A 1.3 GHZ CRYOMUDULE WITH 2X9-CELL CAVITY FOR SETF AT PEKING UNIVERSITY*

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Abstract

The straight beam line of SETF at Peking University is under construction, which consists of a DC-SRF photoinjector and a superconducting linac with two 9-cell cavities. Stable operation of the DC-SRF photoinjector has been realized and the design, manufacture and assembly of the cryomodule with two 9-cell cavities have been completed. Improved capacitive coupling RF power coupler and fast tuner with piezo are adopted.

INTRODUCTION

Since we reported the project of Superconducting ERL Test Facility (SETF) at Peking University (PKU) in SRF 2009 [1] and SRF2011 [2], the progress has been made step by step. After the DC-SRF was put into stable operation in 2014 [3], the efforts have been made to establish the straight beam line which is shown in Figure 1. The most important component in this straight beam line is a 1.3GHz superconducting linac containing two 9-cell cavities, which will accelerate the electrons from DC-SRF photoinjector up to 25MeV. The electron beam with MHz high repetition rate will used to generate infrared free electron laser and THz radiation. In this paper, we mainly report the design, manufacture and assembling of the cryomudule with 2×9-cell cavity.

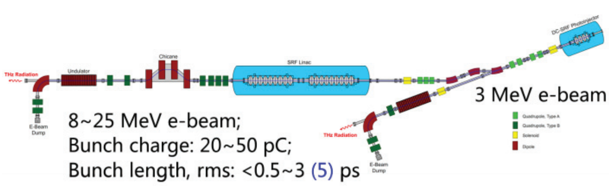

Figure 1: Schematic drawing of the layout of PKU FEL facility.

STABLE OPERATION OF THE DC-SRF PHOTOINJECTOR

The DC-SRF photocathode gun [4, 5] combines a DC pierce structure and a 3.5-cell superconducting cavity. It can provide electron beam with energy higher than 3 MeV and average current of about 1mA. The accelerating gradient of the cavity reached 23.5 MV/m and the intrinsic quality factor Q_0 is higher than 1.2×10^{10} in vertical test [6].

The wavelength of the seed drive laser is 1064 nm. The repetition rate of laser pulses is 81.25 MHz, which is 1/16 of the resonate frequency of the 3.5-cell SRF cavity. The harmonic generators convert the infrared pulses to UV pulses with a wavelength of 266 nm. The drive laser system can provide 1 W power in a train of 6 ps UV pulses with 5% power instability. The quantum efficiency of Cs_2Te photocathode was about 4% for the injector operation.

Figure 2: Beam experiment layout of the DC-SRF photoinjector.

For machine safety, the beam experiments were carried out at an Eacc of 8.5 MV/m. The duty factor of RF power was 7% with a repetition rate of 10 Hz. Average beam current in macro pulses at 1mA for about 10 minutes was obtained and stable operation for more than 6 hours at 0.55mA were tested. Figure 2 shows the beam experiment layout of the DC-SRF injector. The detailed experiment results were published this year [3].

By adding an undulator after the DC-SRF injector and the 3.5-cell cavity works as both the acceleration and RF bunch compression roles, we got successfully THz radiation (700~1200 μ m) in early 2015.

2×9-CELL CAVITY CRYOMODULE

The main accelerator contains two 9-cell TESLA cavities, input power couplers, frequency tuners, helium vessel, liquid nitrogen shield, magnetic shield and its associated auxiliary systems. The sectional view of the cryomodule is shown in Figure 3.

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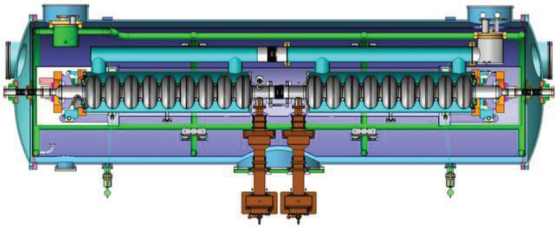
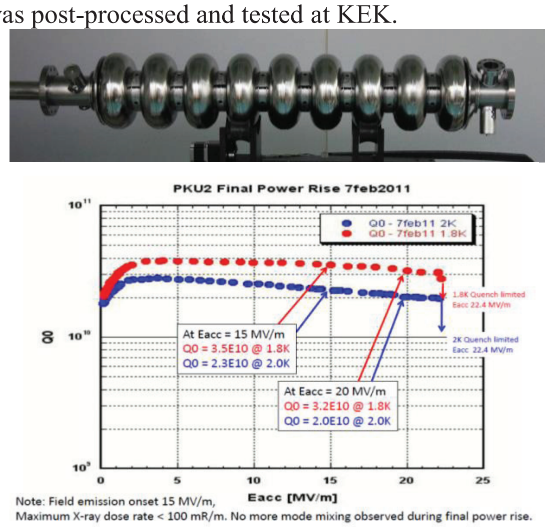
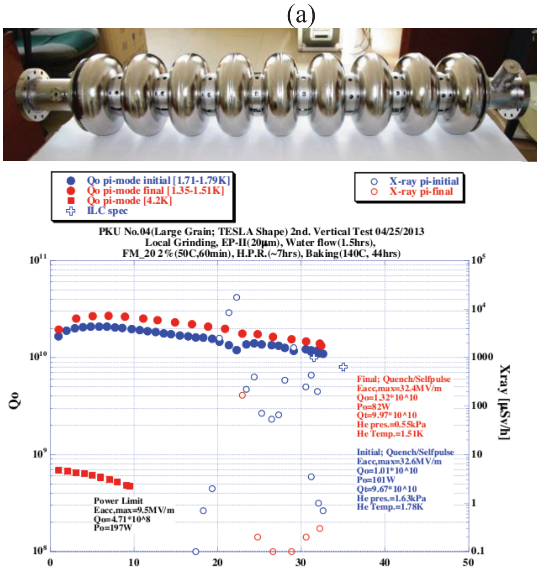


Figure 3: The sectional view of the 2 × 9-cell superconducting cavity cryomodule.

