TEST RESULTS OF RF CAVITY AND POWER AMPLIFIER FOR COMPACT MEDICAL PROTON SYNCHROTRON

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Abstract

A compact proton synchrotron with a circumference of 11.9m is being developed for the medical radiotherapy [1-3]. The synchrotron acceleration system 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 [4-5]. The prototype of the rf acceleration system has been developed. The rf cavity consists of 2 cells loaded with 4 high-permeability magnetic alloy cores in each cell, and a push-pull power amplifier with two 35kW tetrode tubes is used to drive the 2 cells of the cavity in parallel. The test results and design values of the rf cavity and power amplifier will be presented.

1 INTRODUCTION

The compact proton synchrotron is being developed for the medical radiotherapy [1-3]. The protons will be accelerated from 2MeV to 200MeV in the ring of circumference of 11.9m within 5ms. Consequently, the rf acceleration system is required to be of a wide bandwidth with the fundamental frequency sweeping from 1.64MHz to 14.26MHz, and a high gradient with the maximum acceleration voltage of 20kV [4-5]. The prototype of the rf acceleration system has been developed. Fig. 1 shows the rf cavity and amplifier, and Fig.2 shows the power supplies for the rf amplifier.

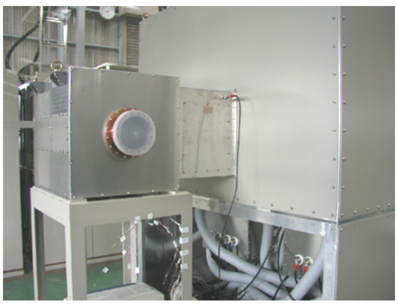


Figure 1: RF cavity and power amplifier.

Figure 2: Power supplies for rf amplifier.

2 RF CAVITY

The rf cavity consists of 2 cells loaded with 4 high-permeability magnetic alloy cores in each cell, as shown in Fig. 3. The cavity length is 500mm. The cavity impedance is calculated by

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

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.

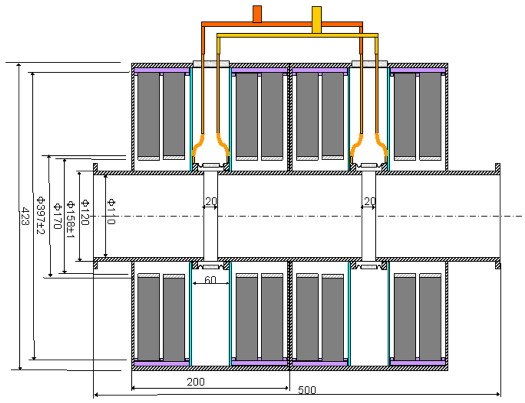
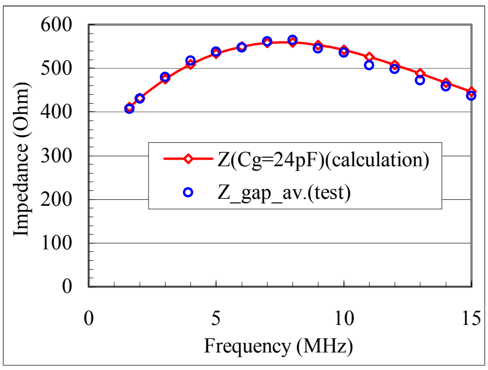
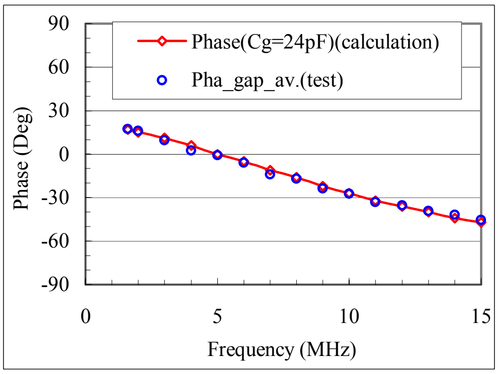


Figure 3: Structure of rf cavity.

The impedances at the two gaps have been measured. The average impedance of test results and the calculation results for gap capacitance of 24pF are shown in Fig. 4. It is shown that the test results agree with the calculation results very well. And for the cores used in this cavity, the measured average value of core permeability is $u' = 880\times(\frac{f}{1.6})^{-0.81}$ and $u'' = 2160\times(\frac{f}{1.6})^{-0.81}$, where f is in MHz.



a) Impedance amplitude



b) Impedance phase

Figure 4: Test and calculation results of cavity gap impedance.

