RADIO FREQUENCY ACCELERATION SYSTEM FOR 150MEV FFAG

Akira Takagi#, Yoshiharu Mori, Joe Nakano, Tomonori Uesugi, Masahiro Sugaya
KEK, Tsukuba, Japan

Abstract

An rf cavity for 150MeV FFAG(Fixed Field Alternating Gradient) proton synchrotron has been developed. The rf cavity consists of four pieces of MA(Magnetic Alloy) core. These MA cores are indirectly cooled by thermally conductive spacers and cooling plates. One piece of MA core (Wide:1700mm, Height:950mm, Length:25mm) is mechanically supported by a cooling plate. The range of acceleration frequency is 1.5MHz to 4.6MHz. The acceleration voltage of 19kV and the acceleration cycle of 250Hz are required. A couple of rf stations are proposed to install in the 150MeV FFAG. Recent developments on the radio frequency acceleration system for 150MeV FFAG proton synchrotron are presented

INTRODUCTION

The fist acceleration of protons in the 500keV FFAG proton synchrotron (PoP=Proof of Principle FFAG) was demonstrated at KEK in March 2000 [1]. After this successes, the design and the construction of a 150MeV FFAG proton synchrotron has been started [2] The 150MeV FFAG is a prototype FFAG to investigate the possibilities of various applications such as proton beam therapy [3].

Since the magnetic field in the FFAG is static, therefore the acceleration cycle depends only on the sweep rate of the accelerating rf frequency. A high gradient rf cavity using the "FINEMET" MA (magnetic alloy) cores [4], has been developed at KEK [5]. With this new type of rf cavity, the acceleration cycle of the synchrotron can become very high, 1kHz or more, which is more than 100 times of the ordinary synchrotron cycle. Thus, the FFAG is an attractive machine for accelerating intense beams.

The rf cavity consists of four MA (Magnetic Alloy) cores. These MA cores are indirectly cooled by thermally conductive spacers and cooling plates. An MA core (Wide:700mm, Height:950mm, Length:25mm) is mechanically supported by the cooling plate. The rf acceleration parameters of the 150MeV FFAG are listed in table 1

Table 1: RF acceleration Parameters of 150MeV FFAG

Acceleration cycle	250Hz
Harmonic Number	1
RF frequency	1.5MHz~4.6MHz
Total acceleration voltage	19kV(peak)
Number of cavity	2

akira.takagi@kek.jp

CAVITY DESIGN

The metal water-cooled plates adopted on the one side of MA cores. A thermally conductive spacer [6] is inserted between the MA core and the cooling plate. The effect of thickness was measured for a small sized MA core (O.D.=340mm, I.D.=140mm, L=25mm). Figure 1 and Figure 2 show the cavity impedances as a function of rf frequency with the different thickness of cooling spacers with and without metal plate.

It was found that the "parallel inductance" of the core was strongly disturbed by the gap between the MA cores and the metal plate as shown in figure 2. The shorter gap between core and metal plate causes severe additional capacitive component. By these results, as a thermally conductive spacer, the thickness of 3mm is adopted to the full-scale design of cavity cooling plate.

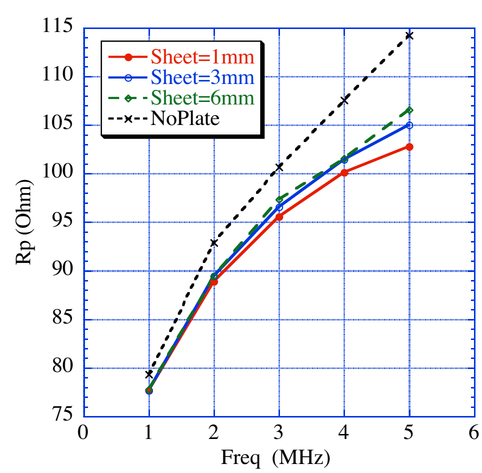


Figure 1: Shunt impedance v.s. rf frequency.

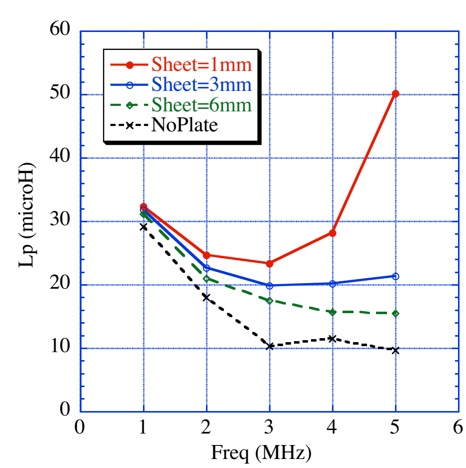


Figure 2: Parallel inductance v.s. rf frequency.

