DEVELOPMENT OF SUPERCONDUCTING RADIO FREQUENCY CAVITIES AT SINAP

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Abstract

This paper will present the recent development of superconducting radio frequency cavities at Shanghai Institute of Applied Physics (SINAP). Firstly, Two KEKB type 500MHz single cell niobium cavities have been fabricated and one of them has been vertical tested successfully in 2010. The highest accelerating gradient higher than 10MV/m was obtained while the quality factor was better than 4E8 at 4.2K. Secondly, a new type of 500MHz single cell cavity has been designed which adopts the fluted beam pipe for higher order modes propagation and a coaxial type high power input coupler. Thirdly, a 500MHz 5-cell superconducting cavity with large aperture, enlarged beam pipe for HOM propagation and high r/Q value has been optimized which can be a candidate cavity for high current FEL and ERL.

INTRODUCTION

Future high current accelerators [1-2] will adopt superconducting cavities to provide energy to the particles. Because of their capability to provide higher cavity voltage, superconducting radio frequency (SRF) modules can be shorter, more compact and thereby impose less disruption on the beam. The 500MHz superconducting cavity has even larger beam aperture and lower HOM impedance, thus it can be adopted in accelerators with higher current.

SINAP and Shanghai key Laboratory of Cryogenics & Superconducting Cavity Technology have started the R&D on 500MHz superconducting cavity and succeeded on fabrication and vertical test of 500MHz single cell niobium cavity. A set of cavity fabrication, surface treatment and vertical test equipments have been constructed and the techniques have been explored. This paper will report the first successful development process of the 500MHz superconducting single cell niobium cavity in China. [3]

With the success on fabrication of the KEKB type single cell cavity, SINAP has carried out further design and simulation on 500MHz superconducting cavities including single cell and multicells. A complete design and simulation has been carried out on a single cell superconducting cavity which combines the fluted beam pipe for HOMs propagation and damping and the coaxial type high power input coupler. The rf performance of the cavity is similar to that of KEKB type and CESR type [4]. A low loss type 5cell superconducting cavity has been designed, deep-drawn and electron beam welded. The progress will be described in detail.

FABRICATION OF KEKB TYPE 500MHz SINGLE CELL NIOBIUM CAVITY

KEKB type 500MHz single cell cavity module has been adopted in synchrotron radiation light sources such as BEPCII besides the high energy electron collider KEKB, and which has been also selected for Taiwan Photon Source (TPS). Initially, we simply adopted the same way of the design scheme of BEPCII superconducting cavities based on KEKB type that is to lengthen the straight section on equator to obtain the operation frequency 499.65MHz.

Fabrication and Surface Treatment of Niobium Cavities

The fabrication procedure of niobium cavity includes the deep-drawing of half cells, trimming, rolling of beam pipes, forming flanges and EBW of cavity. The niobium sheets are selected to be fine grain, 3.0mm in thickness, and have RRR>300. The dies were made of aluminium alloy which has high enough yield strength and reasonable cost.

Figure 1: The deep-drawing process, the half cells and the final electron beam welded KEKB type 500MHz single cell niobium cavities in SINAP.

The niobium half cells and beam pipes were cleaned, degreased carefully, and slightly chemically polished before EBW to remove the oil and dust on the surface, especially on the welding joints. Then EBW was carried out in the vacuum chamber with the pressure better than 5E-5 Torr. The final electron beam welded niobium cavities are shown in Figure 1.

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The fabrication and surface treatment of the single cell superconducting cavity can be concluded:

- Deep-drawing technique used to obtain half cells.
- Electron beam welding of niobium cavity.
- Mechanical grinding of cavity inner surface especially around the welding seam.
- 190 μ m heavy buffered chemical polishing.
- 20 μ m light BCP with fresh acid.
- HPR with ultra-pure water twice.
- Assembly in clean room.
- 100 degree temperature baking under vacuum.

Vertical Test

The vertical test of 500MHz single cell niobium cavity was carried out on the in-house designed and constructed facility at SINAP. The vertical test facility for 500MHz superconducting cavity is composed of the test platform, vertical test stand, vertical test cryostat, a low level radio-frequency control system, vacuum system, radiation shielded test cave, etc. The static loss of the cryostat was better than 11W at 4.2K with the insulation vacuum pressure is better than 1E-3mbar.

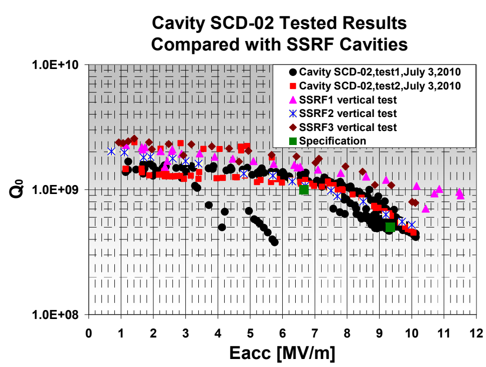

Figure 2: Vertical test results of the 500MHz single cell superconducting cavity fabricated, surface prepared at SINAP, compared with those of the superconducting cavities installed in SSRF storage ring.

After improved final surface treatment including a slight BCP with fresh acid, ultra-pure water rinsing immediately after slight BCP, HPR with fresh ultra-pure water in clean room, assembly immediately in clean room, low temperature baking(~100 ℃) longer than 48hrs quickly after evacuating and successful leak check at room temperature, the cavity was tested again on July 3, 2010 and the results obtained shows excellent performance. The test results show that the highest accelerating gradient is higher than 10 MV/m while the quality factor is better than 4E8. Furthermore, accelerating gradient reaches as high as 7.2 MV/m while the quality factor is still better than 1E9. Figure 2 shows the vertical test results of our fabricated 500MHz cavity in comparison to those of the SSRF superconducting cavities.

