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650 MHz ELLIPTICAL CAVITIES IN IMP FOR CiADS PROJECT*

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Abstract

650MHz multi-cell superconducting elliptical cavities with optimum beta equal to 0.62 and 0.82 were adopted in the driver linac of Chinese initiative Accelerator Driven Subcritical System (CiADS) to accelerate the 10 mA proton beam from 175 MeV up to 500 MeV, with the possibility to upgrade the energy to 1 GeV and higher. Mechanical design and optimization of the niobium cavity-titanium helium vessel assembly will be summarized in this paper. Vertical test results of three single cell prototype cavities will also be discussed, with comparisons with the simulation values.

INTRODUCTION

Chinese initiative Accelerator Driven Subcritical System (CiADS) is a Multi-MW proton source for energy generation and nuclear waste transmutation. The driver superconducting linac is composed of three categories of superconducting cavities, 162.5MHz half-wavelength resonators (HWR) with optimum beta equal to 0.10 and 0.19, 325 MHz double spoke resonators (DSR) with optimum beta equal to 0.42, and 650 MHz elliptical cavities with optimum beta equal to 0.62 (Ellip.062) and 0.82 (Ellip.082), as shown in Fig. 1 [1].

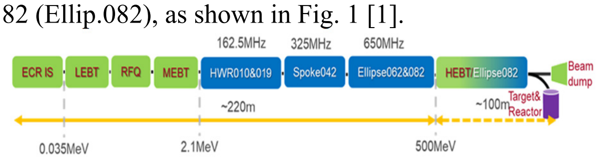

Figure 1: Layout of the CiADS injector linac.

Electromagnetic design and optimization of the six-cell Ellip.062 and five-cell Ellip.082 cavities, as well as the multipacting and high order mode analyses are summarized in [1]. Two different helium vessel options were studied, the titanium helium vessel with close linear expansion coefficient to niobium cavity, and the stainless steel helium vessel technologies with reduced material cost, potential reliability enhancement and well established fabrication and welding technology. Detail design of the stainless steel helium vessel option was summarized in [1], while the Titanium helium vessel option will be discussed in this paper.

CAVITY ASSEMBLY WITH TITANIUM HELIUM VESSEL

Similar mechanical structure of the cavity-helium vessel-tuner-coupler assembly were adopted for both the six-cell Ellip.062 and five-cell Ellip.082 cavities due to their same cavity length and closed equator radius, as shown in Fig. 2. Cavity will be made from 4 mm RRR300 Niobium sheets, while the stiffening ribs between cells and the end vessel plate connected to the beam pipe be made from 3 mm reactor grade niobium. Helium vessel is made from 4 mm Titanium with thicker end plate to get a better stiffness. NbTi55 was adopted to fabricate the flange, as well as the transit between niobium and titanium, as demonstrate in Fig. 3.

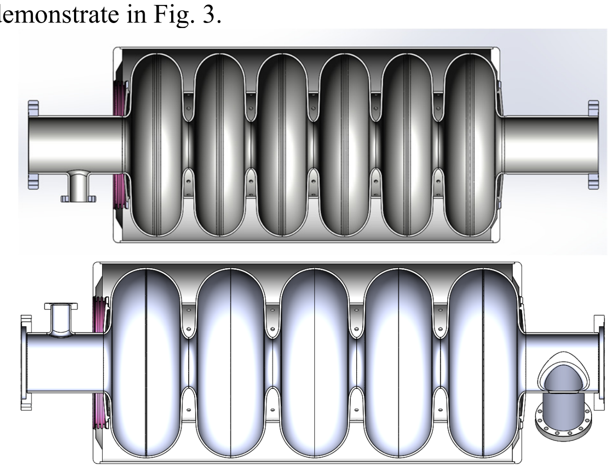

Figure 2: Mechanical structure of the CiADS 650 MHz elliptical cavity with Titanium Helium Vessel (Upper:Ellip.062; Lower:Ellip.082).

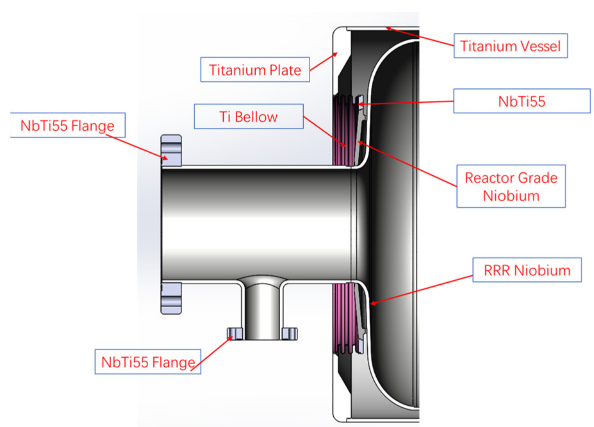

Figure 3: Material demonstration of the cavity-helium vessel assembly.

