DESIGN AND VERTICAL TEST OF A PASSIVE 3RD HARMONIC SUPERCONDUCTING CAVITY FOR HALF STORAGE RING

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Abstract

A 3rd harmonic superconducting (SC) cavity is being developed for lengthening bunch and improving beam lifetime in the Hefei Advanced Light Facility (HALF) storage ring. This SC cavity is excited by an electron beam with 350 mA current, 1 nC charge, and ~6.7 ps length and requires strong damping of higher-order-modes (HOMs) in order to meet beam instability requirements. This paper presents design and vertical test of this passive 3rd harmonic SC cavity in detail. The vertical test results indicate that the cavity accelerating voltage reaches as high as 1.5 MV with the quality factor better than 3.4E8 and there is no multipacting or field emission.

INTRODUCTIONS

Hefei Advanced Light Facility (HALF) [1] is a soft X-ray and Vacuum Ultra-Violet fourth-generation diffraction-limited light source which is being constructed by National Synchrotron Radiation Laboratory (NSRL), University of Science and Technology of China. HALF consists of an injector, a storage ring, a few optical beamlines, and many experimental end-stations. The total length of the linac is 192 m. Electron beam is generated from a thermionic high voltage DC gun and the beam energy can be increased to 2.2 GeV at the exit of the linac. After passing through a 138 m long transport-line, the electron beam is injected into the storage ring. Synchrotron radiation will be generated by the insertion devices and the dipole magnets. The overall layout of HALF is shown in Figure 1. The HALF storage ring employs modified hybrid 6BA lattice as the baseline lattice to generate a beam with 85 pm·rad emittance, 350 mA current and 2.2 GeV energy.

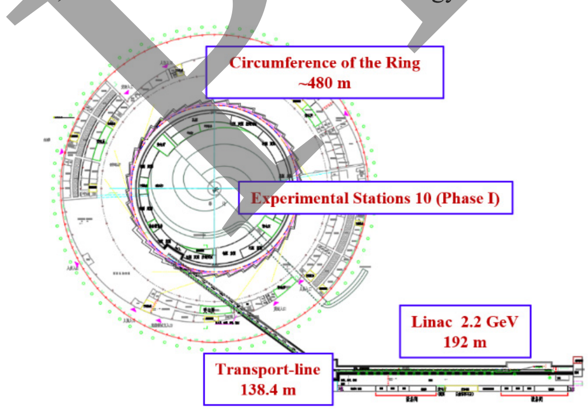

Figure 1: Layout of HALF.

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RF DESIGN ON HARMONIC SC CAVITY

The RF system consists of a main 500 MHz superconducting (SC) cavity and a passive 3rd-harmonic 1.5 GHz SC cavity for the HALF storage ring. The beam lifetime is one of the most important parameters that synchronous radiation users are concerned about, and it directly determines the performance of the electron storage ring. A 3rd-harmonic SC cavity is utilized to lengthen bunch and to improve beam lifetime in the HALF storage ring [2]. The RF system parameters have been calculated for HALF storage ring, as shown in Ref. [3]. The required voltage in 3rd harmonic SC cavity is calculated to be <0.5 MV. The bunch lengthening factor is calculated to be about 6, thereby increasing a Tousheck life time by a factor of 6.

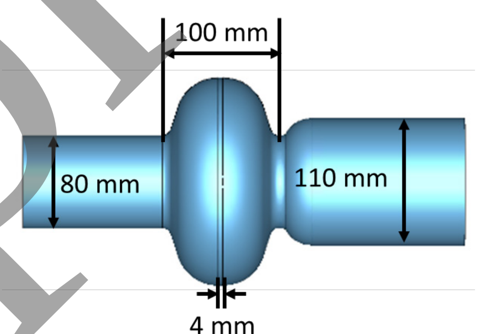

Figure 2: Geometry of a 3rd harmonic SC cavity.

