DEVELOPMENT OF A PROTOTYPE SRF CAVITY FOR THE PROTON BEAM UTILIZATION FACILITY AT NANJING UNIVERSITY*

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Abstract

Nanjing University has initiated the new technology development in the field of high-energy, charged-particle beam application and fundamental sciences. A high-current proton accelerator used for the new energy, new technology and fundamental science applications platform will be the near term goal at Nanjing University. For developing the superconducting RF linac for the proton beam utilization at Nanjing University, the first 6-cell, medium-beta prototype superconducting RF cavity has been fabricated and demonstrated using Chinese vendors only. The low-power test has been completed. The vertical test will be carried out soon.

INTRODUCTION

Nanjing University (NJU), one of the key comprehensive universities in China, has initiated the new technology development in the field of high-energy, charged-particle beam application and fundamental sciences. A high-current proton accelerator used for the new energy, new technology and fundamental science applications platform will be the near term goal at Nanjing University. The beam application platform will provide the proton beam with the different energy for different R&D users, such as in the fundamental sciences, medicine, space irradiation, nuclear analysis, spallation neutron source, radio Isotopes, semiconductor injection etc. that is similar to the PEFP's (Proton Engineering Frontier Project) beam utilization platform [1-6]. In order to complete this goal, the Proton Linear Accelerator Institute (PLAI) of the Nanjing University was established in October of 2011.

The proton linear accelerator will be employed at the beam utilization facility at Nanjing University. A basic frequency choice is 403 MHz for low-beta accelerating part and 806 MHz for medium- and high-beta accelerating part. The superconducting RF (SRF) accelerator will be the first choice to build the proton accelerator at Nanjing University. In order to develop the SRF technology, a prototype of a medium-beta SRF cavity has been developed. The NJU medium-beta cavity design is based on the SNS elliptical SRF cavity, because the operation experiences show that the SNS medium-beta cavities have good quality to proton beam [7-9]. The cavity's beta value is 0.61, and the number of the cells is 6. At present, the niobium cavity with 6-cell has been fabricated, and the basic low-power test has been completed at Nanjing University. The vertical test is going to be carried out at JLab next year, since the vertical system is not ready at Nanjing University. In this paper, the NJU SRF cavity's development is introduced.

MEDIUM-BETA ELLIPTICAL CAVITY DESIGN

Considering using the industrialized parts for building the NJU cryomodules, the beam pipe's diameter and its flange's dimension were chosen the same as that of the SNS SRF cavities'. First, the CavityBuilder was used to design the cavity, then the LabView program (developed by Sun An and Genfa Wu at JLab) and SUPERFISH were used to tune the cavity field flatness, finally the method to combine the ANSYS and SUPERFISH (developed by Sun An and Haipeng Wang at JLab) [10] was used to analyse the cavity mechanical properties, such as Lorentz force factor *K*, cavity deformation under the vacuum pump-down, and field flatness sensitivity under the tuner's driving, etc. as shown in Fig.1. The cavity parameters are listed in Table 1.

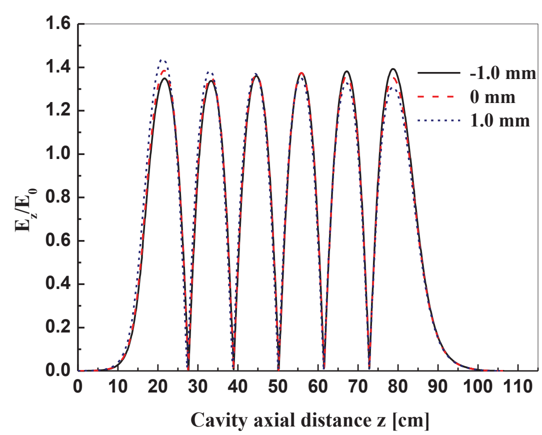

Figure 1: Simulation cavity's on-axis electric field amplitude relative changes in three states. 1.0 mm compressed, 0 mm free, and –1.0 mm stretched. Here E_0 is the normalized electric field set in all SUPERFISH runs. The left side is the FPC end, and the right side is the Field Probe end.

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Table 1: NJU Medium-beta Cavity's Parameters

Parameter	Value
Operation Mode	TM010 π
Frequency (MHz)	806
Geometrical β (β_g)	0.61
Number of cell	6
Cell-to-cell coupling factor (%)	1.61
E_{pk}/E_{acc}	2.72
B_{pk}/E_{acc} [mT/(MV/m)]	5.79
R/Q (Ohm)	278.55
G (Ohm)	176.55
Cavity length (cm)	106.5

HOM COUPLER DESIGN

The accelerating mode of a SRF accelerator built with an elliptical cavity is the TM010 π mode. Except for the TM010 π mode, there are a lot of other eigenmodes in a SRF cavity, which are called higher-order modes (HOM) and could be excited when a particle beam travels through the cavity. The main HOM related issues of a superconducting RF linac are the beam instabilities and the HOM-induced power, which increases the cryogenic heat load and may cause a SRF cavity quenching [11]. The HOM couplers are used to dampen the higher-order modes to prevent a resonant build-up of beam-induced fields by extracting the HOM-induced power from a cavity into the room temperature loads.