STIFFENING RIBS OPTIMIZATION

Position of the stiffening ribs between adjacent cells were optimized to minimize the Lorentz Force Detuning (LFD) and the frequency sensitivity to pressure fluctuation (df/dp). Figure 4 shows the dependence of cavity frequency to the helium pressure (df/dp) on different tuner stiffness for stiffening ring position of 105 mm and 110 mm for Ellip.062 cavity. The expected tuner stiffness is larger than

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40 kN/mm, corresponding to about 2 Hz/mbar pressure sensitivity with stiffening ribs R=110 mm .

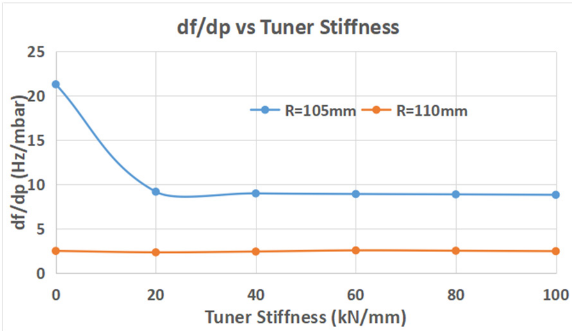

Figure 4: Pressure sensitivity (df/dp) on different tuner stiffness for stiffening ring position of 105 mm and 110 mm for Ellip.062 cavity.

Figure 5 shows the dependence of LFD coefficient (K_{LFD}, which is defined as df/E_{acc}^2) to different tuner stiffness at the ring position of 110 mm for Ellip.062 cavity. The excepted LFD coefficient is -0.7 Hz/(MV/m)^2, which is acceptable for the CiADS project. Optimization for Ellip.082 cavity is similar to Ellip.062 cavity.

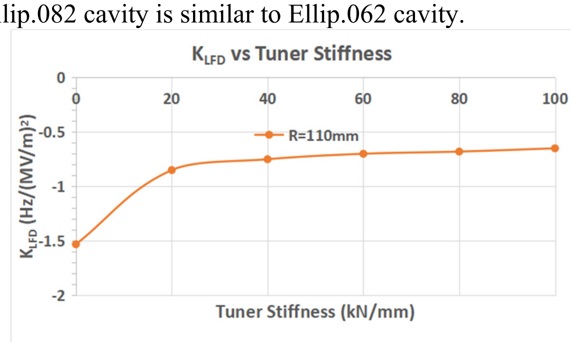

Figure 5: LFD coefficient K_{LFD} on different tuner stiffness for stiffening ring position 110 mm for Ellip.062 cavity.

STRESS ANALYSIS

The cavity-helium vessel system is supposed to be worked under low temperature, high incident pressure conditions with dynamic tuning during the operation. Figure 6 shows the stress analysis result with gravity, cool down to 2 K, 2 mm tuner extension, 0.4 MPa helium pressure. Maximum stress is 539 MPa, which is located at the titanium bellow, and is safety below the yield strength of titanium at 2 K.

SINGLE CELL PROTOTYPE CAVITIES

Three single cell niobium prototype cavities that constructed with end cells of Ellip.082 cavity were developed to explore the manufacture and post-processing technologies, as shown in Fig.7. Cavities were fabricated with the existing 3.5 mm niobium sheets. One of them was equiped with stainless steel flanges and stainless steel-Niobium transit ring, which will further be used for stainless steel helium vessel experiment. Two of them were equiped with niobium flanges, which will be used for Nb3Sn thin film coating study.

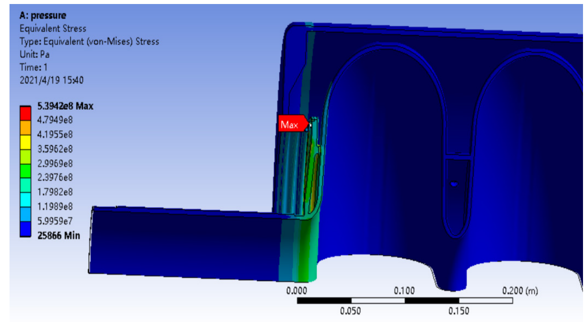

Figure 6: Stress analysis result with gravity, cool down to 2 K, 2 mm tuner extension, 0.4 MPa helium pressure.

