DESIGN AND PRIMARY TEST OF FULL SCALE CAVITY OF CYCIAE-100

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Abstract

The engineering of the RF cavity for cyclotron concerns several aspects, including the vacuum, cooling, mechanical support etc. Sometimes it is even more complex than RF design itself. Given the space limit in a compact cyclotron, to have a voltage distribution of 60kV in central orbit and 120kV for outer orbit, a double stem double gap lambda by 2 cavity has been designed for CYCIAE-100[1]. The RF resonance of the cavity is simulated [1] by finite integral codes, while the thermal analysis and mechanical tolerance is studied using other approaches[2-3]. The mechanical design and fabrications is then carried out under these directions, resulting in a full scale testing cavity. The simulations and mechanical design will be reported in this paper, followed with low level measurement results of quality factor, shunt impedance curve along accelerating gap etc. After surface polishing, the measurement yields an unloaded Q value of 9300, which matches well with the simulation with a neglectable difference of several hundreds. The high power test of the cavity and will be presented in a separate paper of this conference.

INTRODUCTION

A 100 MeV H^- compact cyclotron, CYCIAE-100, is under construction at China Institute of Atomic Energy (CIAE). It will provide a 75 MeV~100 MeV, 200μA~500μA proton beam [1-2]. In the compact cyclotron, the two cavities are designed to be placed in the two opposite valleys. The operating frequency is in the range of 43MHz ~45MHz, which will be fixed after the magnet field mapping. The unloaded quality factor Q_0 should be not less than 8000. The Dee voltage distribution along radius of the accelerating gap is designed to be 60kV at the central region and 120 kV at the extraction region.[1]

The resonance of the cavity is simulated and the mechanical design has been done accordingly. A 1:1 scale cavity is fabricated using oxygen-free copper, with cooling pipes on the outer surface of the liner, cooling water grooves in the Dee plates and stems as well. The resonant frequency, matching, shunt impedance, etc. are measured and compared with the design value. The difference between them is small and acceptable.

DESIGN OF THE RF CAVITY

The structure of the RF cavity in CYCIAE-100 is complex and a large number of parameters of the structure need to be adjusted. The resonant frequency and the electromagnetic field have been taken into account in design of the cavity; the distribution of cavity power loss should not be ignored at the same time. The RF resonance of the cavity is simulated by finite integral codes.

The preliminary consideration is to adopt the two stems structure to control the voltage distribution well and adjust the frequency by changing the position and diameter of the stems[1]. The structure of cavity is shown in Figure 1[4]

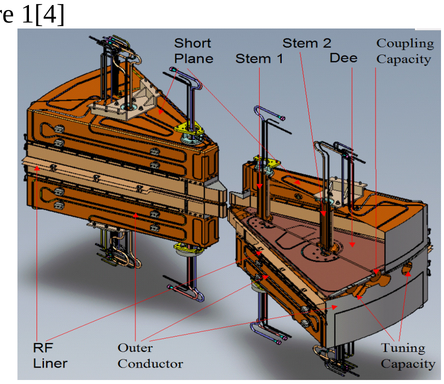


Figure 1: The structure of two stem cavity.

After optimization, the frequency of the cavity simulated to be 44.32MHz, the unloaded Q value is about 10100, Dee-voltage distribution from the center to the extraction area is 60kV to 120kV. The results of the simulation meet the design requirements. The results of the surface current are given by the simulation as well. The power loss distribution of the RF cavity is obvious. The arrangement of the cooling pipes is based on the power loss distribution and the surface current. The E field in the centre plane and the Dee voltage distribution vs. radius are shown in Figure 2.[5] The surface current of the outer conductor and Dee plate are shown in Figure 3.

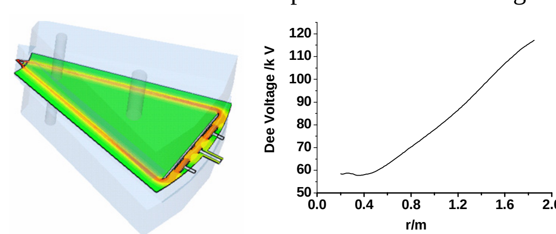


Figure 2: E-Field and the Dee voltage distribution

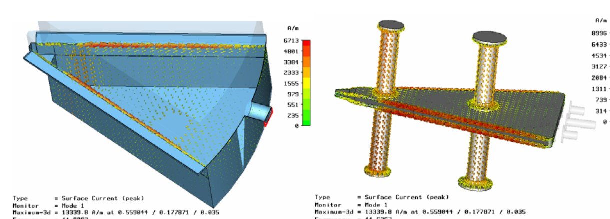


Figure 3: The surface current

Kilpatrick field E_K, as practical indication to breakdown voltages[6], which is known as Kilpatrick limit:

$$f = 1.64 \times E_K{}^2 \cdot e^{-8.5/E_K} \qquad (1)$$

Here, f is the frequency and E_K is the Kilpatrick electric field in megavolts per metre.

