DEVELOPMENT OF SINGLE CELL SUPERCONDUCTING ELLIPTICAL CAVITY (β=0.45)AND SRF TEST FACILITY IN IHEP

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Abstract

The R&D of 700MHz and scaled 1.3GHz (β=0.45) single cell superconducting cavity for high intensity proton linac has been done. We have completed the optimal design of the cavity and fabrication of three 1.3GHz cavities in China. In order to evaluate the performance of superconducting cavity, the cavity preparation and test facility has been established in IHEP. Two radiation shielded test pits have been built. The larger one, with the size of 1.1m diameter by 6m deep, is for 700MHz cavity test, and another one is for 1.3GHz cavity test. 300W solid-state RF power amplifiers, cryostats and LLRF control are all available. We have made a collaboration with Prof. K.Saito's group in KEK. The 1.3GHz cavities have been tested in IHEP and KEK respectively. The maximum surface field gradient Esp= 42.4MV/m was achieved.

INTRODUCTION

We began the research on superconducting RF technology with 700MHz, β=0.45 superconducting single cell cavities for the High Intensity Proton Linac project. In order to save research cost, we fabricated and tested 1.3GHz scaled cavities first.

The SRF Lab was constructed to support our research. The facilities in which can meet the demand of surface preparation and vertical test for single cell superconducting cavities. UP to now, Surface preparation and vertical tests for several types of cavities have been done in the lab, including 1.3G/β=0.45 cavities for the High Intensity Proton Linac, 1.3GHz high gradient and low loss cavities for the International Linear Collider, and 1.3GHz 2-cell cavity for the Photo Cathode Injector. The facilities are proved to have nice performance. In the future, the spare 500MHz cavities for BEPCII storage ring could also be treated and tested in the lab.

CAVITY DESIGN

The influences of various geometric parameters over SC cavity characteristics were analyzed. First of all, the ratios Hsp/Eacc and Esp/Eacc were minimized to improve the accelerating gradient Eacc, in which Hsp and Esp express the peak surface magnetic field and the peak surface electric field respectively. The medium β structure has much flatter shape than electron cavities. So the mechanical stability and the Lorentz force detuning coefficient K_L were considered.

The optimization of single cell shape is a foundation for the multi-cell cavity design. Further consideration were taken on the sufficient cell-to-cell coupling, the field flatness and the higher order mode trap, etc.

The geometric parameters of a superconducting cavity are shown in figure 1. The optimization result of the 700MHz, β=0.45 superconducting cavity is shown is in table 1.

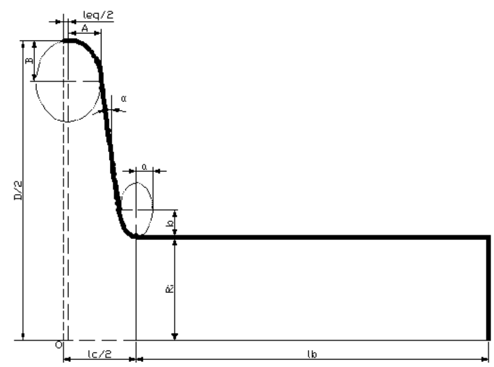

Figure 1: Geometric parameters of a SRF cavity

Table 1: The Optimization result of 700MHz/β=0.45 SRF Cavities

Geometric parameters	
Cell length	L_c =95.88mm
Cavity diameter	D =387mm
Iris radius	R_i=50mm
Beam pipe length	L_b=210mm
Equator length section	L_{eq}=4mm
Slope angle	α= 5°
Equator ellipse	A =21.69mm, B=43.37mm
Iris ellipse	a =18mm, b=36mm
Electromagnetic characteristics	
Resonate frequency	f =696.8MHz
Unloaded quality factor	Q_0 =4.41×10^9 @2K
Geometry factor	G=114.7Ω
Ratio of effective shunt to unloaded quality factor	r/Q_0 =19.4Ω
Ratio of surface peak electric field to accelerating electric field	Esp/Eacc =3.32
Ratio of surface peak magnetic field to accelerating electric field	Hsp/Eacc=81.7Oe/(MV/m)
Ratio of surface peak magnetic field to accelerating electric field	Hsp/Eacc=81.7Oe/(MV/m)

CAVITY FABRICATION

Three 1.3GHz/β=0.45 scaled cavities were fabricated, and the dies of the 700MHz cavity were machined. The process of cavity fabrication was explored in China.

The niobium sheets were from Tokyo Denkai with RRR=300. Circular dishes were deep drawn to form the half cells with an 80 ton hydropress, and then were trimmed. Rectangle sheets were rolled to make beam pipes. In order to meet the requirement of EBW, we developed a special press rolling equipment to get good beam pipe roundness. During the machining process, the circumstance should be clean and the operation should be performed carefully to avoid the grasp and the contamination on the part surface. Then a light BCP was done on the parts to clean the weld places.

