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RESEARCH AND DEVELOPMENT OF 650 MHz CAVITIES FOR CEPC*

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Abstract

650 MHz 2-cell superconducting cavities are proposed for the main ring of the Circular Electron Positron Collider (CEPC) [1]. The design, fabrication, surface treatment (buffered chemical polishing) and vertical tests of the cavities with HOM couplers were conducted. The performance of the cavity at 2 K is not affected by the HOM coupler [2]. The maximum intrinsic quality factor (Q_0) of the cavity with the HOM coupler reached 3.1×10^{10} at 20 MV/m. The vertical test results showed that the fundamental mode external quality factor of all HOM couplers is an order of magnitude larger than quality factor of the cavity. Two 650 MHz 2-cell cavities jacketed have been integrated into a test cryomodule for CEPC. Another 650 MHz 2-cell cavity reached 6×10^{10} at 22 MV/m after nitrogen infusion [3]. In addition, two 650 MHz 1-cell cavities reached 2.7×10^{10} at 35 MV/m (fine grain) and 3.6×10^{10} at 32 MV/m (large grain) after electro-polishing, respectively. In future, electro-polishing will be applied to 650 MHz 2-cell cavity.

INTRODUCTION

Nowadays, cavities with frequency around 650 MHz are widely used by proton accelerators, such as PIP-II, CiADS and CSNS Upgrade. Baseline layout and parameters for CEPC Main Ring SRF system have been public [4]. There're two SRF sections in total, and each one has two SRF stations. There're ten cryomodules per station, which consist of six 650 MHz 2-cell cavities each. So there're two hundred and forty 650 MHz 2-cell cavities in total. These cavities are made of bulk niobium and operated at 2 K with Q_0 higher than 3×10^{10} at 22 MV/m for the vertical acceptance test and Q_0 higher than 2×10^{10} at 20 MV/m for the horizontal test. The accelerating gradient for Higgs is 19.7 MV/m with Q_0 higher than 1.5×10^{10} for long-term operation. This specification is critical for the SRF cavity of a circular collider, which usually have a more constrained environment than superconducting linac (such as LCLS-II and SHINE). So relevant research of 650 MHz cavities was carried out at IHEP, which have achieved some state-of-the-art results.

R&D OF 650 MHz 1-CELL CAVITY

Several 650 MHz 1-cell cavities have been fabricated for high Q & E_{acc}, which are made of fine-grain (650S4) and large-grain niobium (650S7, 650S8), respectively. Firstly, 650S4 and 650S8 received bulk BCP and light EP, while 650S7 received flexible polishing to repair surface defects. Then, all these cavities received annealing of 950°C and electro-polishing (EP). Finally, these cavities received high-pressure rinse (HPR), assembly in clean room and baking at 120°C for 48 h. The vertical test results are shown as Fig. 1. The vertical test results of 650 MHz 1-cell cavities are shown as Fig. 2. 650S4 quenched at 35 MV/m with Q_0 of 2.7×10^{10}. 650S8 quenched at 28 MV/m with Q_0 of 4.6×10^{10}, while 650S7 quenched at 32 MV/m with Q_0 of 3.6×10^{10}. The results above have reached the advanced level of large elliptical (<1 GHz) cavities.

