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STUDY ON A LOW BETA HIGH CURRENT TAPER TYPE SUPERCONDUCTING HALF WAVE RESONATOR FOR BISOL*

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Abstract

Beijing Isotope-Separation-On-Line Neutron-rich Beam Facility (BISOL) for both basic science and applications is a project proposed by China Institute of Atomic Energy and Peking University. Deuteron driver accelerator of BISOL would adopt superconducting half wave resonator (HWR) with low beta and high current. For pre-research of BISOL, a β=0.09 162.5 MHz taper type HWR cavity has been designed for accelerating deuteron beam with several tens of mA. The Design, fabrication, post-processing and room temperature RF measurement of the HWR cavity are presented here.

INTRODUCTION

Many projects based on high current proton and deuteron linear accelerators have been proposed to better support various fields of science. Beijing Isotope-Separation-On-Line Neutron-rich Beam Facility (BISOL) was recently proposed by the union of Peking University (PKU) and China Institute of Atomic Energy (CIAE) [1]. A high current deuteron accelerator is one of two drivers for BISOL. It can also run as an intense neutron beam source. High current deuteron beams will be accelerated by a RF superconducting (SRF) linear accelerator after RFQ to 40 MeV. The deuteron accelerator adopts half wave resonator (HWR) as the SRF accelerating structure because of its good properties. A β=0.09 162.5 MHz HWR cavity has been designed to accelerate several tens of mA deuteron beam after RFQ. We will present the details of design fabrication, post-processing and RF measurement of the β=0.09 HWR cavity in this paper.

DESIGN

Compared to the cylindrical or squeezed HWR cavity, taper type HWR cavity which has conical inner and outer conductors has better mechanical properties, much higher shunt impedance r/Q and lower surface fields [2]. Compared to the race-track shaped center conductor, the ring-shaped "Donut" center conductor has much lower peak magnetic field and thus higher accelerating gradient and much higher shunt impedance meaning same energy gain less power [3]. With this "Donut" shape, there is better symmetric field in radial direction along the beam pipe and can eliminate the quadrupole effect to the beam. In order to accelerate several tens of mA deuteron beams, the HWR cavity has a larger beam pipe diameter of 40 mm. The electromagnetic design was done by CST code [5]. Figure 1 shows the β=0.09 162.5 MHz HWR cavity.

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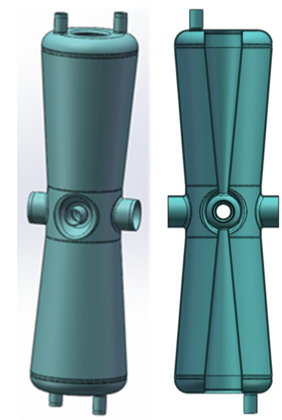

Figure 1: The 162.5 MHz, high current β=0.09 HWR cavity designed by Peking University.

CST particle tracking mode is used to simulate multipacting (MP) in this low β HWR cavity. The simulation result gives that MP in the HWR cavity mainly locates at the dome of the short plate, which is two-point first order MP. Figure 2 shows the MP intensity comparison between the cavity HWR1 with round short plate and cavity HWR2 which has flat short plate with r1 = 5 mm and r2 =35 mm. HWR1 might have strong MP when the accelerating gradient is between 3~8 MV/m. We changed the blending radii of the short plate with the inner and outer conductors and made the short plate flatter to suppress MP. The shape of the short plate is shown in Fig. 3. Simulation results give that smaller r1 and larger r2 has better effect on suppressing MP. When r1 = 5 mm and r2 =35 mm, MP growth rate is less than one in a very big gradient range. The MP intensity is quite low when the gradient is higher than 4 MV/m, which is safe for the cavity operation. Calculation from CST shows that the RF parameters are similar for the two HWR cavities.

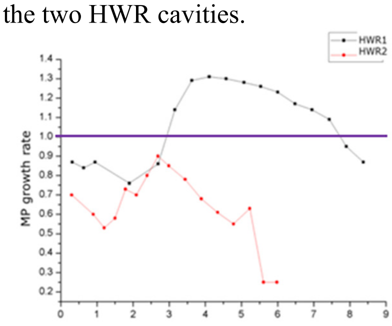

Figure 2: MP intensity v.s. gradient for two different HWR cavities (HWR1 and HWR2).

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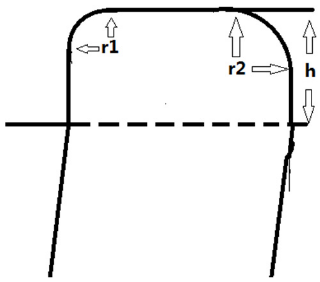

Figure 3: shape of the short plate with different blending radii with the conductors, R1 is the blending radius with the inner conductor and r2 with the outer conductor.

