RF High Power System of the HIMAC Synchrotron

M.Kanazawa , K.Sato , A.Itano , K.Noda
E.Takada , M.Sudo , T.Kouno , A.Kitagawa
H.Ogawa , Y.Sato , S.Yamada , T.Yamada
Y.Hirao

National Institute of Radiological Sciences
4-9-1, Anagawa, Chiba-shi 260, Japan

Y.Morii , K.Katsuki , C.Yamazaki , E.Toyoda
T.Yagi

Toshiba Corporation
1-1-6 Uchisaiwai-cho, Chiyoda-ku, Tokyo, 100, Japan

Abstract

The HIMAC(Heavy Ion Medical Accelerator in Chiba) is now under construction at NIRS(National Institute of Radiological Science). The RF system for HIMAC synchrotron was manufactured and tested. The characteristics and tested results of RF high power system are described in this paper.

Introduction

HIMAC is an accelerator facility for tumor therapy. The accelerator complex consists of injector linac, two separated function type synchrotron rings in parallel and beam transport system to treatment rooms and experimental rooms. The synchrotron accelerates heavy ion (He to Ar) from injection energy of 6MeV/u to maximum energy of 800Mev/u. The specifications of synchrotron are listed in Table 1.

Table 1
Specification of HIMAC synchrotron

Ion species	from ^{4}He to ^{40}Ar
Injection energy	6Mev/u for q/A=0.25, 0.5
Maximum energy	800Mev/u for q/A=0.5
Minimum energy	100Mev/u
Momentum spread	<±0.3%
Circumference of ring	129.6m
Beam intensity	10^{7} - 10^{11} pps
Rf frequency range	1 - 8MHz
Harmonic number	4
Filling factor	0.8
Number of cavity	1 (2 in future)
Total Peak RF voltage	11 kV at 1MHz
Repetition rate	0.3 - 1.5 Hz
Rise time	0.7s
Flat top time	0.5s

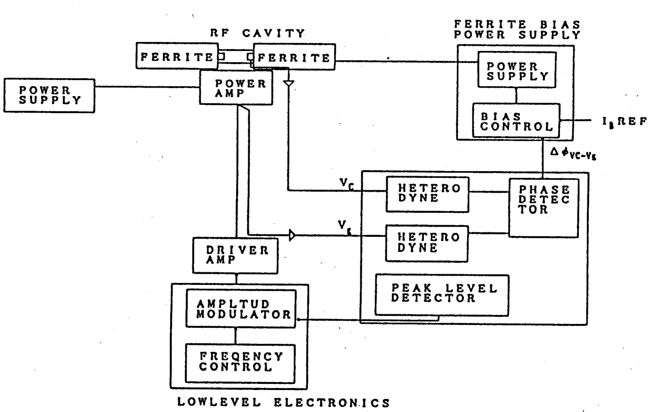

Fig.1 Block diagram of high power RF system for HIMAC

The RF system of synchrotron captures the injected beam and accelerates the beam from injection energy to top energy. The frequency of RF increases from 1MHz to 8MHz synchronized with beam energy. The block diagram of high power RF system for HIMAC synchrotron is showed in Fig. 1. The RF cavity is a ferrite-loaded resonator, and tuned by bias current from a ferrite bias power supply. RF signal from low level electronics is amplified by a transistor driver amplifier and a tetrode amplifier. A tetrode final amplifier is put under RF cavity. Vc which is a cavity gap voltage, and Vg which is a tetrode control grid voltage are monitored. A monitor electronics detect the phase difference between Vc and Vg($\Delta\phi$ (Vc-Vg)), and Vc peak level. $\Delta\phi$ (Vc-Vg) signal is used for the correction of ferrite bias current in order to tune the RF cavity (tuning feed back loop). Vc peak level signal is used for the correction of RF voltage (amplitude feed back loop).

RF Cavity

The RF cavity has a single gap and two ferrite loaded quarter wave coaxial resonator. This cavity is almost same design as one of TARNII at INS.1) A resonance frequency is changed factor 8 by a bias field with a figure-of-eight ferrite bias windings. Fig.2 shows a cross section of the RF cavity. Its current needs to be change from 10A to 600A synchronized with frequency.
The RF cavity should be adjusted to avoid parasitic oscillation and abnormal resonance .

