

3.5-CELL SUPERCONDUCTING CAVITY FOR DC-SRF PHOTOINJECTOR AT PEKING UNIVERSITY

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Abstract

DC-SC photocathode injector was upgraded for Peking University Free Electron Laser (PKU-FEL) facility. A 3.5-cell superconducting cavity is the key component of the DC-SC photoinjector. Design and simulation of the 3.5-cell cavity was finished. Two 3.5-cell SRF cavities were fabricated at Peking University. One is made of large grain niobium and the other is made of fine grain niobium. All the material is from Ningxia OTIC. After BCP treatment and 1250°C post purification by Peking University, the 3.5-cell LG cavity was sent to Jlab for test. Due to the special structure, the cavity was treated with BCP, 800 °C degassing and HPR at Jlab. The Eacc of the cavity reached 23 MV/m with $Q=1.2 \times 10^{10}$ at highest gradient. The 3.5-cell LG Nb cavity was installed to the new DC-SC photoinjector and will be tested with the cryomodule for the next step.

INTRODUCTION

PKU-FEL facility is set up by SRF laboratory at Peking University. PKU-FEL will run in IR (5~10 μm) and THz (100~3000 μm) region with high stability and high average power. It can also provide high-quality electron beams for experimental studies such as nuclear physics, high energy physics, etc. An energy recovery linac (ERL) is designed based on PKU-FEL, see Fig. 1.

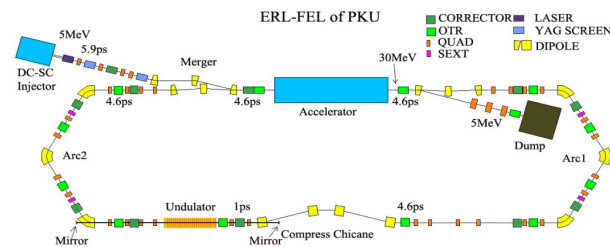


Figure 1: Layout of PKU-FEL.

Electron injector is the key part of the whole system. A DC-SRF photoinjector is used as the electron source for PKU-FEL. The concept of combining of DC and SRF photo-injectors was first proposed by Peking University in 2001[1]. This is a compact electron gun, which integrates a pierce DC gun and a superconducting cavity. This compact structure solved the compatibility problem between the superconducting cavity and the photocathode. It can run at CW mode to provide electron beams with high repetition rate, high average current and high quality. A 1.5-cell DC-SRF photoinjector was tested in 2004 [2]. After the demonstration of the DC-SRF concept, the injector was upgraded to 3.5-cell DC-SRF photoinjector.

Figure 2 gives the structure of 3.5-cell DC-SRF photoinjector. The core elements of the DC-SRF injector are a 100 kV DC pierce gun and a 3.5-cell superconducting cavity. In this paper, the design, fabrication and test of the 3.5-cell SC cavity is reported.

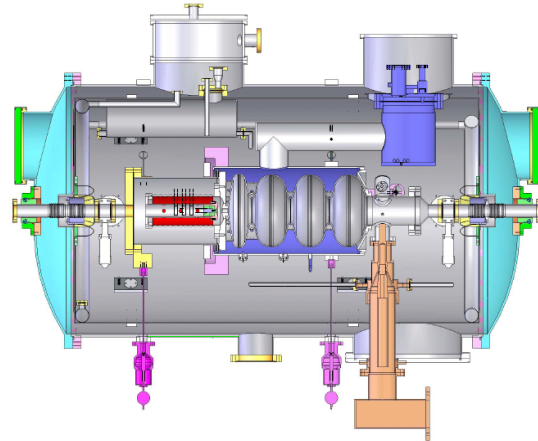
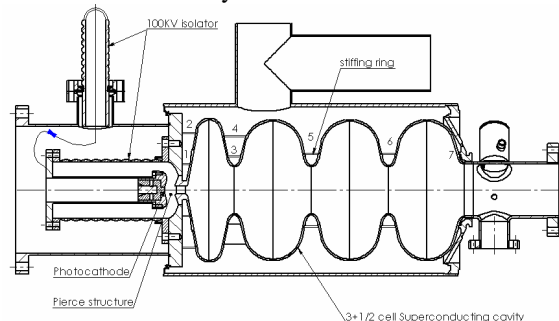


Figure 2: Structure of 3.5-cell DC-SRF photoinjector.

DESIGN AND OPTIMIZATION OF 3.5-CELL SC CAVITY

Geometry Optimization

The structure of the 3.5-cell cavity is showed in Fig. x. TESLA mid-cup and end-cup are adopted for the three $\beta=1$ cells. The first half-cell is designed and simulated carefully. The small beam tube between the DC gun and the superconducting cavity should be as short as possible in order to control the emittance increase. With a conical wall 10.5°, the first half cell has a negative value of the radial field near the entrance of the cavity and focuses the electron beam after the DC structure when the energy is only 90 keV. This also makes it not too difficult for the surface cleaning. Fig 3 and Table 1 gives the optimized parameters of the 3.5-cell cavity. Table 2 gives the RF parameters of the cavity.