Both 9-cell cavities are made from Ningxia large grain niobium material and fabricated in China. Figure 4 shows the two cavities which are named PKU2 and PKU4. PKU2 was post-processed and tested at JLab and PKU was post-processed and tested at KEK.



(a)



(b)

Figure 4: (a) PKU2 and its vertical test result, (b) PKU4 and its vertical test result.

PKU2 quenched at the gradient of 22.4 MV/m at 2K, and PKU4 reached 32.6 MV/m at 1.8K and limited by quench. Quality factor of both cavities was higher than 1 × 10^{10} at the quench gradients. The design operation gradient for the 9-cell cavities is 10 MV/m.

Due to Lorenz force detuning, beam loading effect, microphonics, the frequency of superconducting cavity will change, resulting in perturbation on phase and amplitude of the accelerating field, which may affect the operation of the cavity. Therefore precise control of the cavity frequency during the cavity operation is necessary. A tuning system including slow and fast tuners for the two 9-cell cavities were designed and manufactured under the collaboration between PKU and Institute of High Energy Physics, Chinese Academy of Sciences. The thermal leakage analysis, control of the tuners and tuning efficiency analysis of the tuning system were carried out. The tuner range of motor tuner is about 600 kHz. The tuning range of piezo tuner is larger than 2 kHz. Figure 5 shows 3D model and photo of the tuner.

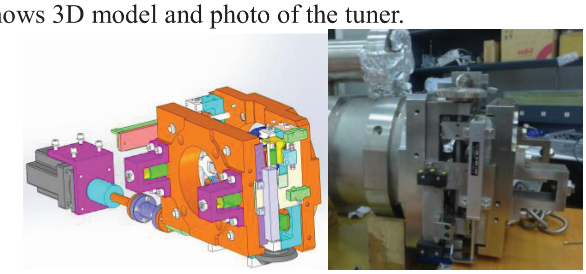


Figure 5: slow and fast tuner for a 9-cell cavity.

A capacitive coupling RF power coupler was used for the DC-SRF injector. During the operation, we found there was an overheating of the inner conductors in both warm and cold section of the coupler when the CW forward power is higher than 5kW or pulsed power higher than 10kW. The capacitive coupling cold window has a high electrical field at the centre of the ceramic. For the two 9-cell cavities couplers, we made some improvements of the capacitive coupling power couplers [7]. The main modifications include enlarging the supporting rods of inner conductors in order to increase heat conduction, moving the bellows from the quarter-wave transformer to the 50 Ohm coaxial line to avoid the mismatch during Q_{ext} adjusting, and changing the design of inner conductor to reduce the electric field of cold window. Figure 6 shows the cross section view and the photo of the input coupler for 9-cell cavity.

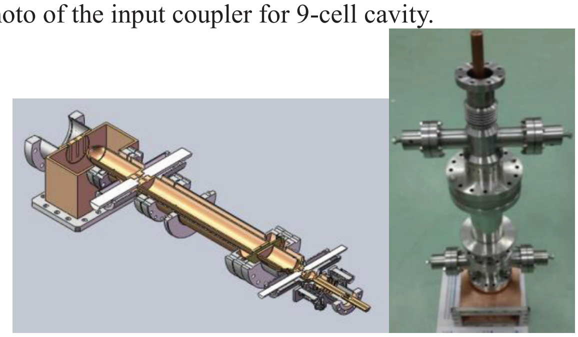


Figure 6: input coupler for the 9-cell cavity.

Before assembled to the cavity, the couplers were conditioned. Both couplers can transfer 10kW RF power with 10Hz and a duty factor of 30% and can satisfy the requirement.

Between the room temperature vacuum vessel and the 2K cavities, liquid nitrogen is used for the 80K shield of the cryostat. Magnetic shield made of low temperature permalloy covers the tuners and the cavities to prevent the terrestrial magnetism increasing the surface resistance of the cavity. Both the magnetic shield and nitrogen shield are covered with 20 layers of low temperature adiabatic films to reduce the heat load of the cryostat.

CONDITIONING PREPARATION OF THE 2×9-CELL CAVITY CRYOMODULE

After welded with the liquid helium jackets, the 9-cell cavities were treated with light buffered chemical polishing and high pressure rinsing. Then the cavities and the cold window parts of two couplers were assembled together in class 100 clean room. The high order mode couplers were adjusted to make sure they could cut off the fundamental mode and absorb the higher order modes.

The tuners were mounted on each side of the beam pipes of the cavity string. Rectangle shaped magnetic shields covered the tuners and cylindrical magnetic shield covered the body of the cavity and the helium tank.

Figure 7: Layout of the 9-cell cryomodule and the DC-SRF photoinjector.

The cryomodule has been assembled and been connected to the 2K cold box and the liquid nitrogen supply system. More than 30 temperature sensors were mounted inside the cryostat. Figure 7 shows the layout of the 9-cell cavity cryomodule and the DC-SRF photoinjector.

The low level RF control system for the 9-cell cryomodule is ready. The conditioning of the 2×9-cell cavity cryomodule and the 2K cryogenic system just started. The beam loading experiment will be carried out at the end of this month or next month.

CONCLUSION

After stable operation of DC-SRF photoinjector, the design, manufacture and assembling of the 2×9-cell cavity cryomodule have been completed recently. The main coupler and fast tunner has been tested at room temperature. The crymodule has been connected to 2K cryogenic system and ready for RF and beam test. It is expected to accelerate the electron beam up to 25MeV together with the injector.

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