Figure 7: Single cell niobium prototype cavities with stainless steel flanges (left) and niobium flanges (right).

Vertical test results of these cavities were summarized in Fig.8. Cavity with stainless steel flanges were electropolished with straight electrode, thus iris region was polished more than the equator region. Low field Q0 is about 2.8e10 due to additional cryogenic losses of the stainless steel flanges, maximum achievable peak surface electric field is only 32 MV/m, which is limited by field emission. Cavities with niobium flanges were polished with standard BCP. For both cavities, the low field Q0 is larger than 4.7e10. However, achievable peak surface electric field is only 21.5 MV/m for BCP#1 cavity, which is limited by field emission. With improved post-processing, maximum peak surface electric field is increased to 43.7 MV/m for BCP#2 cavity. Further study on the post-processing technology to push the peak surface electric field to higher level is on the way.

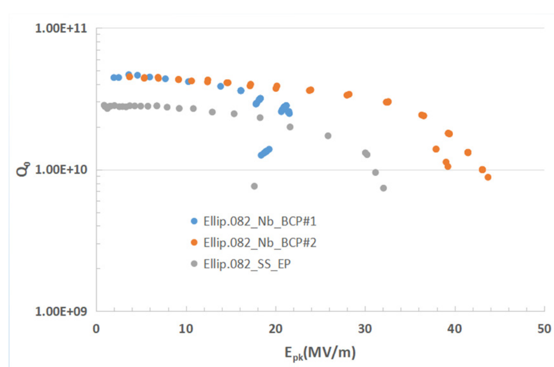

Figure 8: Vertical test results of single cell niobium prototype cavities.

Mechanical instabilities such as cavity frequency shift due to liquid helium pressure fluctuation (df/dp) and Lorentz force detuning coefficient were measured during the vertical test, as shown in Fig.9 and Fig.10. From the

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test results, df/dp is about -624 Hz/mbar, KLFD is around -17 Hz/(MV/m)2. Compared with the simulated values in ANSYS Workbench [2], df/dp is -606 Hz/mabr and KLFD is -19 Hz/(MV/m)2. The experimental results agree well with the simulation results.

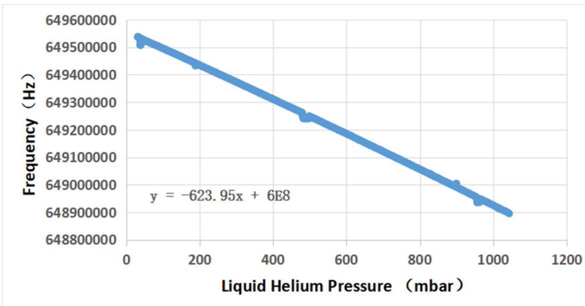

Figure 9: Frequency shift vs liquid helium pressure fluctuation during the vertical tests.

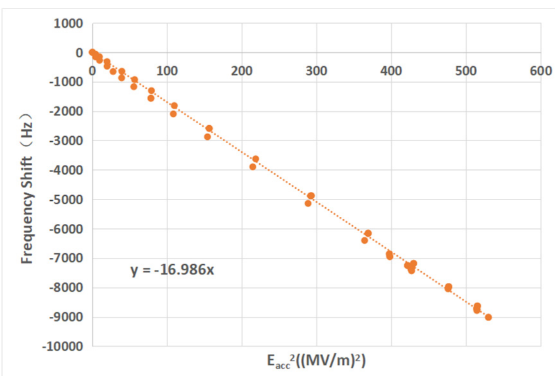

Figure 10: Lorentz Force Detuning (LFD) coefficient measurement during the vertical tests.

CONCLUSION

Mechanical design of the CiADS 650 MHz elliptical cavities with titanium helium vessel was discussed in this paper. Stiffening ribs between adjacent cells are optimized to minimize the Lorentz Force Detuning and frequency sensitivity to helium pressure. Measured LFD coefficient and df/dp agreed well with the simulation values for the Ellip.082 single cell prototype cavities. Multi-cell prototype cavities are under manufacturing and are expected to be ready for vertical test at the end of 2021.

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[2] Ansys, https://www.ansys.com