Horizontal test for BEPCⅡ 500 MHz spare cavity*

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Abstract: The horizontal test for the BEPCⅡ 500 MHz spare cavity has been completed at IHEP. The maximum voltage of the cavity reached 2.17 MV, while Q_0 was 5.78×10^8. The process and results of the high power horizontal test are presented and discussed in this paper.

Key words: horizontal test, spare cavity, 500 MHz cavity

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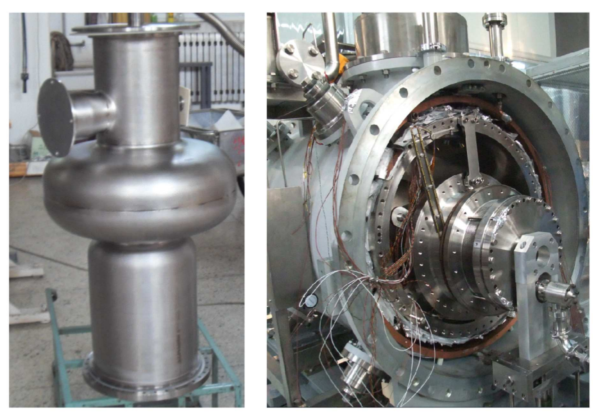
1 Introduction

A 500 MHz superconducting cavity was fabricated at IHEP in 2011. After completion of assembly, a horizontal test was carried out for the spare cavity at IHEP. This one was the 1st 500 MHz spare superconducting cavity of BEPCⅡ. Key components of the cavity were all made in China. During the horizontal test, performance of the cavity has exceeded the design values. The maximum voltage of the cavity reached 2.17 MV with 5.78×10^8 of Q_0.

2 Design and manufacture

All components of this spare cavity were made by spinning technique and welded together by electron beam welding (EBW). The spinning parts included half cells, beam pipes and the support pedestal of the coupler. Many methods have been adopted to improve the surface quality, such as manual grinding, buffered chemical polishing (BCP), ultrasonic water rinsing (UWR), high pressure water rinsing (HPR) and high temperature annealing. The vertical test of this cavity was accomplished on July 7th, 2011. The Q_0 value was 1.2×10^9 at 2.3 MV of V_C. The structure of the cavity is shown in Fig. 1(a). The assembly was accomplished by the IHEP staff independently. Fig. 1(b) shows the assembly. After assembly, the cavity was transported to the horizontal test room [1].



(a) (b)

Fig. 1. (a) 500 MHz spare cavity; (b) assembly of cryomodule.

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Table 1. Main design parameters.

technical index	design value
V_{acc} (Max)	1.5–2.0 MV
Q_0	$>5.0\times10^8$
frequency	499.8±0.05 MHz
Q_L	$1.7\times10^5\pm10\%$
coupler power (total reflection)	50 kW
HOM power	>4 kW

3 Horizontal test

Figure 2 shows the sketch of the horizontal test of the cavity. The value of Q_0 is calculated through the total power $P_{totalloss}$, as follows:

$$Q_0=\frac{V_C^2}{R/Q}\times\frac{1}{P_C}=\frac{V_C^2}{95.3}\times\frac{1}{(P_{totalloss}-P_{staticloss}-P_{heater})}. \quad (1)$$

For the accurate measurement of Q_0 value, the cavity voltage V_C and cavity loss P_c must be calibrated exactly. Therefore, the cavity voltage was calibrated with the incident power and pickup power respectively in advance, as shown in Fig. 2. V_C is calculated according to the formulas of (2) and (3):

$$V_C\approx\sqrt{4\times R/Q\times Q_L\times P_{incident}}, \quad (2)$$

$$V_C\approx\sqrt{R/Q\times Q_{15D}\times P_{15D}}, \quad (3)$$

Q_{15D} is 2.78×10^{10}, which was calculated in the vertical test. Through mutual verification, the error of V_C is below 8%.