3 POWER AMPLIFIER

In the rf system, two tetrode tubes 4CX35,000C are used to form a push-pull amplifier to drive the two cells of rf cavity in parallel, as shown in Fig. 5. 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 of 0.1uF.

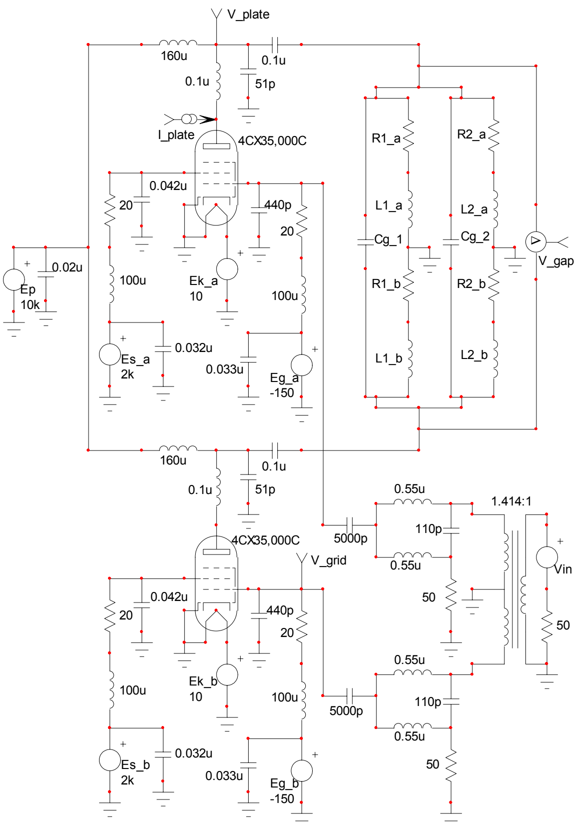


Figure 5: Circuit of rf system.

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.

Table 1: Specifications of power supplies.

	Specifications	Working point	No. of sets
Anode PS Voltage DC current	 9~11 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	2 sets
Grid PS Voltage DC Current	 -800, -300~-100 V 1.2 A	 -800V,-300~-100 V <0.6 A	2 sets

A 2kW preamplifier T145-6346B (Thamway Co., LTD) has been developed and is used to drive the main amplifier. The performance of preamplifier is shown in Fig. 6. It shows that the gain of preamplifier depends on both frequency and driving power.

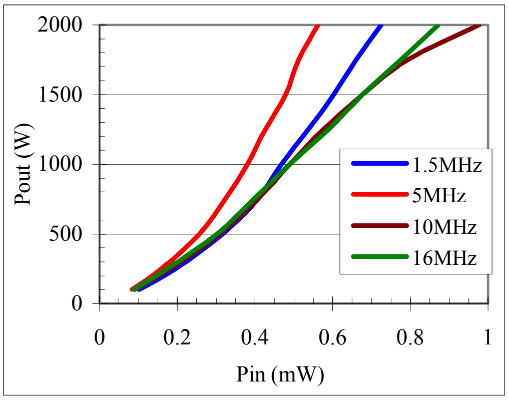


Figure 6: Preamplifier output power as function of input power for different frequency.

Two all-pass networks are applied to the input circuits matching the tubes' input capacitances. The all-pass networks are formed by 110pF capacitors and 0.55uH inductors, as shown in Fig. 5. And these parts have been adjusted a little to match the actual input capacitance of tubes, and SWR smaller than 1.07 has been obtained in the frequency range from 1MHz to 15MHz, as shown in Fig.7.

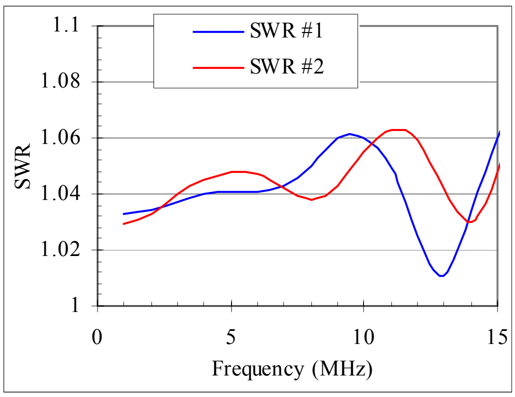


Figure 7: SWR of two input matching circuits for tubes.