LARGE MA CAVITY

The full-scale cavity design is base on the rf cavity of PoP FFAG [7]. The horizontal dimension of vacuum duct is very large because of the orbit excursion of the FFAG is very large. By this reason, core size of 150MeV FFAG has a very large horizontal dimension. The mechanical dimensions of large MA core are listed in table 2.

Table 2: Mechanical dimension of large MA core

Core material	FINEMET(FT-3M)
Outer size	1700x950 mm
Inner size	980x230 mm
Aperture of metal frame	940x190 mm
Core Length	25 mm

The MA cores are indirect cooled by aluminum water cooled plates with the thermally conductive spacer (DENKA, FSL-B: 3W/mK). Total of four cores were installed in a cavity. When the power loss in a MA core is about 15tW/core, the estimated power density is about $1 W/cm^3$ in a MA core.

Figure 3: Photograph of cooling plates and MA cores

Figure 4: Photograph of the 150MeV FFAG cavity.
(After a vacuum duct with a ceramic gap was inserted)

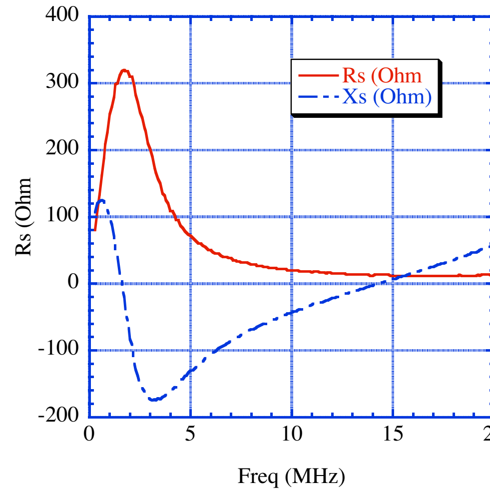


Figure 5: Measured values of the cavity impedance.
(Rs is real part and Xs is imaginary part)

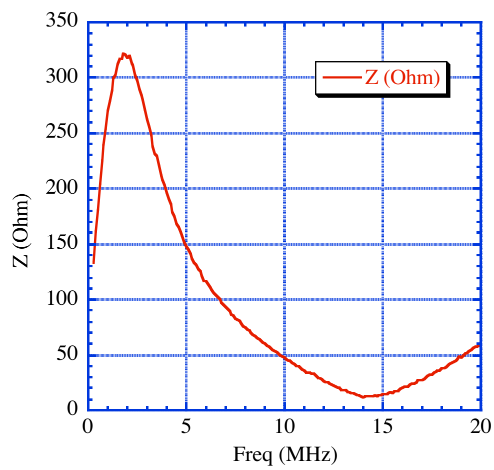


Figure 6: Measured values of the cavity impedance.
(Z is the impedance magnitude)

Total cavity cooling water flow rate of 70 litter/min is required. Figure 3 shows a photograph of cooling plates and MA cores during assemble a cavity.

Actual impedance of cavity is strongly affected by additional stray capacitance from the cavity components such as a ceramic gap, cooling plates and so on. The rf cavity is connected with the vacuum tubes of a high power rf amplifier. The cavity impedance with vacuum tubes was measured by using the network analyzer. Figure 4 and 5 show the results of these measurements.

It was found that the big capacitance components cause the reduction of cavity impedance. The measured impedances (Z) of 320~170Ω are correspond to the acceleration frequency range of 1.5~4.6MHz. We prepared one set of rf station (cavity & amplifier) only, The second rf station of 150MeV FFAG will be newly designed after actual operation of this rf system.

WIDE BAND AMPIFIER

The radio frequency high power amplifier supplies rf power to the cavity. Specifications of the rf wideband amplifier for the 150MeV FFAG proton synchrotron are listed in table 3.

Table 3: Specifications of the rf amplifier

RF frequency	1.5 MHz~4.6 MH
RF voltage	0.5 kV(peak)
RF output power	55 kW
Class	B class, Push-pull
Power Tube	4CW25000Ax 2

Several types of wide band rf power amplifiers was developed at KEK [8],[9].