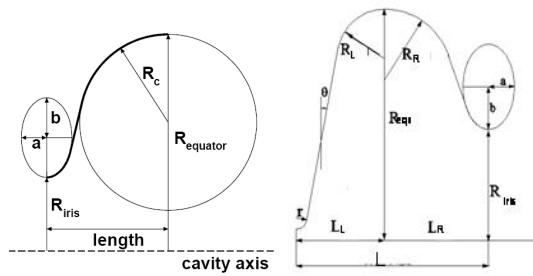


Figure 3: Geometry of 3.5-cell cavity.

Table 1: Geometry Parameters of 3.5-cell Cavity

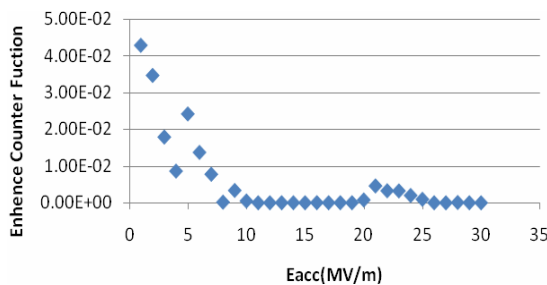
	Mid-cell	Left cup (1st cell)	Right cup (1st cell)	End-cup
Requator	103.3	105.3	105.3	103.3
Riris	35	6	35	39
Rc	42.0	17.14	17.14	40.3
a	12	3	12	10
b	19	3	20	13.5
Length	57.7	35.19	37.72	56.0

Table 2: Design Parameters of the 3.5-cell SRF Cavity

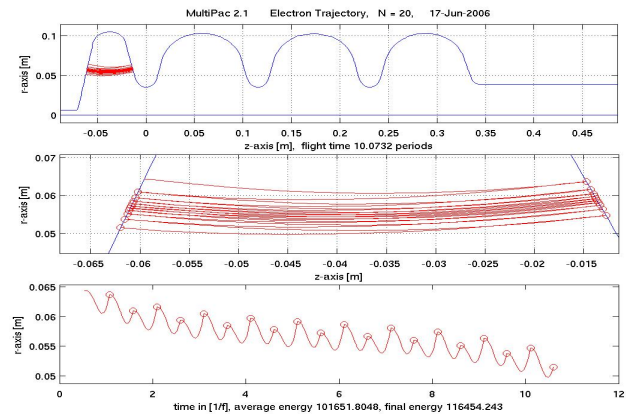
Mode	TM010,π-mode
Frequency	1300MHz
Q ₀	1×10 ¹⁰
E _{eacc}	13 MV/m
Effective Length	0.417 m
G-factor	242 Ω
E _{peak} /E _{eacc}	2.12
B _{peak} /E _{eacc}	4.95 mT/(MV/m)
Shunt Impedance r/Q	417 Ω

Multipacting Simulation

Multipacting simulations for the 3.5-cell SC cavity are done with code MultiPac and FishPact. Fig 4 gives the electron trajectory orbit and enhanced counter function respectively. The results indicate that the multipacting barrier can be processed for good cavity surface.



(a)



(b)

Figure 4: Multipacting simulation: (a) by FishPact (b) by MultiPac.

Lorentz Force Detuning

The bandwidth of the cavity is only about 130 Hz since the external Q value (Q_e) is about 1×10⁷. The frequency shift caused by the Lorentz force detuning is higher than 500 Hz when the cavity is operated at 13 MV/m if there is no stiffen rings. It is difficult for the control system at pulsed mode. Stiffen rings are added to the cavity. By optimization, the Lorentz force detuning coefficient is reduced to 1.2 Hz/(MV/m)².

Cross Talk

Due to the DC structure, the two HOM couplers, main power coupler port and pick-up port are located at the same end of the 3.5-cell cavity, see Fig. x. The RF power from the pickup antenna could have the signal directly from the main power coupler. To guarantee the low level control of the injector, cross-talk should be avoided. Calculation and RF measurements are done with a two-cell copper cavity. The results showed that the transmitted power to the pickup from the cavity is 6 order higher than from the main coupler at superconducting conditions. Thus the cross talk between the pickup and the main power coupler can be neglected for the injector running.