Table 2
Specification of the RF cavity

Peak gap voltage (cw)	6kV
Total length	2800mm
Number or ferrite bias windings	4
Ferrite data	
Outer diameter	500mm
Inner diameter	320mm
Thickness	25mm
Number of ferrite	2×24
Material	TDK SY6
Relative permeability	18 - 1200
B·f	<10mTMHz
Shunt impedance	350 - 650

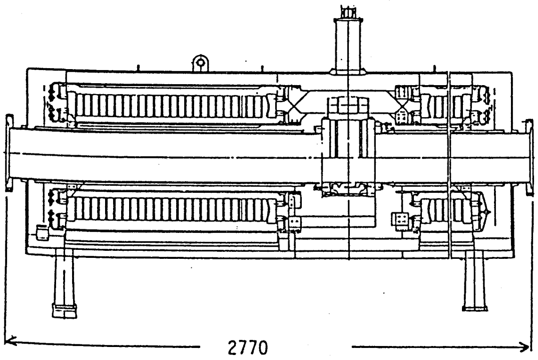

Fig.2 RF cavity

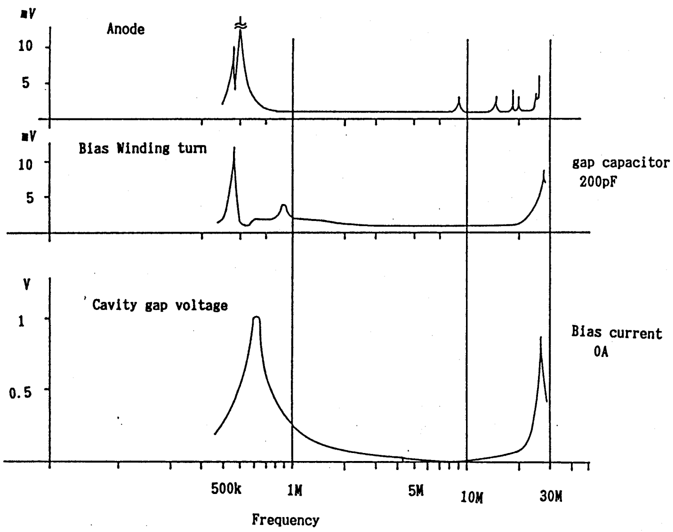

Fig.3 Low power test

RF high power amplifier

RF high power amplifier consist of a transistor 500W driver amplifier (ENI A500) and a final tetrode amplifier (Eimac 4CW100000E). These amplifiers are wide band frequency type. All pass network is adopted at the input circuit of the final amplifier. Table 3 shows specification of RF high power amplifier.

Table 3
Specifications of RF high power amplifier

Maximum output power	30kW
Tetrode tube	Eimac 4CW100000E
Typical operation Parameter	
Anode	6.5kV 7A
Control grid	-150V
Screen grid	1kV
Filament	17V 200A
Driver amplifier	ENI A500

Ferrite bias power supply

Ferrite bias power supply is operated by the pattern function of the pattern memory and correction function from $\Delta\phi$ (Vc-Vg) signal(see ref. 2)). It is a transistor dropper power supply which output current is from 10 to 900A. Its load is ferrite bias windings, and the inductance of the load changes from 16μH to 1mH because permeability of ferrite changes with bias current. Therefore current feed back gain has to be variable as out put current increases. And phase ($\Delta\phi$ Vc-Vg) feed back control loop gain has to be variable, too. Table 4 shows specifications of ferrite bias power supply.

Table 4
Specifications of ferrite bias power supply.

Output DC current	10 - 900A
Rise time	0.45mS
Accuracy of current	0.2A ; 10 - 200A
	1.0A ;200 - 900A

High power test

The RF high power and control system have been combined and tested at Toshiba Fuchu Works.

We have confirmed that there were no abnormal resonance in the cavity at low power. Fig.3 shows frequency vs. voltage at Anode, bias winding and cavity gap against earth. It shows no abnormal resonance from 860kHz to 9.03MHz.

We confirmed the performance of the tetrode amplifier at 6kV, and obtained good result. Since the good high power and wide band dummy load is not obtainable, this test was the first time to confirm the performance of the tetrode amplifier by combined RF system. Fig.4 shows ferrite bias current, Q-factor, frequency at Vc=6kV. Fig.5 shows Vc and Q-factor at 1, 3 and 8MHz. Q-factor decreases but saturates as Vc increases.

