DEVELOPMENT OF THE RF SYSTEM FOR THE COMPACT PROTON SYNCHROTRON

Z. Fang, K. Endo, K. Egawa, KEK, Tsukuba, Japan
T. Hirashima, Denki Kogyo Co., Aikou-gun, Japan

Abstract The rf system for the compact proton synchrotron is being developed, which is required to be of a wide bandwidth with the frequency sweeping from 1.64MHz to 14.26MHz, and a high gradient with the maximum acceleration voltage of 20kV. The acceleration section consisting of 2 cells of rf cavity loaded with 4 high-permeability magnetic alloy cores in each cell has been designed. A push-pull power amplifier with two 35 kW tetrode tubes will be used to drive the 2 cavities in parallel. The present status of the rf system development is described.

1. Introduction

The compact proton synchrotron is being developed for proton therapy [1-5] with a ring of circumference of 11.9m. The protons will be accelerated from 2MeV to 200MeV within 5ms. Fig. 1 shows the bending magnetic fields, the fundamental rf frequency, and the proton energy, as functions of acceleration time. It shows that the fundamental rf frequency increases from 1.64MHz to 14.26MHz. Fig. 2 shows the required beam accelerating voltage, the rf cavity voltage and the acceleration phase, as functions of acceleration time. It is shown that the maximal rf cavity voltage of the fundamental is 13kV at the start of acceleration. In order to increase the capture efficiency, high order harmonics will also be applied to the cavity to get a flat region in the cavity voltage signal. Consequently, the rf system is designed to produce maximal gap voltage of about 20kV.

Therefore the rf acceleration system should be developed with a wide bandwidth and a high gradient. The acceleration section consisting of 2 cells of rf cavity loaded with high-permeability magnetic alloy cores has been designed, and a push-pull power amplifier with two 35 kW tetrode tubes will be used to drive the 2 cavities in parallel [6].

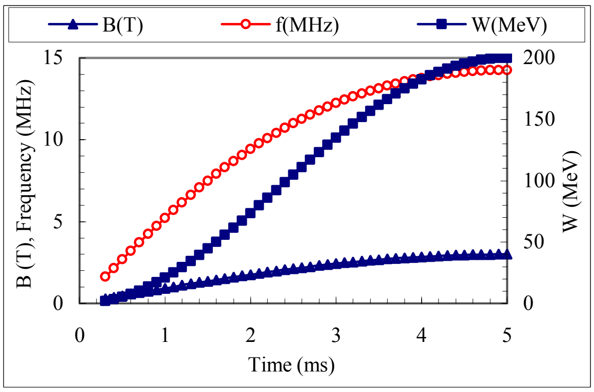


Figure 1: Bending magnetic fields, fundamental rf frequency, and proton energy, as functions of acceleration time.

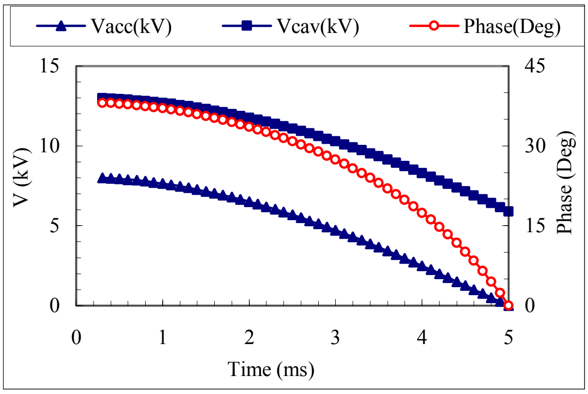


Figure 2: Required beam accelerating voltage, rf cavity voltage, and acceleration phase, as functions of acceleration time.

2. RF Cavity

The designed rf cavity structure is shown in Fig. 3. It consists of 2 cells, loaded with 4 high-permeability magnetic alloy cores in each cell. The core dimension is 397 mm and 170 mm in outer and inner diameters, and 25 mm in length. The length of each cell is 200 mm, and the total length of the acceleration section is 500 mm.