FABRICATION AND TEST OF THE 3.5-CELL CAVITY

Fabrication

Peking University has started researches on large grain niobium superconducting cavity since 2005. A 1.3 GHz single-cell and 2-cell TESLA type cavities were fabricated with Ningxia large grain niobium sheets[3-5]. They were tested by Jefferson Lab (USA) and DESY (Germany) separately. Gradients are higher than 40MV/m and Q value is higher than 1×10¹⁰ for both cavities:

Based on the experience on large grain cavity researches, two 3.5-cell SRF cavities were fabricated by Peking University. One is made of large grain niobium and the other is made of fine grain niobium. All the material is from Ningxia OTIC. The large grain cavity,

see Fig. 5, is adopted for the DC-SRF injector since the post treatment procedure can be simplified.



Figure 5: Large grain niobium 3.5-cell cavity made by PKU.

RF Test at Room Temperature

After the fabrication, RF measurements have been done for the 3.5-cell LG cavity. The field flatness is tuned to 94%. Since the cavity will be sent to Jlab for cold test, it is not necessary to tune the field flatness to a better value. When the injector operates, the dissipated power by HOMs is less than 1 W. TELSAs type HOM couplers are chosen for the cavity. Measurements for HOMs are done at room temperature and the results show that the fundamental mode TM₀₁₀ is cut off and HOMs can be extracted effectively.

Vertical Test at Jlab

After RF test and flatness tuning, the surface of the LG 3.5-cell cavity was removed 100 μm with BCP treatment and then post purified under 1250°C temperature at Ningxia OTIC for 3 hours. After a flash BCP and HPR, the cavity was sent to Jlab for vertical test.

Due to the special structure of the 3.5-cell cavity, further treatment was done in J-Lab by Dr. Rong-Li Geng. After delivery to JLab, the cavity had only high pressure rinsing and the first and second cold tests were done. The gradient of the cavity is only 7 MV/m, limited by strong field emission. New BCP treatment and special optimized high pressure rinsing were applied for the 3.5-cell cavity. 45° nozzles were added based on the standard 9-cell cavity HPR system. After 30μm BCP removal and new HPR at JLab, the cavity had the third cold test. There was no field emission for this time, and the gradient increases to 11 MV/m, limited by strong multipacting, which occurred from 8 MV/m. Q₀ is only 6×10⁹ even at low field.

Multipacting simulation was done again for the 3.5-cell cavity and it predicts two possible regions for multipacting. One gradient region is lower than 10 MV/m, referring to the first half cell. The other is 18~23 MV/m, responding to three TESLA type cells. See also Fig. 4.

The barriers are not so strong. The low Q₀ means that the surface of the cavity is polluted during BCP due to the small hole. In order to cure Q-drop and MP, 800°C heat treatment and additional 30 μm BCP were done followed by HPR. During the first power rise of the 4th test, two MP barriers encountered from 8 MV/m and 18MV/m and processed through finally. The gradient reached 23.5 MV/m, and Q value is higher than 1.2×10¹⁰, limited by quench, see Fig. 6.

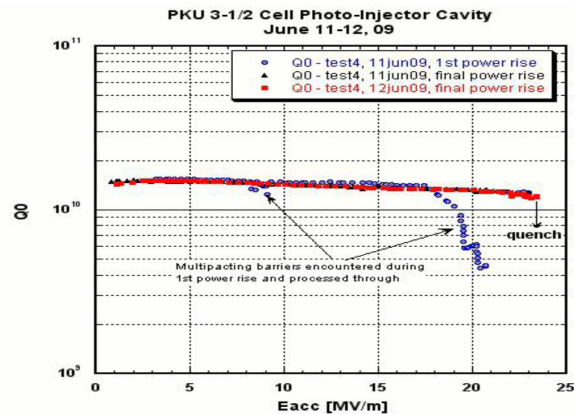


Figure 6: Final test result of 3.5-cell LG SC cavity.

SUMMARY

3.5-cell cavity is designed by Peking University. Field flatness tuning, Lorentz for detuning, HOM extraction and cross-talk are solved by optimization, calculation and RF measurements. A large grain and a fine grain 3.5-cell cavities are fabricated by Peking University. The LG 3.5-cell cavity was BCP and 1250°C treated in China and sent to Jlab for test. The accelerating gradient of the LG 3.5-cell cavity reaches 23.5 MV/m and the Q₀ is above 1.2×10¹⁰, which is very well for the DC-SRF photoinjector. The 3.5-cell LG Nb cavity was welded with liquid helium tank and installed to the new DC-SRF photoinjector and will be tested with the cryomodule for the next step.

ACKNOWLEDGEMENT

The authors give great thanks to Ningxia OTIC colleagues for the cavity treatment, Prof. J. He at Harbin Institute of Technology for the cavity welding and Dr. Rong-Li Geng and many other colleagues at Jlab for the cavity treatments and test.

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