R&D OF A NEW TYPE 500MHz SINGLE CELL NIOBIUM CAVITY

A new type 500MHz single cell superconducting cavity with fluted beam pipe for higher order modes propagation and coaxial type input coupler for high power has been designed and simulated [4]. The beam aperture is kept same with that of CESR cavity, and the coaxial dimensions are same with that of KEKB type cavity except a straight outer-conductor is adopted. The fluted beam pipe's dimensions are kept same with that of CESR type cavity. The shape of the new type cavity and the model constructed by CST can be seen in Figure 3. The coupling strength of the coaxial type high power input coupler can be adjusted for different beam currents. The higher order modes power will be absorbed by the beam pipe type HOM loads equipped at both ends of the cavity.

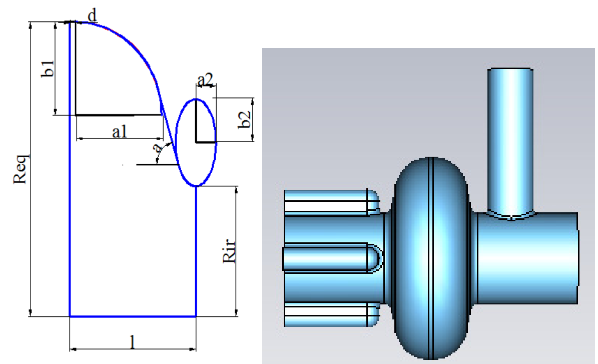

Figure 3: Cell shape and CST model of the new type single cell cavity.

For the cavity, the beam aperture radius Rir=120mm, the equator radius Req=269.2mm, a1/b1=89/89mm and a2/b2=20/40mm. The wall slope is 80 degree with l=120mm same with CESR type cavity. The straight section is used to tune the frequency and it equals to 4.9mm in our simulation. The simulation results show that the accelerating performance of the cavity is r/Q~90 Ω , Ep/Eacc=2.36 and Hp/Eacc=4.94 mT/(MV/m). And almost all the higher order modes can propagate out the cavity, especially the two lowest dipole modes TE111 and TM110 propagating through the fluted beam pipe. The resonant frequency of TE111 and TM110 are 625.2MHz and 676.8MHz which are higher than the cut-off frequency of TE11 mode of the fluted beam pipe so that both of them could propagate out the cell and absorbed by the HOM damper on the beam pipe.

One important progress was achieved in developing the seamless fluted beam pipe that the 1/3 scaled OFHC prototype and niobium material prototype were fabricated successfully as shown in Figure 4. This technique can ensure good repeatability, high yield, and completely simplify the processing procedures.

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Figure 4: Scaled OFHC prototype and fabricated niobium seamless fluted beam pipe.

R&D OF A 500MHz 5-CELL SUPERCONDUCTING NIOBIUM CAVITY

For high beam current energy recovery linac, different kinds of multi-cell superconducting cavities have been developed [1-2, 5-7]. In principle, the lower the frequency, the lower the BCS losses. However, the performance is limited by the inner surface condition which is a result of the fact that large cavities are difficult to obtain a well treated inner surface. A low loss type, 500MHz 5-cell cavity has been designed and carried out the fabrication. With frequency optimized to 499.6MHz, the inner cell shape dimensions are obtained. The beam aperture radius Rir=105mm, Req=263mm, a1/b1=112/89.3mm, a2/b2=30/30mm, l=150mm and the wall slope is 90 degree. The straight section on the equator d is adjusted to tune the frequency. The simulation results show that the r/Q=515 Ω, G=275 Ω, cell coupling =3.18%, Ep/Eacc=2.51 and Hp/Eacc=4.29mT/(MV/m).

The shape of end cell is similar to that of inner cell except that different length of the straight line on the equator which is adjusted to tune the cavity field flatness. One advantage of this method is that it is only need one set of dies for both inner cell and end cell shaping and trimming. An enlarged beam pipe with 320mm diameter can allow higher order modes propagate out the cell but not the accelerating mode. Figure 5 shows the field flatness output from CST and Superfish respectively.

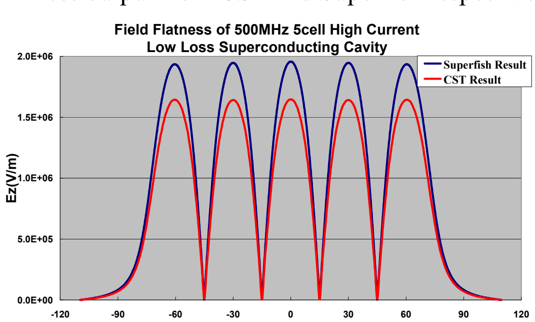

Figure 5: 500MHz 5cell cavity model by CST and field flatness output of CST and Superfish.

A copper prototype cavity without the beam pipes has been fabricated to study the deep drawing and electron beam welding techniques. Finally it succeeded in fabrication of niobium half cells and a 5-cell niobium cavity without the beam pipes has been electron beam welded which are shown in Figure 6.

Figure 6: The pressed niobium half cells, copper half cells and EBWed cavity.

SUMMARY AND OUTLOOK

A 500MHz KEKB type single cell superconducting niobium cavity has been fabricated and vertical tested which reaches quality factor 4E8 with accelerating gradient 10MV/m. The new type single cell cavity combined the fluted beam pipe for HOM damping and the coaxial type high power input coupler has been designed. A large aperture 500MHz 5-cell cavity has been electron beam welded without the beam pipes. The whole 5-cell niobium cavity fabrication will be finished soon and followed with surface treatments and vertical testing.

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