Electron beam welding (EBW) is a key procedure in cavity fabrication. The proper operation parameters of EBW have been obtained through many times welding test. The cavity fixture and the diagraph precision of the rotating frock were improved to ensure the weld quality. After weld, the weld slot looked smooth and even, and few defects were found by CCD detection.

Figure 2 shows the three 1.3GHz/β=0.45 superconducting cavities we fabricated.

Figure 2: 1.3 GHz/β=0.45 cavities

SRF LOBORATORY

The area of the SRF laboratory is about 250 m^2, comprising 40m^2 of clean room, 15 m^2 of chemical polishing (CP) and washing room, 6 m^2 of ultra water system, 15 m^2 of control room, 18 m^2 of pumping room, 5 m^2 of cavity mount stage. There we have barrel polishing (BP) and centrifugal barrel polishing (CBP) equipments. Two test pits of different sizes were excavated: the small one with 1 m diameter by 6 m deep for 1.3GHz cavity tests, and the big one with 1.1 m diameter by 6 m deep for 700MHz or 500MHz cavity tests. Figure 3 shows the lay out of the laboratory.

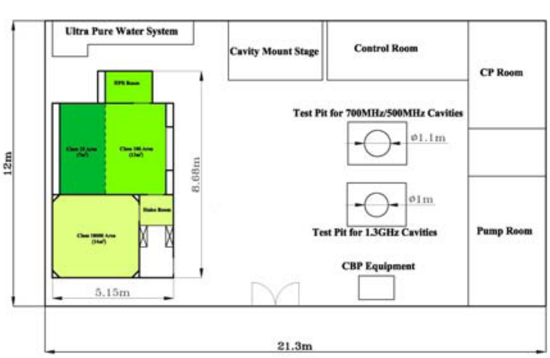

Figure 3: SRF lab lay out

Clean room

There are three areas with different air quality in the clean room. The area of class 10000 is 14 m^2, used for cavity vacuumizing and baking. The area of class 10 is 7 m^2. The area of class 100 is 13 m^2. Both of the two areas are used for cavity assembly. The high pressure water rinsing stand is in the class 100 area. Before entering the area of class 10000 and class 100, we go through a wind shower for person cleaning.

The evacuating and leakage detecting system is in the class 10000 area. The evacuating system consists of a set of turbopump with pumping speed 70 L/s, and an ion pump with pumping speed 200 L/s. The vacuum of the system can reach to 5×10^{-8}Pa at 20 °C. Heating covers and temperature control system are available for cavity baking.

Ultra pure water preparation and high pressure rinsing (HPR) system

Ultra pure water preparation system provides high quality water for HPR. The resistivity of the processed water is 18MΩ-cm. The latest examination indicates the TOC of the water is less than 14 ppb. The system can provide the water flow of 8-12 L/min, and can store 1200 L pure water to supply for 2 hour high pressure rinsing.

The HPR system consists of a high pressure pump, a 0.1 μm filter, a nozzle, a relief valve and the HPR stand etc. The nozzle is fixed. During the rinsing, the cavity moves up and down as well as rotates to be fully cleaned on the inner surface. The maximum travel distance of the cavity is 1.1 m with a speed of 4-16 cm/min adjustable, and the rotating speed can be 2-10 cycles per minute adjustable. The water pressure can be set in the range of 0-100 kgf/cm^2. The rinsing water flow can reach to 12 L/min, while the water pressure is 80 kgf/cm^2.

Vertical test facilities

There we have 2 pits for two kinds of cryostats, the pumping systems to decrease the temperature of liquid helium below 2 K, the low level control system and the data acquisition system for the vertical test.

The smaller cryostat is 335 mm in diameter and 2.8 m deep for 1.3 GHz single cell cavity test. The bigger one is 560mm in diameter and 3.8 m deep for 700 MHz single cell cavity test. The heat leakage for liquid helium of the cryostats was measured. The results are 0.7 w per hour and 1.15 w per hour respectively. Magnetic shields equipped in the cryostats are made from permalloy material. They can keep the residual magnetic field in the cryostats below 1.4 mGs at room temperature [3]. The pumping system includes a mechanical pump with pumping speed 150 L/s and a roots pump with pumping speed 1000 L/s, which can decrease the temperature of the liquid helium in the cryostat to the lowest temperature of 1.5 K.