We also did mechanical study of the β=0.09 HWR cavity [4]. The simulation results give that the cavity has very low df/dP and Lorentz force coefficient. With stiffening rings, |df/dP| could be less than 1.0 Hz/mbar.

The position and orientation of four cleaning ports added to the short plated were optimized to get good RF parameters and good cleaning effects.

Table 1 gives the main geometry and RF parameters of the final designed HWR cavity.

Table 1: RF and Geometry Parameters of the β=0.09 HWR Cavity.

Parameter	Value
Frequency/MHz	162.5
β	0.09
Cavity diameter /mm	260
Beam aperture /mm	40
Diameter of coupler port	80
Cavity height /mm	990
L_{cav}=βλ /mm	166
R/Q /Ω	255
Geometry factor /Ω	39
Bpk/Eacc /(mT/(MV/m))	6.4
Epk/Eacc	5.3

FABRICATION AND POST-PROCESSING

Two β=0.09 162.5MHz HWR cavities were fabricated with fine grain niobium material at Ningxia Orient Superconductor Technology Co. Ltd (OSTEC). The inner and outer conductors, short plates, beam cups were deep drawn. The thickness of the niobium sheet is 3 mm. All the flanges were made of NbTi alloy. Aluminium alloy gaskets are used for the sealing of the cavity.

We used buffered chemical polishing (BCP) to get rid of the damage layer of the cavity. Figure 4 shows the BCP treatment of the cavity. The acid flew into the cavity from the two bottom cleaning ports and out of the cavity through all the other ports. The temperature of the acid was about 15℃ ~ 17℃ during the cavity etching. After 75 minutes, the cavity was polished upside down. After BCP, the cavity went through high pressure rinsing (HPR) and 800℃ heat treatment for 3 hours.

Because the HWR cavity is slim and has conical conductors, effective HPR cleaning is not easy. The diameter of the cleaning port is 30 mm and that of the nozzle is 20 mm. The cavity has to be rinsed from all the eight ports. We fabricated a special nozzle with 13 holes. The diameter of the nozzle hole is 0.4mm and the angles between the axis of holes and that of the nozzle stem are 0°, 30°, 60°, 90° and 120°. A special frame was designed to rotate the cavity in three directions, seen in Figure 5. The rotation speed of the cavity was about three circles per minute and the moving speed of the stem was about 25 mm per minute.

Figure 4: BCP treatment of the HWR cavity.

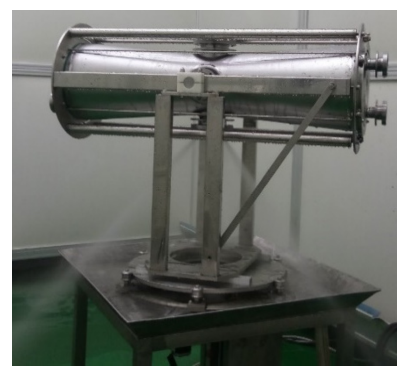

Figure 5: HPR of the β=0.09 HWR cavity.

ROOM TEMPERATURE RF MEASUREMENTS

We have done some room temperature measurements on the HWRs. Figure 6 shows the layout of the experiment system of the HWR cavity. A vector network analyzer was used to measure the frequencies and Q_L of the cavity's eigenmodes. Figure 7 shows the measured frequency spectrum. Table 2 gives the frequencies of HOMs (both experiment and simulation results). The measured frequency of the accelerating mode is 162.22 MHz, which is quite similar to the simulated frequency 162.23 MHz. After cavity post treatment, vacuum pumped and cooling down to 4.2 K, the cavity is supposed to have 162.5 MHz at the accelerating mode. The HOM studies of this high current β=0.09 HWR cavity were analyzed in [5].

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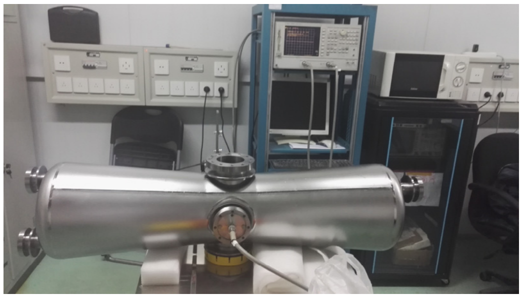


Figure 6: Cavity RF measurements at room temperature.