3.1 Test during room temperature

At room temperature, the performance of the tuner was tested and it worked well. This is the most important test at room temperature. If there is anything wrong with the tuner, it can be found during this step [2].

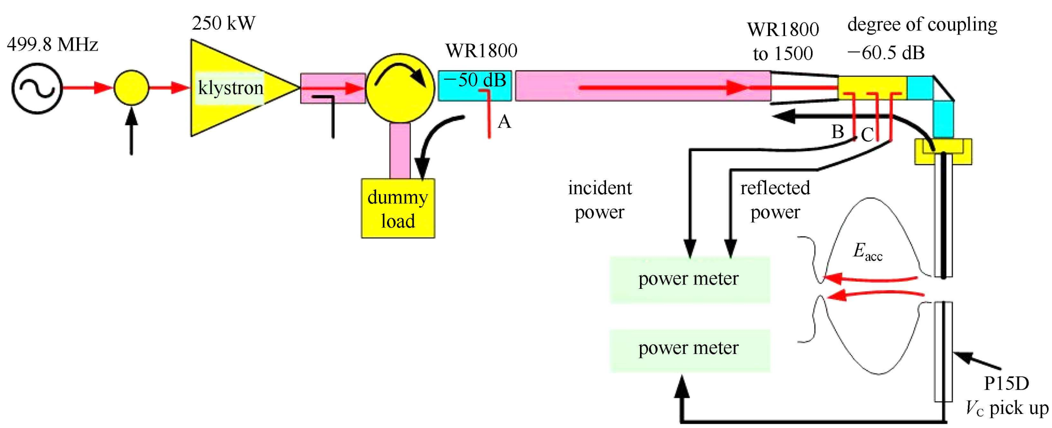

Fig. 2. Sketch of the horizontal test.

The testing and conditioning of the coupler were carried out by making the tuner detune the cavity. The coupler was preheated before conditioning to avoid cracking of the coupler window. Both pulsed and continuous waves were applied repeatedly as it can save conditioning time and improve safety [3]. The maximum input power finally exceeded 106 kW, which was totally reflected.

3.2 Test during cool-down

During cool-down, the frequency and the loaded Q value of the spare cavity were monitored with a network analyzer every few hours.

Figure 3(a) shows that the frequency of the spare cavity increased during cool-down. The loaded Q of the cavity also increased. After the cavity temperature reached 80 K, the loaded Q increased quickly. At 4.4 K the loaded Q of the spare cavity was 1.3×10^5, and the frequency was 499.507 MHz, while the result calculated was 501.24 MHz under free load. It indicates that the assembly of the cavity has affected the frequency of the cavity [1].

Figure 3(b) shows that there was no evidence of vacuum leakage during cool-down. Fig. 3(c) shows that during the first 20 h the cool-down rate was about 0.91 K/h, which was intentionally very slow to avoid vacuum leakage. In the next 40 h, the cool-down rate was about 6.8 K/h [2].

Two displacement meters were respectively installed on the short beam pipe (SPB) and long beam pipe (LBP) ends, before cool-down. As shown in Fig. 3(d), the displacement of the SBP end was about 0.752 mm, compared with 1.438 mm of the LBP end, while the simulation result was 2.085 mm under free