Table 1: RF Parameters of a Harmonic Cavity

RF parameters	
Working mode	TM_{010}-π
frequency *f* [MHz]	1499.4
Cavity length [mm]	360
Geometry factor G [Ω]	291.6
Design voltage [MV]	0.5
R/Q [Ω]	81.8
E_p/E_{acc}	2.05
B_p/E_{acc} [mT/(MV/m)]	4.72

Considering its straightforward fabrication process, proven technological maturity, and reliable operational performance, such a 3rd harmonic SC cavity utilizes the TESLA shape with different beam pipes. Through optimizations by CST [4], the small beam pipe has a diameter of 80 mm while the large beam pipe has a diameter of 110 mm, as shown in Fig. 2. This ensures that the frequencies of first monopole mode (TM_{011}) and the first dipole mode (TE_{110}) are below of cut-off frequencies in the large beam pipe. The lengths of small beam pipe and large beam pipe are chosen to be 120 mm and 140 mm in order to ensure the fields from the fundamental mode stay inside the central cavity rather than leaking out of the beam pipes. The RF parameters of this 3rd harmonic SC cavity are listed in Table 1.

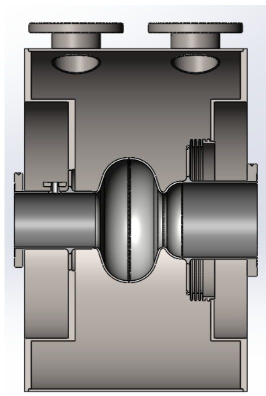

Figure 3: 3D modelling of a helium vessel welded with the 3rd harmonic SC cavity.

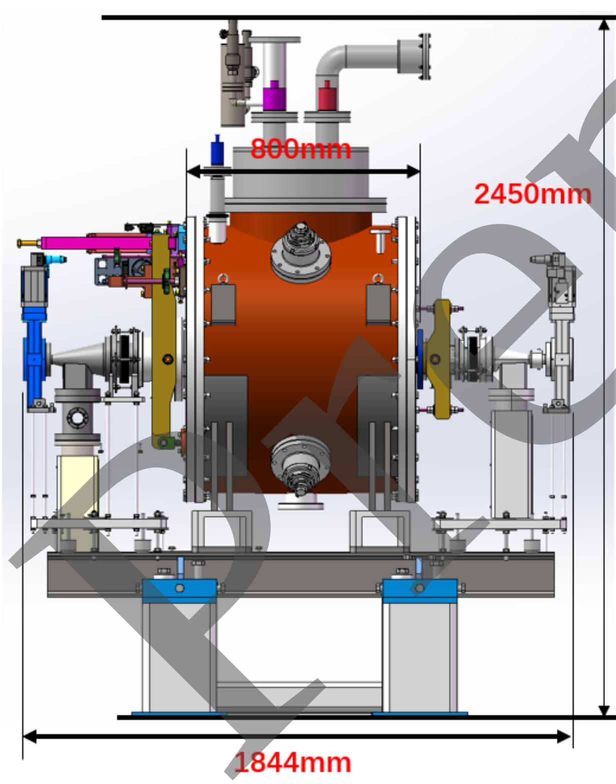

Figure 4: The entire module of a 3rd harmonic SC cavity for HALF storage ring.

It should be noted here that the helium vessel is welded with the SC 3rd-harmonic cavity in order to avoid cavity vacuum leak inside the thermal cycles, as shown in Fig 3. This is quite different from other SC modules which is separated between the helium vessel and the SC cavity. The entire module of SC 3rd-harmonic cavity is listed in Fig 4. The longitudinal length is set to be 1844 mm and the height is 2450 mm in order to keep it in a middle section of 2.2 m.

FABRICATIONS ON HARMONIC SC CAVITY

The deep-drawing together with the electron beam wielding (EBW) technology was adopted to fabricate the niobium half cells and the seamless beam pipe. The niobium half cells and beam pipes were cleaned, degreased carefully and rinsed with ultra-pure water before EBW to remove the oil and dust on the surface, especially on the welding joints. Then EBW was carried out for half cells and beam pipes. After EBW, careful surface preparations were applied for smoothing the inner surface. Two same niobium cavities are successfully fabricated, as shown in Fig. 5. Each niobium cavity is then welded with a helium vessel, as shown in Fig. 6.