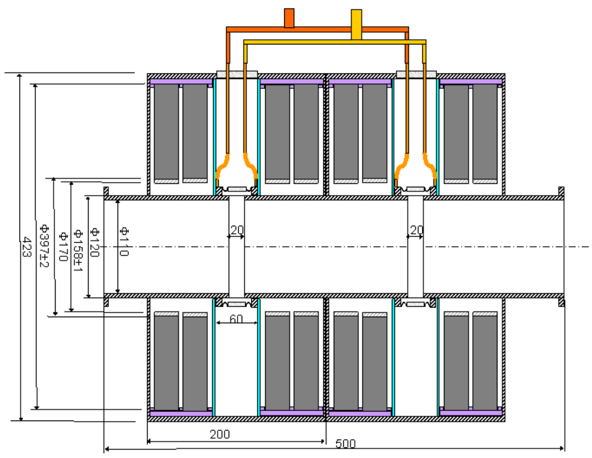


Figure 3: Structure of rf cavity.

Since the cavity wall is connected to the ground and the 2 rf cavities are driven by a push-pull amplifier, the equivalent circuit of the rf cavity can be illustrated by using Fig. 4. Since the rf cavity consists of 4 same units, the cavity characteristics can be evaluated just with the impedance of one unit, namely, one quarter of the rf cavity.

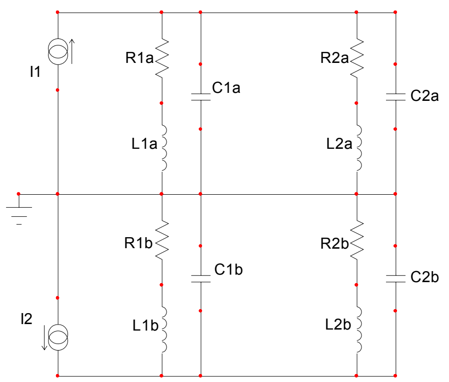


Figure 4: Equivalent circuit of rf cavity.

The impedance of one unit is calculated by:

$$Z_{cav} = \frac{1}{\dfrac{1}{j\omega(u' - ju'')L_0} + j\omega C}$$

where $u = u' - ju''$ is the complex permeability of cores, and $L_0 = \frac{u_0}{2\pi} h \ln\frac{b}{a} = 2\times10^{-7}\times h\ln\frac{b}{a}$, where a and b are the inner and outer diameters of cores, and h is the core length. C is the distributed capacitance for one unit.

The rf cavity has been developed, as shown in Fig. 5, and the impedance of the 4 units has been measured. The test and calculation results of the average value of impedance of each unit are shown in Fig. 6. It is shown that the test results agree with the calculation results very well. The distributed capacitance for each unit is about 35pF. Also as shown from Fig. 6, the rf cavity is of a very good performance of frequency response, with a high shunt impedance over the whole operating frequency range.

For the cores used in this cavity, the measured average value of core permeability is:

$$u' = 2409\times(\frac{f}{0.5})^{-0.8} \quad \text{and} \quad u'' = 6047\times(\frac{f}{0.5})^{-0.85}$$

where f is in MHz.

The high power test of the rf cavity is planned in the coming months.