4 RF SYSTEM TEST

A low input power of -16dBm has been fed to the preamplifier, and voltages at tube grids and cavity gaps have been measured with plate, screen, and grid voltages setting at 10kV, 1.5kV, and -150V, respectively. The test result is shown Fig. 8. The grid voltage as function of frequency shows the performance of the preamplifier and input matching circuits, and the ratio of gap voltage to grid voltage shows the performance of cavity and tube output circuits. The ratio of gap voltage to grid voltage as function of frequency has been compared with the equivalent load impedance of half cell of cavity including half of tube output capacitance, as shown in Fig. 9, and it shows that these two curves have a very close shape. In the future a feedback control system will be applied to the rf system to obtain the required acceleration voltage at cavity gaps.

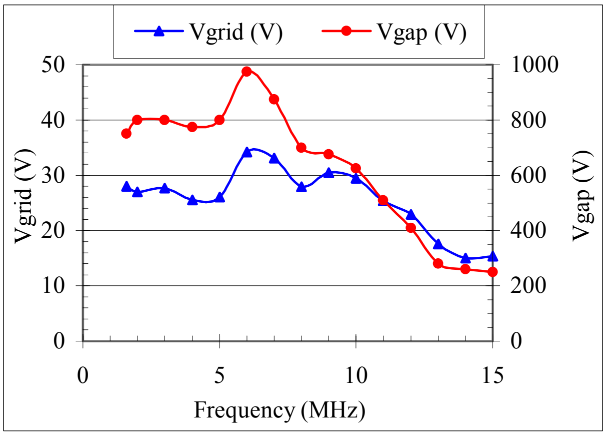


Figure 8: Grid and gap voltages as functions of frequency (P_{in} of preamp -16dBm, E_p 10kV, E_s 1.5kV, E_g -150V).

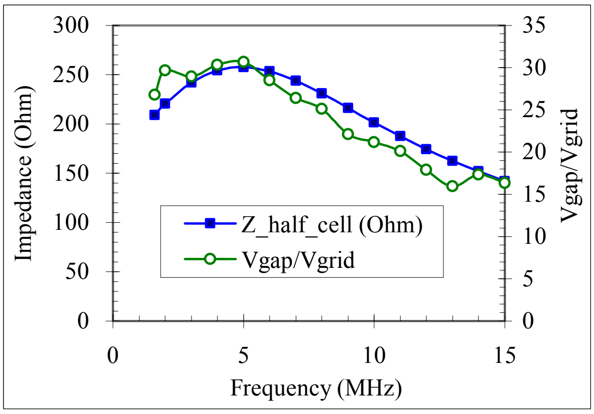


Figure 9: Comparison of V_{gap}/V_{grid} (P_{in} of preamp -16dBm, E_p 10kV, E_s 1.5kV, E_g -150V) and equivalent load impedance of half cell of cavity including half of tube output capacitance.

A high power test has also been performed at 6MHz. With the input power of preamplifier increasing, the tube grid and cavity gap voltages have been measured as shown in Fig. 10. It shows that V_{gap} increases with V_{in} almost nearly. The gap voltage is got up to 6.5kV, totally 13kV for 2 gaps, which is higher than the required acceleration voltage of 12.6kV at 6MHz. And at gap voltage of 6.5kV, the output power of preamplifier is only about 1kW. From next month, high power test will be performed at different frequency and driving power, with a higher screen voltage of 2kV.

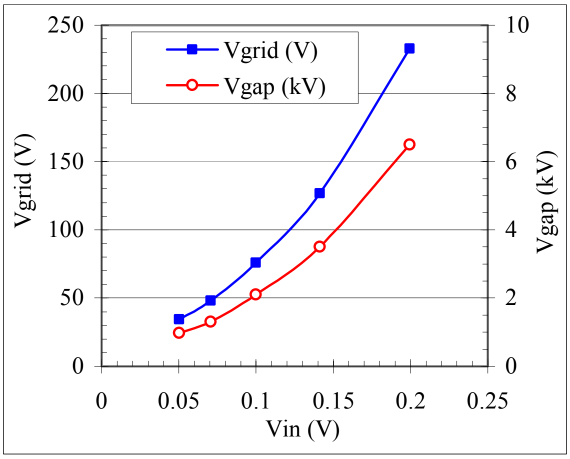


Figure 10: Grid and gap voltages as functions of input voltage of preamp at 6MHz (E_p 10kV, E_s 1.5kV, E_g -150V).

5 SUMMARY

The rf cavity and power amplifier for the compact proton synchrotron have been developed. The rf cavity has relatively high impedance over the operation frequency range. The rf power amplifier works well at low level of input power. A high power test has been successfully performed at 6MHz, and more high power tests will be performed soon.

6 REFERENCES

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