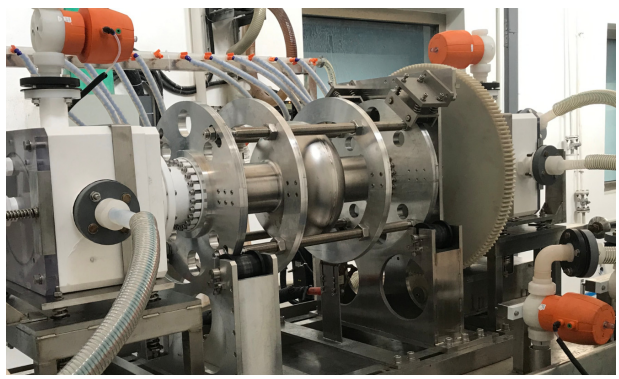

Figure 1: EP of 650 MHz 1-cell cavity

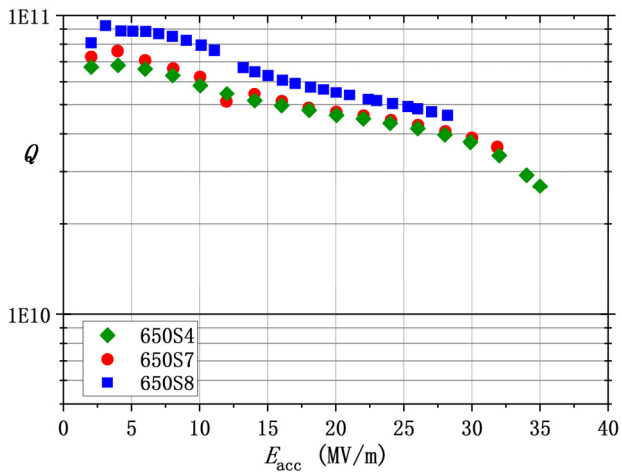

Figure 2: Vertical test results of 650 MHz 1-cell cavities

THE 650 MHz TEST CRYOMODULE

The 650 MHz TEST cryomodule consists of two 650 MHz 2-cell cavities, fundamental couplers, tuner, HOM couplers and other ancillaries, which is shown as Fig. 3. It will be connected with a DC photo-cathode gun at the Platform of Advanced Photon Source Technology (PAPS), which will produce 1~10 mA electron beam with 10~15 MeV.

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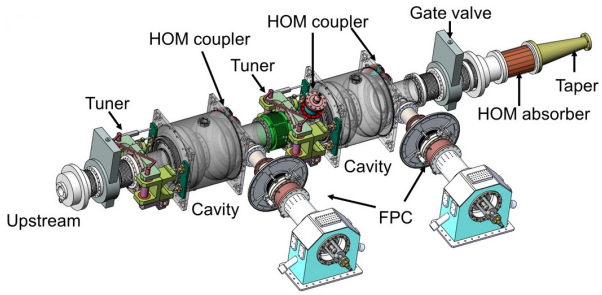

Figure 3: Cavity string of 650 MHz test cryomodule.

RF DESIGN OF 650 MHz 2-CELL CAVITY

The detailed RF optimization design of the 650 MHz 2-cell cavity has been completed [1]. The final RF parameters are listed in Table 1. Two detachable coaxial HOM couplers with double-notch filter are installed on both sides of the cavity beam pipes to damp the higher order modes. In order to damp different polarization modes, the angle between the two HOM couplers is determined to be 110◦after optimization as Figure 4.

Table 1: Main Parameters of 650 MHz 2-Cell Cavity

Parameters	Value	Units
Beam tube diameter	160	mm
R/Q	211	Ω
G	279	Ω
E_{peak}/E_{acc}	2.4	
B_{peak}/E_{acc}	4.2	mT/(MV/m)
E_{acc}	22	MV/m
Q_0	4E10	
Q_e of HOM coupler	>4E11	TM010

VERTICAL TEST OF 650 MHz 2-CELL CAVITIES

Three 650 MHz 2-cell cavities (4#, 5#, 6#) have been fabricated, BCP processed and received vertical tests. A fixed input antenna is mounted on the flange of the beam pipe at the fundamental power coupler side with an Q_e of about 2.2×10^{10}. The Q_e of pickup is about 8.2×10^{10}. The vertical test results are shown as Figure 4. All the cavities exceeded 25 MV/m with no multipacting, which verified the RF design. There was no field emission during the vertical tests, which indicated no pollution during HPR and assembly. These three cavities quenched at 28.4 MV/m, 25.2 MV/m and 26.0 MV/m, respectively. And the Q-slope behaviour is obvious above 20 MV/m, which is typical for large elliptical cavities (>1 GHz) with BCP treatment. In a word, the vertical test results of 650 MHz 2-cell cavities are acceptable and qualified.

Moreover, cavity 4# was then assembled with a HOM coupler (Figure 5) and received vertical test again, which is also shown in Figure 3. After installing HOM coupler, Q_0 of the cavity was almost the same. Field emission began at 13 MV/m, which is mainly caused by the water of HPR. Field emission also occurred on several 1.3 GHz cavities processed in the same batch. There is no multipacting occurred. The max gradient was 27.3 MV/m and limited by quench.