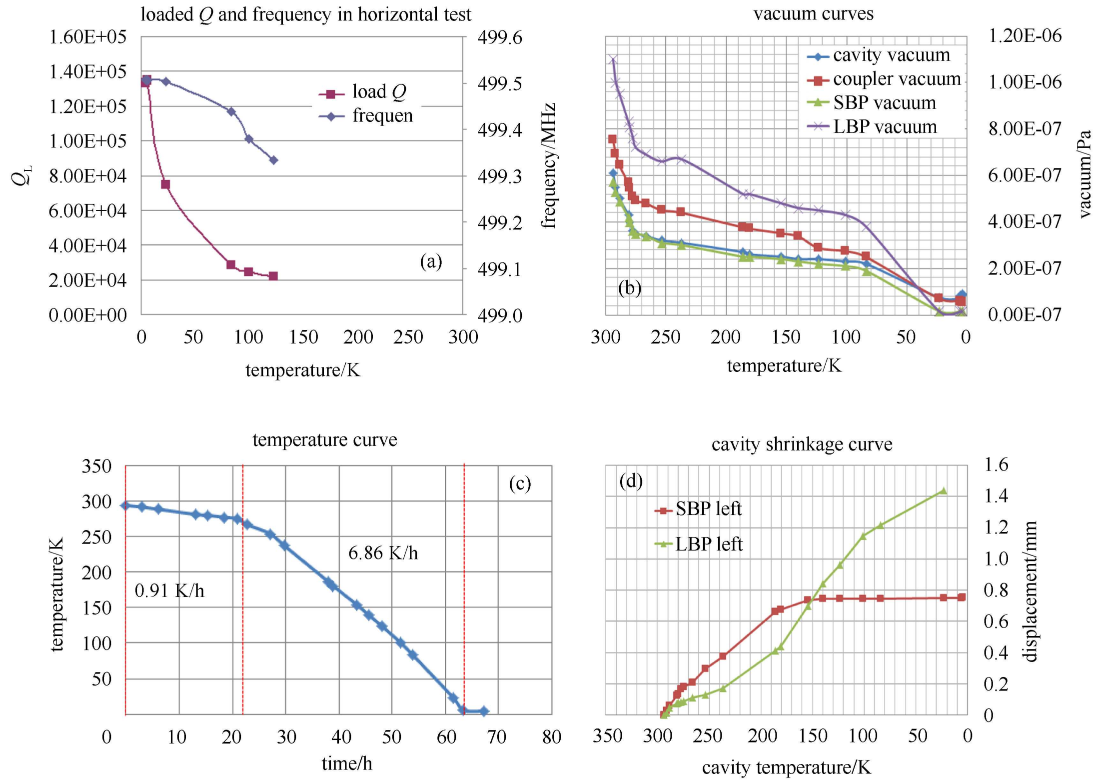

Fig. 3. (a)The frequency and loaded Q; (b) The change of vacuum during cool-down;(c) The time profile of cavity temperature during cool-down; (d) Shrinkage of spare cavity.

load. The error of about 0.65 mm, which was due to the fixed bracket, greatly impacted the deformation of the cavity.

3.3 Test under 4.4 K

After the temperature decreased to 4.4 K, the tuner was operated to find the resonant frequency 499.8 MHz. The change of the cavity frequency with load during the tuning process was measured through the network analyzer as shown in Fig. 4. It shows that the cavity frequency has a linear relation with load, and the elastic coefficient of the cavity is about 1 kHz/kg.

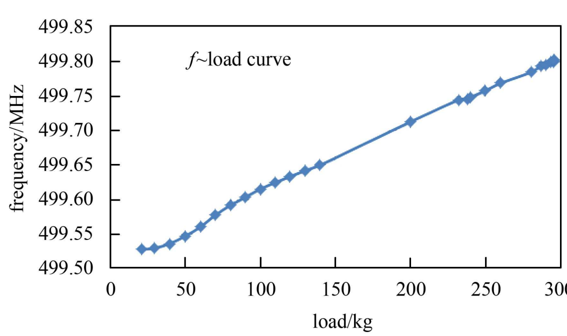

Fig. 4. The frequency-load curve.

When the cavity was tested at high power, the coupler vacuum deteriorated. Several hours later, the test was repeated, and the coupler vacuum had improved. This phenomenon indicates that the time of the coupler conditioning was maybe too short [4].

Figure 5(a) shows the Q_0 value is lower in the horizontal test than in the vertical test. In the horizontal test, Q_0 decreased rapidly when the cavity voltage exceeded 1.5 MV, while in the vertical test the Q_0 declined slowly over 2 MV.

