

RF CAVITY FOR TABLE-TOP PROTON SYNCHROTRON

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Abstract

An rf cavity is being developed for a table-top proton synchrotron with a ring of circumference of 11.9m. The rf cavity 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. The calculation and test results of the cavity will be presented.

INTRODUCTION

The table-top proton synchrotron is being developed for proton therapy [1-6] with a ring of circumference of 11.9m. Fig. 1 shows with protons accelerated from 2MeV to 200MeV within 5ms, the fundamental rf frequency will increase from 1.64MHz to 14.26MHz, and the required fundamental value of 13kV at the start of acceleration. Since high order harmonics will also be applied to the cavity to get a flat region in the cavity voltage signal to increase the capture efficiency, the rf cavity is designed to produce maximal gap voltage of about 20kV. Thus the rf cavity with a wide bandwidth and a high gradient should be designed to obtain a high shunt impedance over the whole operation frequency range.

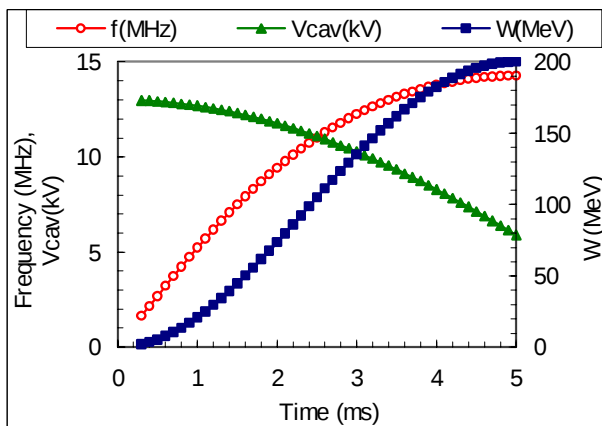


Figure 1: fundamental rf frequency, cavity voltage, and proton energy, as functions of acceleration time.

RF CAVITY STRUCTURE

The rf cavity has been designed and developed with 2 cells loaded with 4 high-permeability magnetic alloy cores in each cell as shown in Fig. 2 and Fig. 3. 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. A push-pull power amplifier with two tetrode tubes 4CX35,000C will be used to drive the 2 cavities in parallel [7-8].

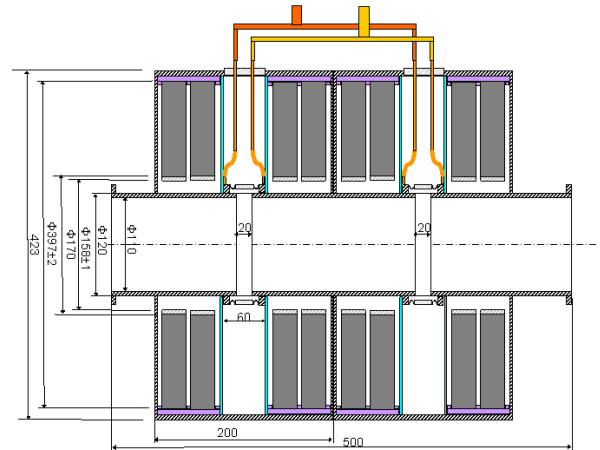


Figure 2: Structure of rf cavity.

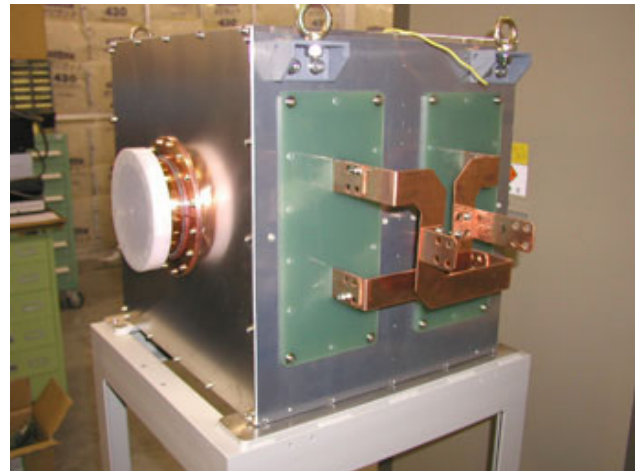


Figure 3: RF cavity.

EQUIVALENT CIRCUIT AND CAVITY CHARACTERISTICS

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.

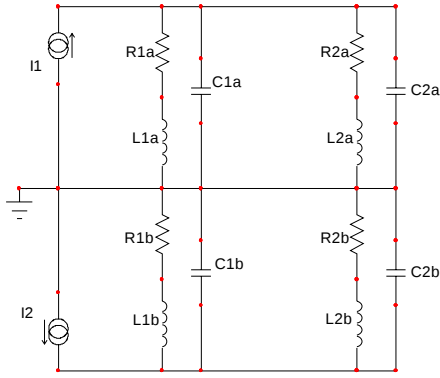


Figure 4: Equivalent circuit of rf cavity.

The impedance of one unit is calculated by:

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

where $u = u' - ju''$ is the complex permeability of cores, and $L_0 = \frac{\mu_0}{2\pi} h \ln \frac{b}{a} = 2 \times 10^{-7} \times h \ln \frac{b}{a}$, 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.

CORE PERMEABILITY

Firstly 4 cores, and later 10 cores, totally 14 cores, are manufactured and tested. The measurement results of permeability of the 14 cores are shown in Fig. 5. We can see there is a large discrepancy of permeability between these cores. For example, at 1.6MHz, $|u|$ can be from 2214 to 2842, namely, $\pm 12\%$ around 2528. At 15MHz, $|u|$ can be from 388 to 469, namely, $\pm 9.5\%$ around 428.5. From these 14 cores, the best 8 cores with relatively higher permeability are chosen out and used in our cavity. Furthermore, considering the balance of the impedance of each unit in the rf cavity, a core with a relative higher permeability and another core with a relative lower permeability are combined to form a pair. Thus 4 pairs are obtained and filled in the rf cavity.