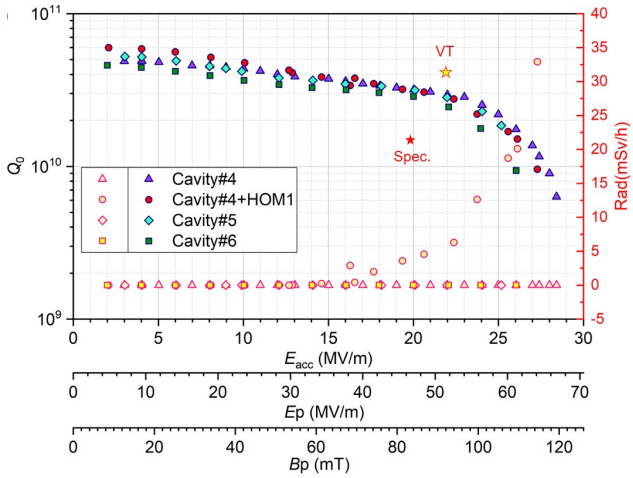

Figure 4: Vertical test results of 650 MHz 2-cell cavities.

Besides, the external quality factor Q_e of each HOM coupler port for the fundamental mode was measured before, during and after the vertical test. The test results show that the suppression of HOM couplers on the fundamental mode at 2.0 K differs little between the designed and measured value, which satisfy the damping requirement at cryogenic temperature.

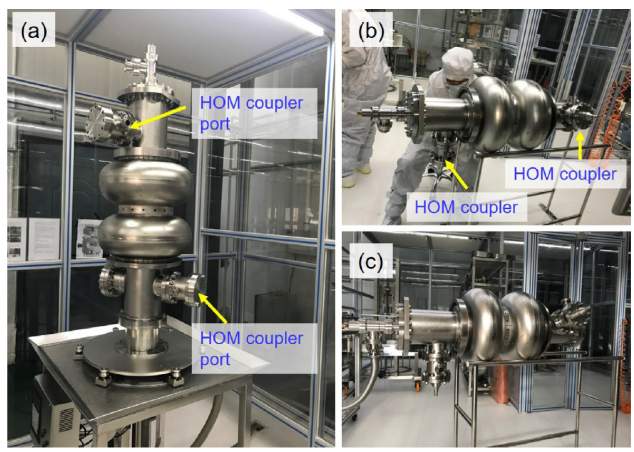

Figure 5: HPR of the assembled cavity (a), and installation of HOM coupler with cavity (b), and slow pumping of the assembled cavity (c).

INTEGRATION OF 650 MHz 2-CELL CAVITIES

After vertical test, 650 MHz 2-cell cavities were welding with helium vessel as Figure 6. The frequency was measured again for cavities jacketed.

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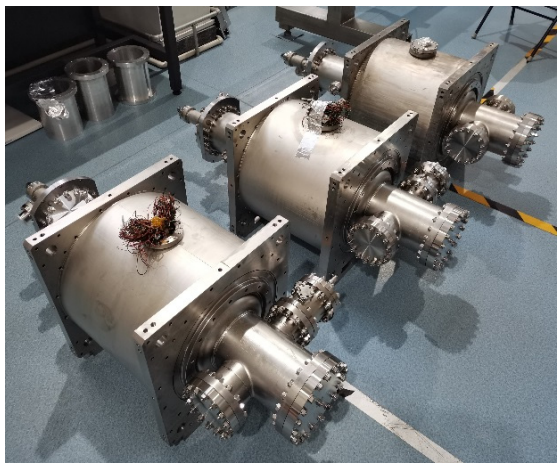

Figure 6: 650 MHz 2-cell cavities jacketed.

Then, the outer and inner surface of two 650 MHz 2-cell cavities (4# and 6#) received light BCP as Figure 7. Then, cavity 4# and 6# were transferred to cleanroom for assembly of cavity string, which is shown as Figure 8.

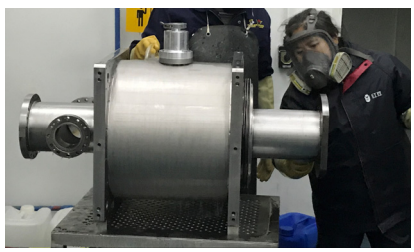

Figure 7: BCP of outer surface (up) and inner surface (down).

Figure 8: cavity string in cleanroom.

CONCLUSION

High Q and E_{acc} have been achieved for 650 MHz 1-cell cavities. The fabrication, BCP process and vertical test of 650 MHz 2-cell cavities have been completed for a 650 MHz test cryomodule. In future, the horizontal test and commissioning with beam will be carried out soon.

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