In the simulation of the RF cavity in CYCIAE-100, the maximum electric field is located in the gap between the head of the central region, it's about 9.5MV/m. It is less than the experienced limit.

PRIMARY TEST OF FULL SCALE CAVITY

The mechanical design and fabrications are then carried out after the simulation. Consequently, a full scale cavity model has been successfully manufactured. The mechanical design of the cavity is in accordance with the conditions in CYCIAE-100. The cooling pipes are soldered on the outer surface of the liner. The full scale cavity model is shown in Figure 4.

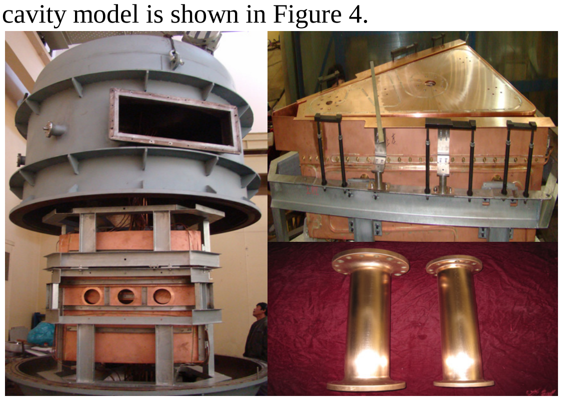
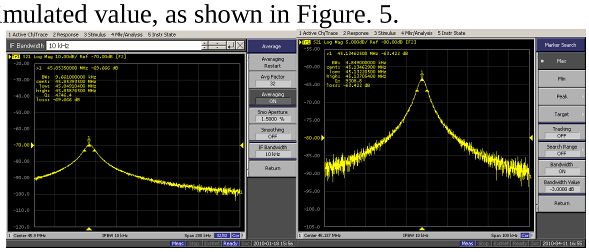


Figure 4: The full scale cavity model

The Test of the Q Value

Thermal deformation and oxidation caused by welding occur on the surface of the outer conductor, and the primary test has been done after simple handling. The unloaded quality factors is measured with the aid of Vector Network Analyser, by connecting two ports to pickups located in upper and lower half cavity. The coupling capacitor is not installed when measuring. The result shows the cavity has a very low Q of 4746, about only half of simulation. The same test is repeated again, after surface polishing according to the surface currents in the simulation and using finger contacts for connections. The new unloaded Q value is ~ 9300, which is 92% of the simulated value, as shown in Figure. 5.



(Without finger contact) (With finger contact)

Figure 5: The unloaded Q value of the cavity

After the test of unloaded Q value, the two tuning capacitors and the coupling capacitor are put on the full scale cavity. The frequency of cavity is adjusted to 44.5MHz and the critical coupling is approached by changing the distance of the capacitance. The cavity is measured with the Network Analyzer, for which two ports are used, i.e. the sampling port on the upper short plate and the port connected with the coupling capacitance. The result from the Network Analyzer is shown in Figure 6.The loaded Q value is ~ 4404 from test and the unloaded Q value of 8808 can be calculated. The calculated unload Q value is closed to the one we get from two sampling ports directly.

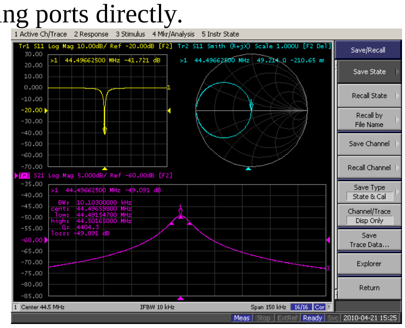


Figure 6: The loaded Q value of the cavity

Shunt Impedance Measurement

Power efficiency of the cavity is usually characterized by a parallel resistance defined as

$$P = \frac{V^2}{2R} \qquad (2)$$

Where, P is the power loss in the cavity to obtain the accelerating voltage, which is identified as V in the formula. The equivalent shunt impedance at the accelerating gap can be evaluated with low level measurements. The principle of the measurement is taking the cavity as a two-port network, and measuring the reversed transmission between the coupling and the gap. Detailed information about the method itself can be found in [7], in which the shunt impedance of the accelerating gap can be calculated from scattering parameter as following,

$$R = \frac{Z_0}{S_{21}^2} \qquad (3)$$

The probe (with 50Ω) is put on one accelerating gap, as stimulating port. The receiving port, port 2, is connected though transmission line to the coupling window. The measuring positions are selected along the gap from the central region to outer orbit, with an interval of 0.2m. The VNA measured S_{21} parameters are recorded for each position, as shown in table 1. The shunt impedance and the accelerating voltage (assuming input power of 33.7kW) across the gap can be obtained accordingly. Note that, the two gaps are specified as Gap A and Gap B, as shown in Figure 7.The comparison of simulated voltage distribution and measured one is shown in Figure 8.

