnetomotive force of the bias current is 2400 AT. We intend to use three loops for the bias current. Maximum power for bias current supply is estimated to be 400 W.

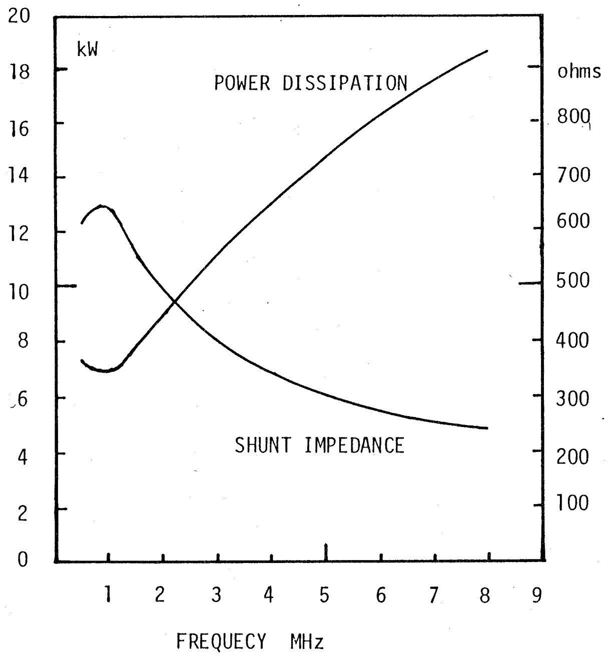

Fig. 3 Frequency Dependence of Power Dissipation and Shunt Impedance of the cavity.

Curie temperature of ferrite with high remanent permiability is very low. The Curie temperature of the TDK SY6 ferrite is 90 °C. Water-cooled copper plates are inserted between the ferrite rings for cooling. Total cooling water flow is 600 l/min.

Table 2 summarises the specifications of the cavity.

Table 2

Specifications of the RF cavity

Frequency range	0.76 - 7.50	MHz
Harmonic number	2	
Peak RF voltage	6	kV
Peak RF power	19	kW
Total length	2.50	m
Ferrite material	TDK SY6	
Ferrite ring dimensions	500 x 320 x 25	mm^3
Number of ferrite rings	2 x 23	
RF induction if ferrite	10	mT·MHz
RF power density	160	mW/cm^3
Number of bias turns	3	
Bias current	20 - 800	A
Cooling water flow	600	l/min

FERRITE MEASUREMENT USING TEST CAVITY

The data of ferrite used in the above calculations came from measurement on samll sample and with operation conditions which did not cover our RF cavity.

To verify the maximum RF induction in ferrite applicable without instability due to Q-loss effect and to measure general performances of ferrite rings, we are now preparing an experiment with full sacle ferrites.

Test cavity for the measurement is based on two quarter-wave coaxial lines loaded by two ferrite rings. The cavity is excited in pararel mode.

Shunt impedance, μ-H relation, Q-factor,bias-responce and Q-loss effect will be studied.

ACKNOWLEDGEMENT

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