The first is the direct loop couple method by using an anode wire. Second is the choke couple method with dc cut capacitors. A schematic diagram of choke coupling circuit is shown in figure 7. A practical choke circuit is shown in figure 8. This second method has an advantage about the voltage holding in the cavity circuit. But the defect is that the choke has some resonance mode.

The 2nd resonance of the choke is the serial resonance mode. As this serial resonance makes the short circuit to the anode potential, the fr voltage at the anode of the tube is eliminated by the second resonance.

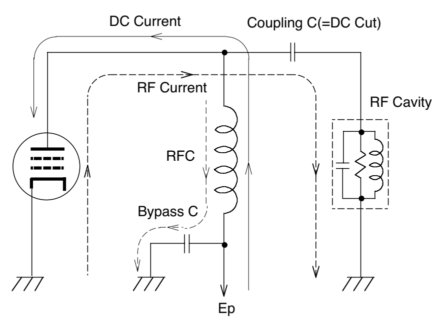


Figure 7: Diagram of the output circuit with RFC (Radio Frequency Choke) and the dc cut capacitor.

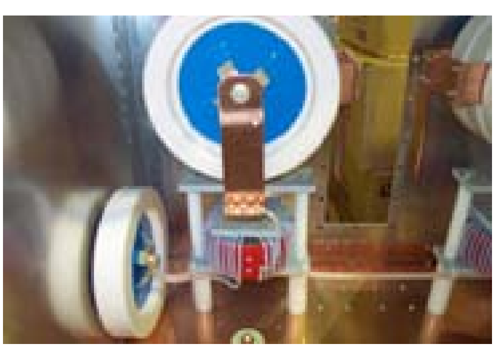
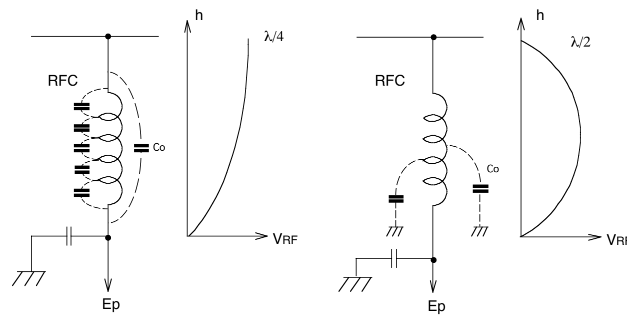


Figure 8: Photograph of the output circuit in the rf power amplifier. An RFC and dc cut capacitor are connected by the large sized cooper bus bar. RFC is winding on three pieces of toroidal cores.

Figure 9 shows origins of these resonances in the anode choke coil. The 1st resonance is a parallelresonance, this resonance mode has not severe effect. The measured 2nd resonance frequency of the actual choke coil was about 12MHz. This higher frequency of 2nd resonance is achieved by using special toroidal cores.



(a) (b)

Figure 9: Resonance modes of anode RFC coil.
(a) 1st resonance (=parallel resonance).
(b) 2nd resonance (=serial resonance).

SUMMARY

A wideband rf acceleration system for the 150MeV FFAG proton synchrotron has been developed at KEK. The indirect cooling core cooling method was developed with a special thermally conductive spacer sheet. An anode choke coil shows good quality by using special toroidal cores.

REFERENCES

[1] M. Aiba *et al.*, “Development of a FFAG proton synchrotron”, EPAC2000, p. 581.
[2] T. Adachi *et al.*, “A 150MeV FFAG synchrotron with return-yoke free magnet”, PAC200, p. 3254.
[3] http://hadron.kek.jp/FFAG/.
[4] Hitachi Metals, Ltd., FINEMET: FT-3M.
[5] Y. Mori *et al.*, “A new type of rf cavity for high intensity proton synchrotron using high permeability magnetic alloy”, EPAC98, p. 299.
[6] DENKA, Ltd., General type: FSL-B.
[7] Y. Mori *et al.*, “Multi-beam acceleration in FFAG synchrotron”, PAC2001,p. 588.
[8] C. Ohmori *et al.*, “A wide band rf cavity for JHF synchrotron”, PAC97, p. 2993.
[9] Y. Sato *et al.*, “Wide-band push-pull amplifier for high gradient cavity”, PAC99, p. 1007.