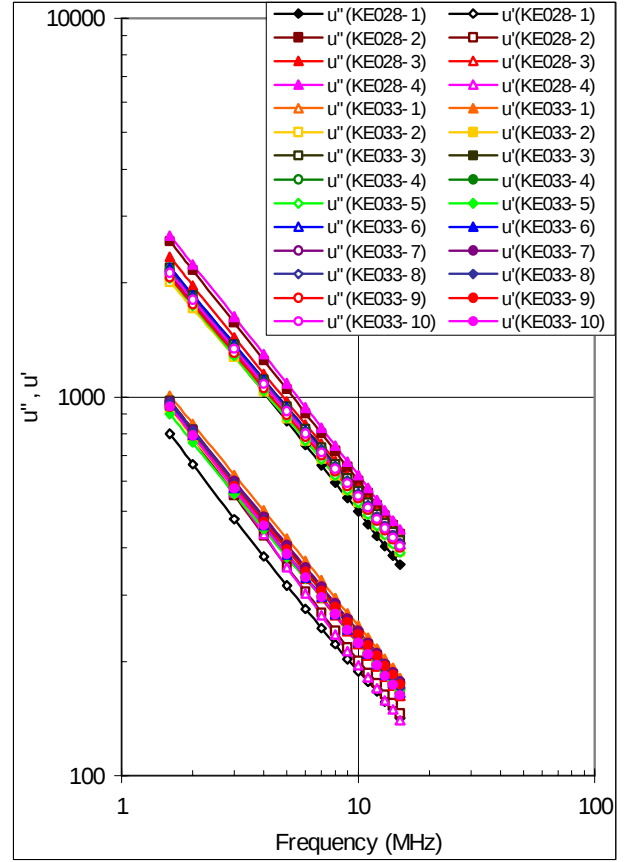


Figure 5: Measurement results of permeability of 14 cores.

TEST RESULTS OF CAVITY IMPEDANCE

The impedances of the 4 units have been measured as shown in Fig. 6. It is shown that the impedances of the 4 units are very close, that is, a very good balance has been obtained. The impedance amplitude of each unit is about 215Ω at 1.6MHz, and 268Ω at 15MHz. The test results of the average value of impedance of the 4 units have been compared with the calculation results, as shown in Fig. 7. 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. 7, 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:

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

where f is in MHz.

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

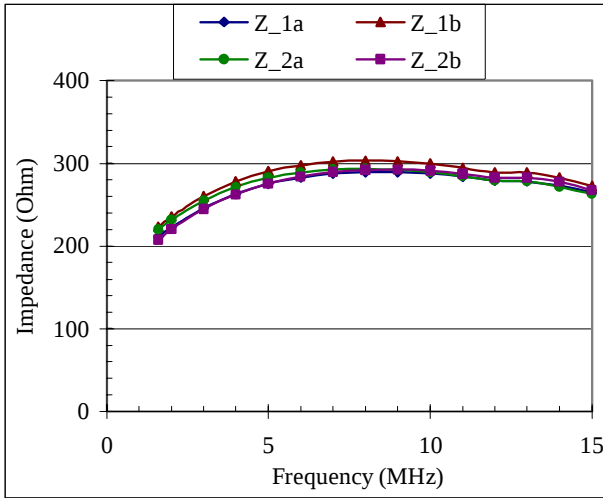
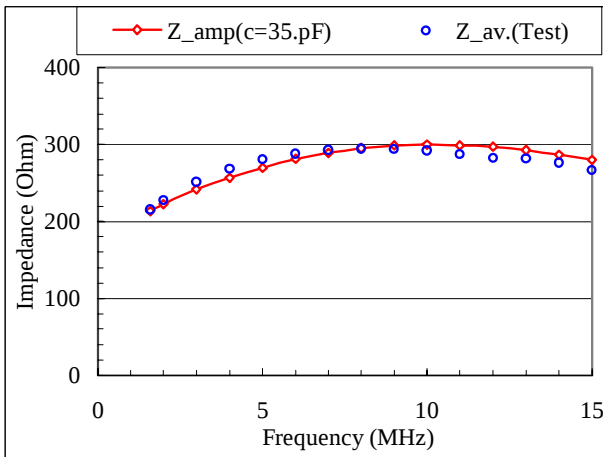
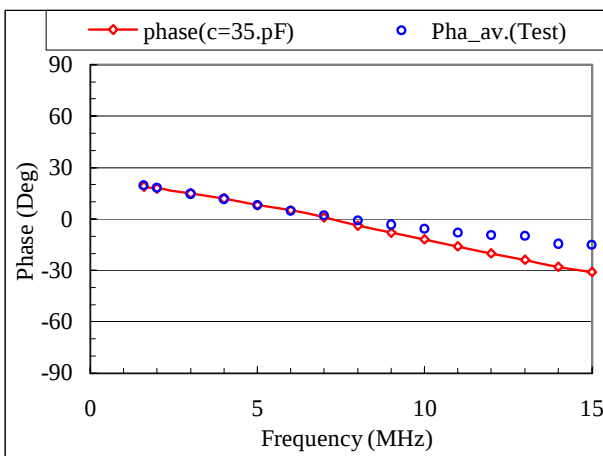


Figure 6: Test results of impedance amplitude of 4 units in rf cavity.



a) Impedance amplitude



b) Impedance phase

Figure 7: Test and calculation results of average value of impedance of one quarter of rf cavity.

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. And a high power test of the rf system will be performed soon.

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