Figure 4 shows the schematic of the vertical test equipment for the superconducting cavities. 700MHz and 1.3GHz, 300w solid-state RF power amplifiers are

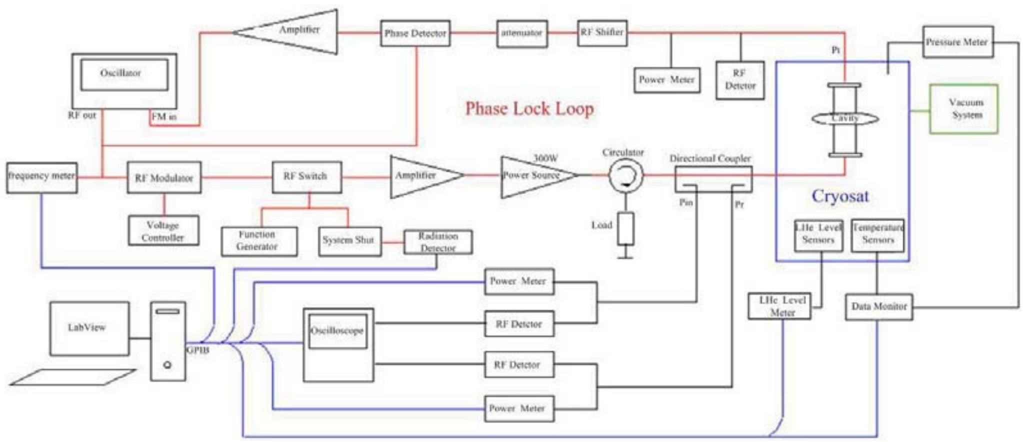

Figure 4: the schematic of the test equipment for rf measurement on a superconducting cavity

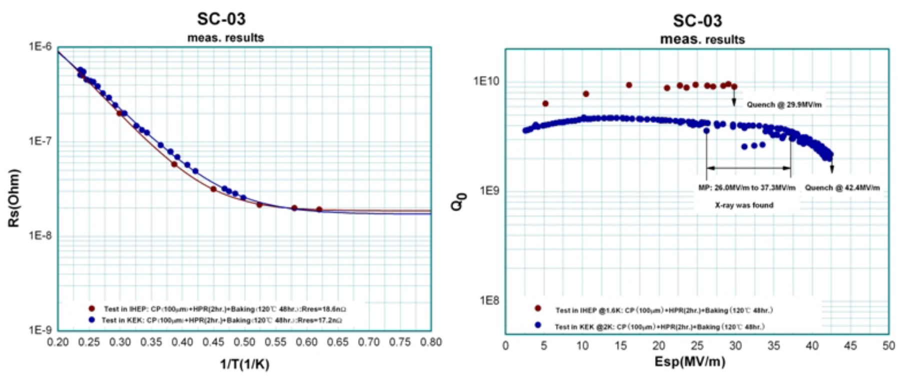

Figure 5: Test results of SC-03 cavity

employed to provide the power for vertical tests. A phase-locked loop is used to keep the RF source operating at the peak of the cavity resonance. Test data are collected to the computer through a GPIB card and the serial port. The system status is monitored and the test results are calculated using a Labview 6.1 program.

CAVITY TEST RESULTS

One of the three cavity, SC-03, was treated and tested in our lab. The maximum peak field reached to 29.9MV/m, and the residual resistance was 18.6 nΩ. Then the cavity was transported to KEK, and was measured directly. In this measurement, the maximum peak field reached to 42.4MV/m, and the residual resistance was 17.2 nΩ. Figure 5 shows the test results.

The temperature dependence of surface resistance was close between the two measurements. It proves our facility works well. The liquid helium temperature was kept at 1.6 K and 2 K respectively during the accelerating gradient measurements in the two labs. So the measured unloaded quality factors (Q_0) were obviously different between the two tests.

The cavity quenched at 29.9MV/m of surface peak electric field (Esp) in the measurement of IHEP. In the KEK measurement, X-ray was found around Esp=30MV/m. After RF processing, the gradient reached to a higher value. Theoretically, two point and one order multipacting should happen at 30MV/m of surface peak electric field for this structure with a ratio Hsp/Eacc=133Oe/(MV/m) [4]. It was probably caused by insufficient RF processing that we did not attain a higher gradient in IHEP.

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REFERENCES

[1] Zhao Shengchu, Sun Hong, Sun An, Zhou Demin, “Design Study on the 1.3GHz Scaled Superconducting Cavity for High Intensity proton Linac”, Journal of the Graduate School of the Chinese Academy of Sciences, 2003: 57-61.

[2] Ge Mingqi, “High Gradient Superconducting Cavity R&D”, Doctoral Thesis of the Graduate School of the Chinese Academy of Sciences, 2007.

[3] Sun Hong, Zhao Shengchu, Ge Mingqi “Magnetic Shield for the Vertical Test System of Superconducting Cavity”, HEP & NP,2005,29(10), p. 989-992.

[4] K.Saito “High Gradient Superconducting RF Cavity and International Liner Collider (ILC) Project”, 2000, p. 217-219.