Before the test, radiation detectors were installed at the SBP, LBP ends and sides of the cryostat. Fig. 5(b) shows that the radiation was weak below 1 MV, and it increased quickly above 1 MV. The radiation was more intense in the axial direction (197 msv) than the transverse (76 msv).

These above-mentioned facts indicate that the inner surface of the cavity is not very smooth or that there are pollutants on the surface. When the rf power increases, field emission suddenly happens, resulting in the decrease of Q value and field level. With conditioning, the surface of the cavity would become smooth, the field emission become stable, and the performance of the cavity would be further improved.

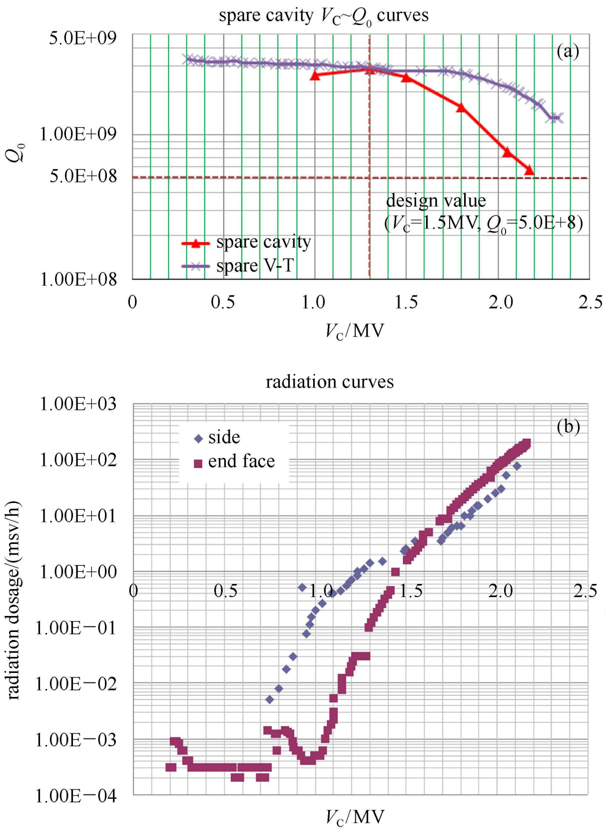

Fig. 5. (a) Comparison of Q_0 vs. V_C curve between the vertical and horizontal tests; (b) The radiation curves of the horizontal test.

As shown in Table 2, the spare cavity performance is better than the east cavity, but worse than the west cavity operating in the BEPCⅡ storage rings.

Table 2. The BEPCⅡ spare cavity main parameters.

	voltage/MV	Q_0
spare cavity	2.05	7.67×10^8
east cavity	2.0	5.45×10^8
west cavity	2.05	9.5×10^8

Table 3. The BEPCⅡ spare cavity test results.

technical index	test value
V_{acc} (Max)	2.17 MV
Q_0	7.67×10^8(@2.0 MV)
work frequency	499.8 MHz
Q_L	1.33×10^5
coupler power (total reflection)	100 kW
HOM power	9 kW

4 Conclusion

1) The BEPCⅡ 500 MHz superconducting cavity is entirely made in China, which is a big breakthrough in the development of the superconducting technique of China. We have mastered the technology parameters of the spinning technique, welding and surface processing.

2) Q_0 of the spare cavity is 5.78×10^8 at 2.17 MV in the horizontal test, exceeding the design index.

3) Q_0 of the spare cavity in the horizontal test is lower than the vertical test. Q_0 decreased greatly and the radiation increased substantially over 1.5 MV. The results suggest that there may be pollution during the assembly process. The cavity performance would be further improved with conditioning [1].

4) The frequency of the BEPCⅡ spare superconducting cavity is measured as 499.507 MHz at 4.4 K with free load. When the load is 295 kg, the cavity frequency is 499.8014 MHz without compensating springs. Cavity polishing, and assembly may affect the frequency.

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