Table 1: Data of the test

S_{21} /gapA	R / kΩ	Vp / kV	S_{21} /gapB	Rp / kΩ	Vp / kV
-30.3	53.3	60.0	-30.3	53.3	60.0
-30.2	51.9	59.2	-30.2	51.9	59.2
-30.1	51.2	58.8	-30.1	51.4	58.9
-30.9	61.1	64.2	-30.9	61.7	64.5
-31.9	77.1	72.1	-31.9	78.0	72.6
-32.8	94.6	79.9	-32.9	96.8	80.8
-33.7	116.7	88.8	-33.8	119.7	89.9
-34.7	146.9	99.6	-34.8	150.0	100.6
-35.6	179.9	110.2	-35.6	182.4	111.0
-36.2	207.5	118.4	-36.2	209.9	119.0
-36.4	215.8	120.7	-36.4	218.3	121.4

The voltage distribution from the test is similar to the simulation. When the Dee voltage at the center is proportional to 60kV, the power loss of cavity is about 33.7 kW according to the measurement.

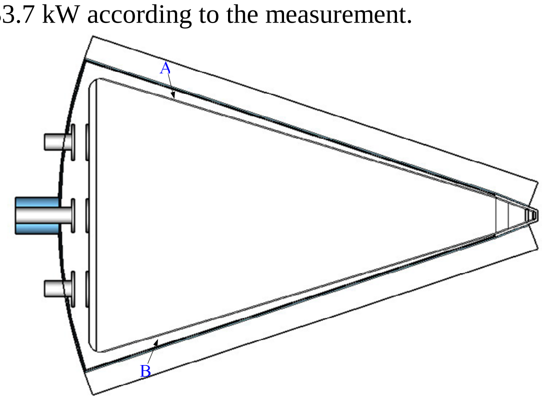


Figure 7: The accelerating gap

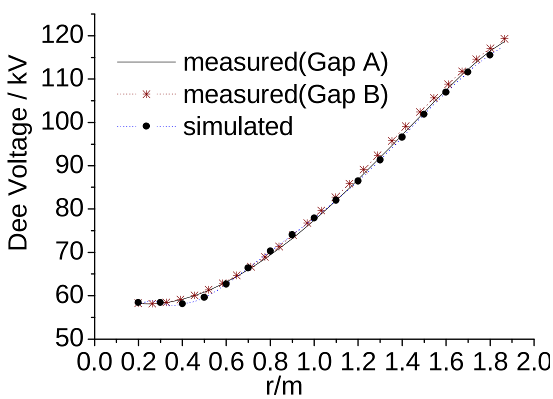


Figure 8: The Dee Voltage of the model cavity vs. the radius

The Test of the Tuning Range

The tuning range of cavity is measured in the test. When the distance between the capacitance plates is 17mm, the resonant frequency is 43MHz, corresponding to 38mm at 45MHz. The tuning rang meets the design requirements. The frequency curve is shown in Figure 9.

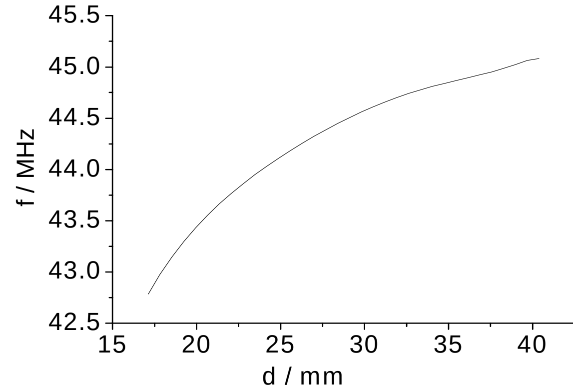


Figure 9: The frequency curve

SUMMARY

Following the simulation by finite integral codes, a full scale RF cavity has been made accordingly, and it is suggested that the test result agrees well with the simulation. Then improvements are made in terms of the design and fabrication technology based on the primary tests conducted on the full scale cavity. The high power test of the cavity will be presented in a separate paper of this conference.

ACKNOWLEDGEMENTS

The authors are very much grateful to a number of scientists from TRIUMF, e.g. Drs. Yuri Bylinsky, Ken Fong, Shuyao Fang and Qiwen Zheng, and those from PSI, e.g. Drs. Peter Sigg, Wolfgang Tron for their helpful discussion, suggestion and comment and very productive visit to the Cyclotron Lab at CIAE for scientific collaboration.

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