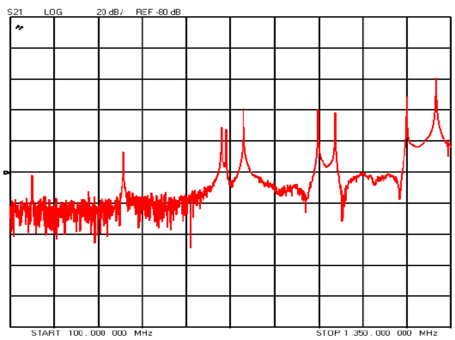


Figure 7: HOM spectrum of the HWR cavity.

Table 2: Experimental Results and Simulated Results

Mode	Freq(simulation)/MHz	Freq(experiment)/MHz
1	162.23	162.22
2	422.35	420.78
3	697.35	699.06
4	715.51	713.22
5	759.86	761.87
6	973.25	972.97
7	1004.43	1002.09
8	1160.36-	1157.68
9	1226.76-	1225.68
10	1232.05-	1234.05
11	1243.51	1240.25

We also used a perturbation method to measure the electric field along the axis of the beam pipes with a small aluminium bead. The axial field distribution is shown in Figure 8. The experimental R/Q is about 278Ω, which is similar as the simulated one of 255Ω. Considering to fabrication errors and the experimental error, the experimental results and simulative results are in good agreement.

Before the vertical test of the HWR cavity, we did external quality factor (Qe) calculation and measurement. Figure 9 shows Qe v.s. d (the distance from the cavity centre and the antenna tip). The variation of Qe from 107 to 1010 during cavity vertical test is normally enough. For such a Qe variation range, the length of the antenna inserted from the coupler port changes about 60 mm, which is almost double than that of the antenna inserted from the beam port. Therefore, we decide that test antenna feeds in power from the beam port.

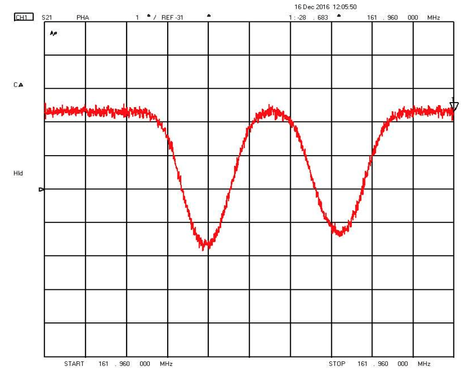
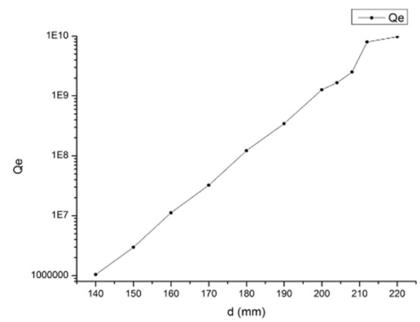
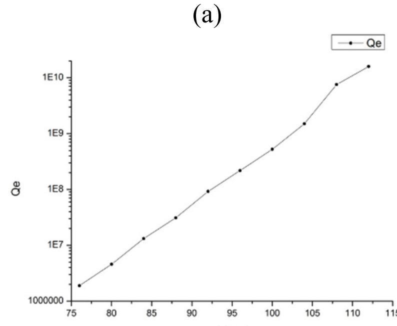


Figure 8: The electric field distribution along the cavity axis.

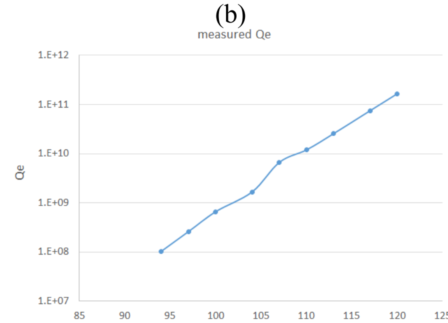
Q_e was measured with antenna inserted from the beam port. There is a bellow that can change d ±20 mm. Figure 9 (c) gives the measurement result, which is in good coincidence with the simulation result.



(a)



(b)



(c)

Figure 9: Qe v.s. position of the test antenna tip. (a) Simulation result of Qe calculation when power feeds in from the coupler port. (b) Simulation result of Qe calculation when power feeds in from the beam pipe port. (c) Measured result of Qe when power feeds in from the beam pipe port.

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CONCLUSION

For BISOL pre-research, Peking University has designed a β=0.09 high current 162.5 MHz HWR cavity for the high current deuteron driver accelerator. The design shows that the cavity has good RF parameters, good mechanical properties and less possibility to have MP. Two prototype HWR cavities have been fabricated and post-treated and are ready for vertical test.

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