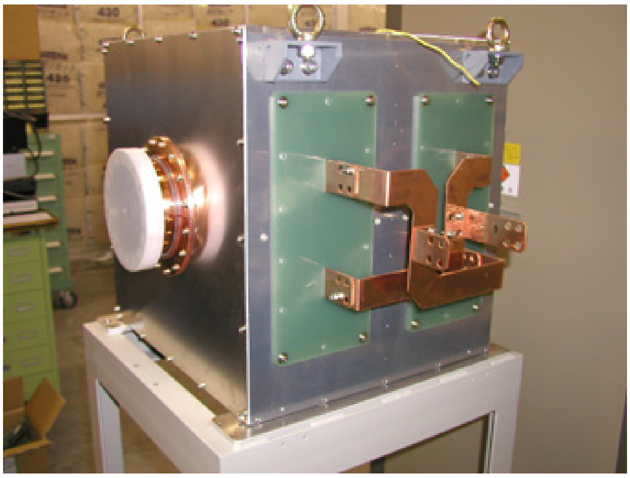
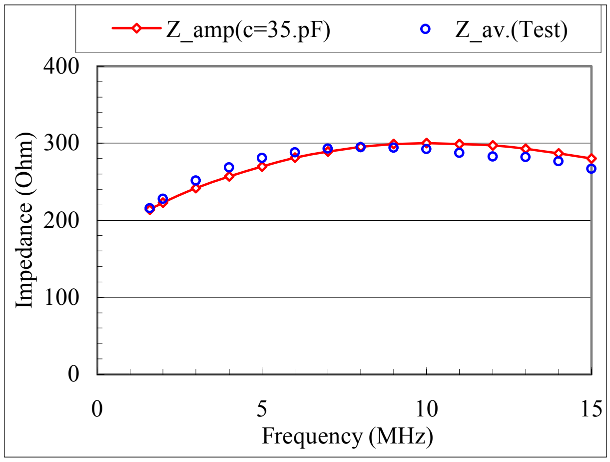
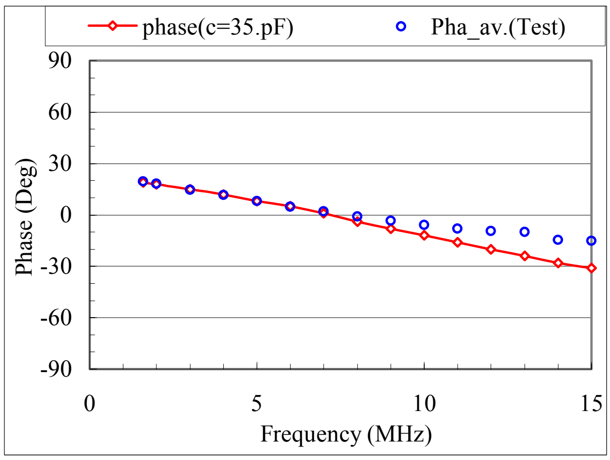


Figure 5: RF cavity.



a) Impedance amplitude



b) Impedance phase

Figure 6: Test and calculation results of average value of impedance of one quarter of rf cavity.

3. Power Amplifier

In the rf system, two tetrode tubes 4CX35,000C is used to form a push-pull amplifier to drive the two cells of rf cavity in parallel. The plate, screen and grid dissipations of the tube are 35kW, 1750W, and 500W, respectively. The input and output capacitances of the tube are 440pF and 51pF, respectively. Each side of the cavity gaps is directly connected to the anodes of the two tubes through the DC blocking capacitors. The rf system has been simulated by using ICAP code, as shown in Fig. 7. The anode and screen voltage are set as 10kV and 2kV, respectively. Due to the wide bandwidth, two rf driving sources are used for the two tubes respectively, and the phase difference between the two rf driving voltages is 180 degrees. In Fig. 7, the distributed capacitance for each unit is set as 40pF.

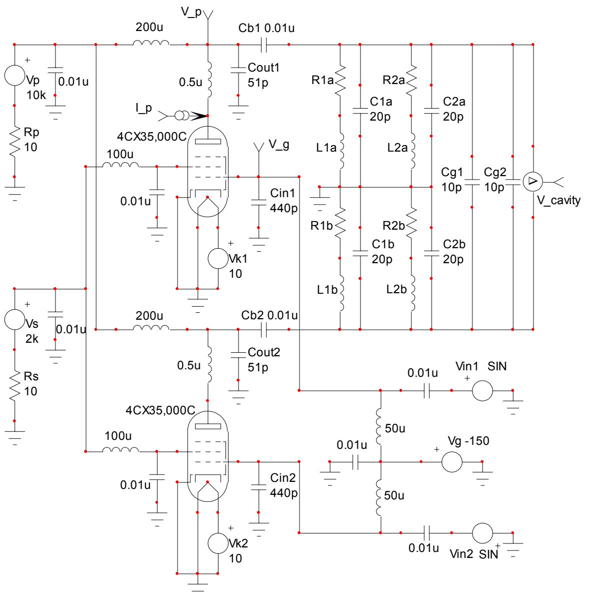


Figure 7: Simulation of rf system by using ICAP code.

Table 1: Specifications of power supplies.

	Specifications	Working point	No. of sets
Anode PS Voltage DC current	 9,10,11 kV 100 A	 10 kV 90 A	1 set
Screen PS Voltage DC Current	 1.0~2.5 kV 2 A	 2 kV 1 A	1 set
Grid PS Voltage DC Current	 -800, -300~-100 V 1.2 A	 -800V,-300~-100 V 0.6 A	2 sets
Heater PS Voltage DC Current		 10.0±0.5 V 295 A	2 sets

For the power amplifier, the specifications of power supplies are listed in Table 1. For the grid power supply, the voltage is set to -800A during the cutoff; and for beam on, it can be set from -300 to -100 V.