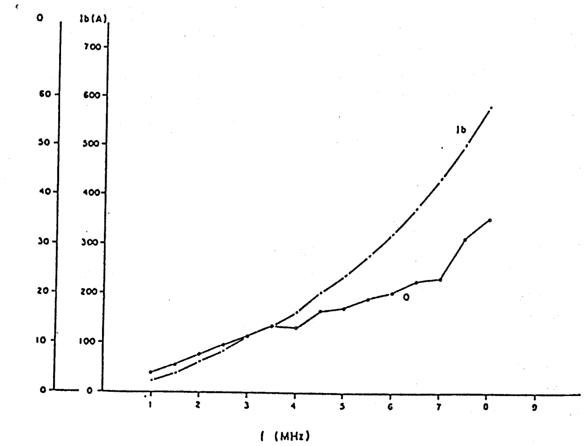

Fig4. Ferrite bias current, Q factor, Frequency at Vc = 6kV

Provided a RF cavity is a LCR concentrated constant circuit , the Q factor of RF cavity is followed.

$$Q = R/(\omega L)$$

Where R is a shunt impedance, L is an inductance. Since the variation of permeability of ferrite SY6 is rather small, the inductance L is considered as constant value. So the shunt impedance R at Vc=6kV is followed.

$$R = (QRo)/Qo$$

Where Ro·Qo are measured at Vc=0kV. The result is showed at Fig.6. The shunt impedance R is nearly constant from 1MHz to 8MHz.

Then high power system and control system were combined and were operated a typical acceleration pattern of frequency, bias current and Vc as shown in Fig.7.

After the high power test the cavity has been checked, and a break of the capacitor which is attached to a ferrite bias winding was found. This break is due to two small parasitic resonances which were not found at low power test with zero ferrite bias current. The frequencies of these resonances were 2.3MHz and 4.3MHz. But these resonances don't affect the cavity under the normal operation.

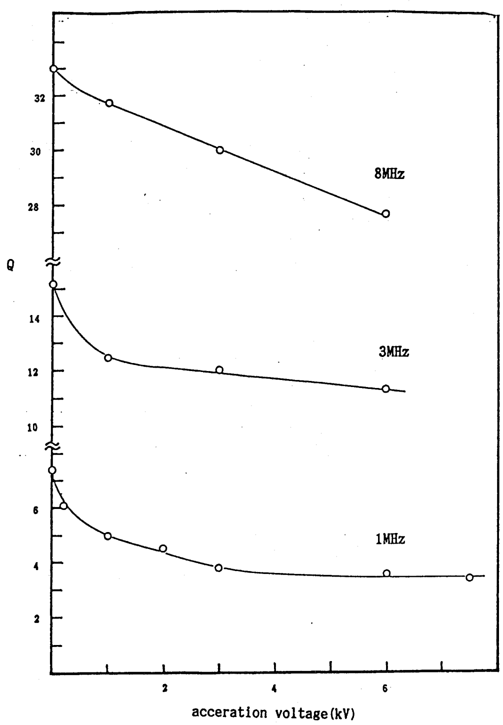

Fig.5 Vc and Q factor

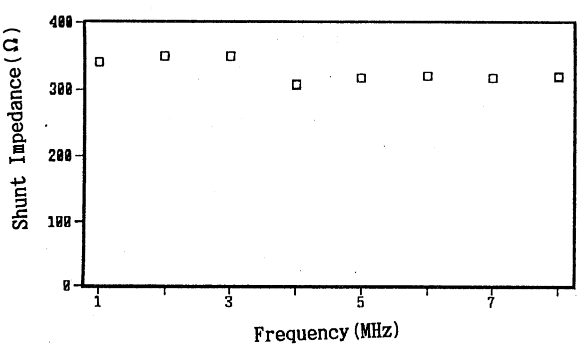

Fig.6 Frequency and Q factor

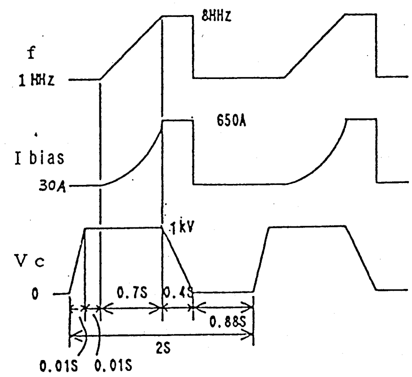

Fig.7 Acceleration pattern

Conclusion

We confirmed that the RF high power system for HIMAC synchrotron was stably operated at Vc=6kV from 1MHz to 8MHz, with a typical acceleration pattern. It is difficult to confirm the performance of the high power RF system consisted of several equipments. So it is profitable to test the RF system at works before it is operation on site. In the next high power test, we will try to remove the parasitic resonance and increase the acceleration voltage.

Acknowledgment

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Reference

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