There are three main kinds of HOM couplers to remove a HOM induced power from a SRF cavity: waveguide HOM coupler with dissipative loads for the CEBAF (Continuous Electron Beam Accelerator Facility) cavity of Thomas Jefferson National Accelerator Facility (JLab), fluted beam tube leading to ferrite dissipative loads for a CESR (Cornell Electron-positron Storage Ring) cavity and a coaxial loop-type HOM coupler using a notch filter to reject a fundamental mode. Because of its smaller size, simpler structure, lower heat load for a cryogenic system and easy tuning of the notch frequency compared with the waveguide HOM coupler, the coaxial HOM coupler was used in many multi-cell cavities, such as TESLA cavities, SNS (Spallation Neutron Source) cavities, Low Loss cavities for ILC (International Linear Collider), High Gradient cavities for ILC, CEBAF upgrade cavities, etc.. Based on the TTF HOM coupler, a new coaxial HOM coupler with one hook and two rods has been designed for the PEFP SRF cavities [12]. Here we choose the PEFP type HOM coupler for the NJU medium-beta cavities.

The structure of the NJU-PEFP type HOM coupler is shown in Fig. 2. The CST Studio is used to simulate the notch frequency and field distribution. Figure 3 shows the Out-coupled power and notch distribution of the NJU HOM coupler. The simulation results show that the notch depth at 806 MHz is around -110.85 dB; that means the NJU HOM coupler can reject the TM 010 π. And the HOM coupler can transfer the HOM power without any rejection; that means the coupler can dampen the HOM excited power fully.

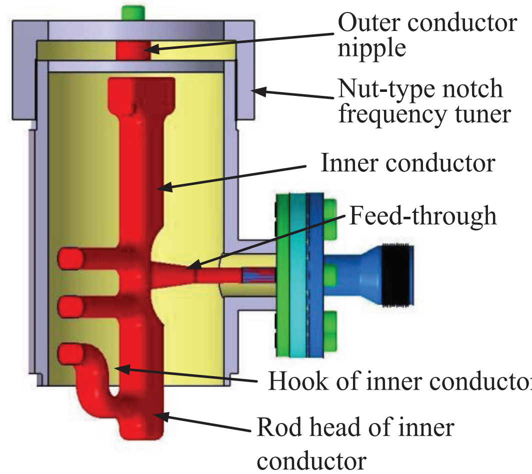

Figure 2: A cutaway of a 3-D NJU-PEFP type HOM coupler.

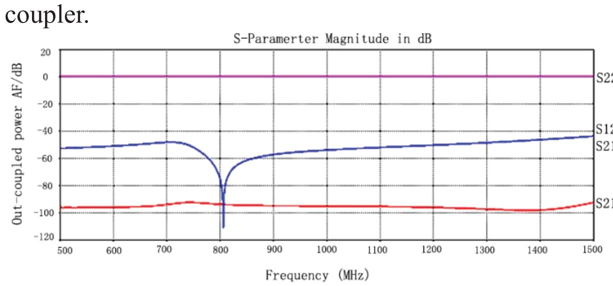

Figure 3: Out-coupled power and notch position of the NJU HOM coupler.

FABRICATION OF THE CAVITY

Normally, the fabrication procedure of an elliptical cavity is:

1. Produce the mechanical (or engineering) drawings.
2. Design the dies and jigs.
3. Deep-draw the half cells, beam-pipe transition, nipples for the FPC, FP and HOM couplers; fabricate the flanges etc.
4. Trim the edges.
5. Polish the cavity parts using the BCP.
6. Weld the cavity in the electron beam welder (EBW).

Based on the simulation results, the NJU cavity and its deep-drawing dies, trimming fixtures and the jigs for the electron beam welding have been designed. The niobium materials from Ningxia Orient Tantalum Industry Co., Ltd. were used to fabricate the NJU cavities. The 400 ton hydraulic machine was used to deep-draw the half-cell, beam-pipe transition, nipples for the FPC, FP and HOM couplers. After trimming the edges, all the parts have been cleaned by supersonic wave washer with DI water and polished about 10 μm by using BCP. After the part surface processing, the dumbbell cavities and end parts were welded in an electron-beam welder. Here we welt the dumbbell cavity from both sides at the iris position. For the EB welt parts, we need to take a cleaning and BCP polishing again before welding a full cavity. Figure 4 shows a prototype NJU cavity.

Figure 4: Prototype of the NJU medium-beta SRF cavity.

CAVITY TEST

The cavity test includes the vacuum leak-check, field-flatness tuning, low-power test and vertical test at low temperature. The vacuum test result showed that the welding quality can meet the requirements (see Fig. 5). In order to seal the cavity, the AlMg alloy gaskets have been fabricated. The field flatness tuning and low-power test has been described in many papers, here we don't describe. The vertical test for the prototype cavity will be carried out soon.

Figure 5: Vacuum test for the NJU medium-beta SRF cavity.

CONCLUSIONS

Nanjing University is going to develop the beam utilization platform for the fundamental sciences, medicine, space irradiation, nuclear analysis, spallation neutron source, radio Isotopes, semiconductor injection etc. A SRF accelerator will be used for the platform. In order to develop the SRF accelerator technology, a 6-cell medium SRF cavity prototype has been fabricated. The vacuum leak-check and low-power test have been done. The vertical test of the prototype cavity will be carried out soon.

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