Figure 5: The fabricated 3rd harmonic SC cavity.

Figure 6: The fabricated 3rd harmonic SC cavity is welded with a helium vessel.

VERTICAL TESTS ON HARMONIC SC CAVITY

The vertical tests on both niobium cavities welded with helium vessels were carried out at platform of advanced photon source technology R&D (PAPS) at Institute of High Energy Physics, Chinese Academy of Sciences, as shown in Fig. 7.

Figure 7: Two niobium cavities are put for vertical tests.

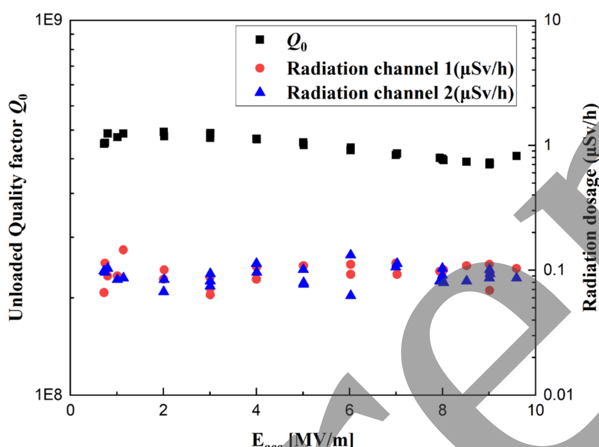

Figure 8: The vertical test results of the No. 1 niobium cavity.

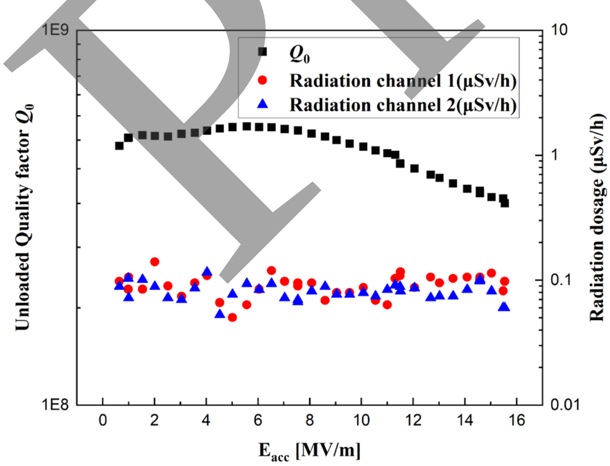

Figure 9: The vertical test results of the No. 2 niobium cavity.

An input coupler with fixed coupling coefficient was applied to drive each niobium cavity through a feedthrough at the end of beam pipes. The vertical tests at 4.2 K have been carried out for both niobium cavities successfully, as shown in Fig. 8 and Fig. 9. The vertical tests results show that the highest accelerating gradients of 10 MV/m (corresponding voltage of 1.0 MV) and 15 MV/m (corresponding voltage of 1.5 MV) are achieved with unloaded quality factor better than 4.3E8 and 3.4E8 for No. 1 and No. 2 niobium cavity, respectively, as shown in Table 2. There is no multipacting or field emission observed when the accelerating gradients are lower than 10 MV/m and 15 MV/m for both niobium cavities, respectively.

Table 2: Vertical Test Results on Two Niobium Cavities

	Highest Accelerating Gradient
No. 1 niobium cavity	10 MV/m with unloaded quality factor $Q_0 = 4.3E8$
No. 2 niobium cavity	15 MV/m with unloaded quality factor $Q_0 = 3.4E8$

CONCLUSION

The studies on a 3rd harmonic SC cavity including the design, fabrication and vertical tests have been carried out in this paper. Two niobium cavities are fabricated and employed for vertical tests. The vertical tests results indicate the highest accelerating gradients of 10 MV/m (corresponding voltage of 1.0 MV) and 15 MV/m (corresponding voltage of 1.5 MV) are achieved with unloaded quality factor better than 4.3E8 and 3.4E8 for both niobium cavities, and there is no multipacting or field emission. In the next step, the No.2 niobium cavity will be used for assembly of the module. The horizontal tests are planned to be performed for the assembled module by October 2026.

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