Fig. 8 shows the simulation results at different acceleration time. It is shown that we can get the required voltage at gap by applying a driving rf voltage, which is nearly proportional to the ratio of the required gap voltage to the impedance of one quarter of the rf cavities, which is shown in the black curve in Fig. 8. From the simulation results, the rf system will work well to satisfy the rf requirements of the proton synchrotron.

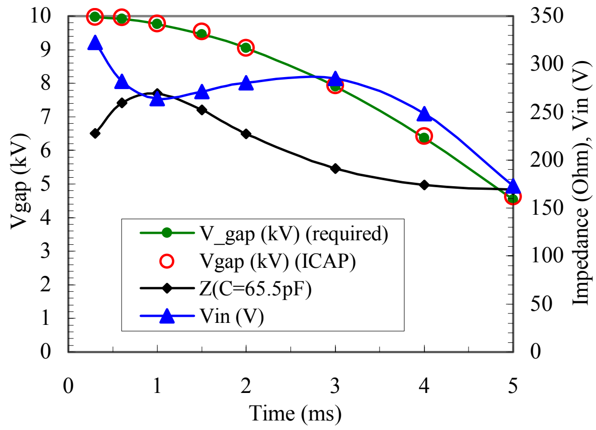


Figure 8: Simulation results of rf system at different acceleration time.

The power supplies of anode, screen, grid, and filament have been developed as shown in Fig. 9, Fig. 10, Fig. 11, and Fig. 12, respectively.

The main amplifier is under manufacture. And the rf system test will be performed soon.

4. Summary

The rf cavity has been designed and developed to be of a wide broadband and high gradient. The test results agree with the calculation results very well. The power amplifier system with two tetrode tubes 4CX35,000C has been simulated by using ICAP code. The power supplies of the amplifier have been developed. And a high power test of the rf system will be performed soon.

5. References

[1] K. Endo et al, Compact Proton Synchrotron, Proceedings of the 4th Symposium on Accelerator and Related Technology for Application (ARTA 2001), Japan, 11-14, Oct. 2001.

[2] K. Endo et al, Compact Proton and Heavy Ion Synchrotron for Cancer Therapy and Bio-Science, Proceedings of the 13th Symposium on Accelerator Science and Technology (SAST 2001), Japan, 426-428, Oct. 2001.

[3] K. Endo et al, Compact Proton and Carbon Ion

Synchrotrons for Radiation Therapy, Proceedings of the 8th European Particle Accelerator Conference (EPAC 2002), France, 2733-2735, Jun. 2002.

[4] K. Endo et al, Development of High Field Dipole and High Current Pulse Power Supply for Compact Proton Synchrotron, Proceedings of the 2003 Particle Accelerator Conference (PAC 2003), USA, May 2003.

[5] K. Endo et al, Development of Compact Proton Synchrotron for Radiation Therapy, this conference.

[6] Z. Fang et al, RF Cavities and Power Amplifier for the Compact Proton Synchrotron, Proceedings of the 2003 Particle Accelerator Conference (PAC 2003), USA, May 2003.

Figure 9: Anode power supply.

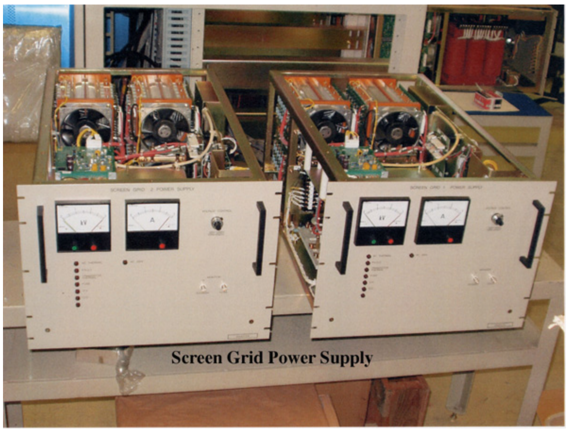


Figure 10: Screen power supplies.

Figure 11: Grid power supplies.

Figure 12: Filament power supplies.