

STATUS OF THE DC-SRF PHOTOINJECTOR FOR PKU-SETF*

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Abstract

DC-SRF photocathode injector developed by Peking University is a good candidate for obtaining high average current, low emittance, short electron beam pulse. Much progress has been made on the 3.5-cell cavity DC-SRF injector since SRF2009. The assembling of the cryomodule was completed with the 3.5-cell SRF cavity which has an accelerating gradient of 23.5MV/m in the vertical test. The preliminary RF experiment has been carried out soon after the installation and commissioning of 2K cryogenic system was finished. The accelerating gradient of the cavity is 11.5MV/m in a horizontal cold test and the Q_{ext} is 5×10^6 . The limitation of the gradient is mainly from our present low RF power source. Higher gradient is expected with a new 20kW solid state RF power source which will be delivered to Peking University soon.

INTRODUCTION

Peking University (PKU) is developing a superconducting energy recovery linac (ERL) test facility – PKU-SETF. Figure 1 shows the schematic drawing of the layout of PKU-SETF. It has roles as accelerator physics and ERL technology test facility, and providing infrared free electron laser (FELs), THz (400-1200 μm), and further x ray through Compton Backscattering (CBS) for research in many areas such as chemistry, material science, life science, etc.

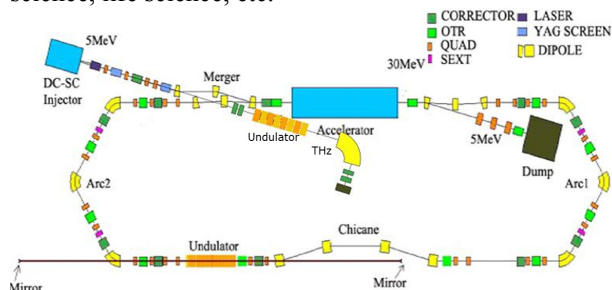


Figure 1: Schematic drawing of the layout of PKU-SETF.

The photoinjector for PKU-SETF is a DC-SRF photocathode gun [1, 2]. It combines a DC pierce gun structure and a 3.5-cell superconducting cavity, and can provide high average current, low emittance and short pulse electron beam. Figure 2 shows the sectional view of

the DC-SRF injector. The injector has two different operation modes. One mode provides electron beam for ERL-FEL. The other is a RF bunch compression mode, and the injector works as a THz source.

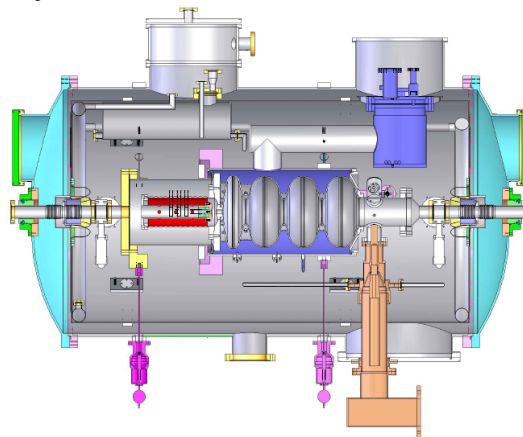


Figure 2: The sectional view of the 3.5-cell superconducting cavity DC-SRF photoinjector.

KEY COMPONENTS OF THE DC-SRF INJECTOR

The key components of the DC-SRF photoinjector are a 100kV DC pierce gun and a 3.5-cell superconducting cavity. Figure 3 shows the sketch of the pierce structure and its corresponding high voltage isolation structure. The designed DC voltage is 90kV. The distance between the anode and the cathode is 14mm. Figure 4 shows the adaxial electric field distribution. The surface electric field on the cathode is almost 5 MV/m, and the peak electric field is lower than 13 MV/m. The electron beam gets a focusing force when it leaves the cathode and is defocused around the anode. The anode is connected to the 3.5-cell cavity through a small beam pipe. A single crystal niobium sheet with a diameter of 70 mm is used to make the anode and the entrance of the first half cell. This avoids discharging at high surface field. By controlling the concentricity of the connecting flanges, we can get good alignment of the pierce structure and the cavity.

* Work supported by National Basic Research Project (No. 2011CB808302) and National Natural Science Funds (No. 11075007)

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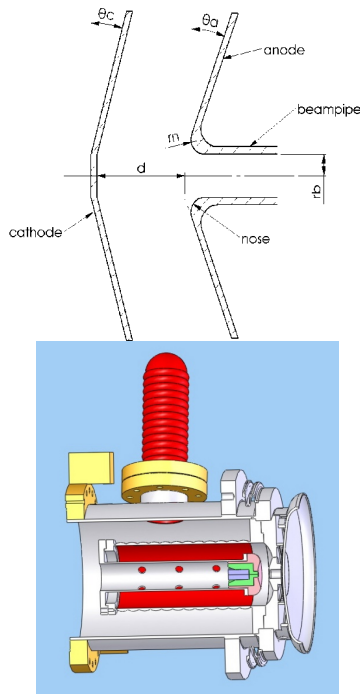


Figure 3: Top: Sketch of the pierce structure, bottom: Mechanical design of the DC high voltage isolation structure.

After the DC pierce structure, the electron beam still has low energy and the space charge effect is obvious. To maintain good emittance, a 3.5-cell superconducting cavity focuses and accelerates the electron beam as near as the pierce structure. To avoid the RF field and DC static field infiltrating into each other, the distance of the connecting beam pipe between the DC anode and the half cell of the cavity is designed at 17mm long. RF Design, fabrication, 1250°C post-purification of the cavity were done in China. The vertical RF test was done at Jefferson Lab. The gradient of the cavity reaches 23.5 MV/m, and the Q_0 value is higher than 1.2×10^{10} [3].

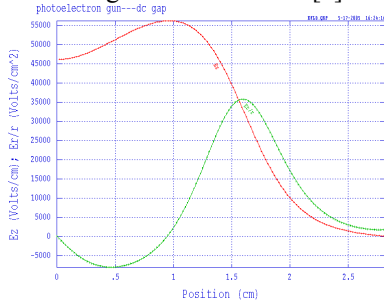


Figure 4: Electric field distribution along the axis of pierce structure.

BEAM DYNAMIC SIMULATION

Beam dynamics simulation of the photoinjector was done by using software POSSION, SUPERFISH, PARMELA, ASTRA etc. Figure 5 gives the layout of the injector and its beam line. Electron bunches start from the

photocathode, and then go through the pierce gun and the 3.5-cell cavity. A solenoid is adjacent to the exit of the cryostat, used to compensate the emittance and focus the electron beam. Figure 6 shows the simulation results when the injector works at different modes. Figure 7 a) gives the bunch shape, energy-phase relation and energy spectrum of the electron beam just after the 3.5-cell cavity when the injector provides electron beam for ERL facility. Figure 7 b) gives electron beam property diagrams when the injector provides electron beam for THz facility. Table 1 gives the simulation results of the injector at two operation modes. For ERL mode, the cavity operates at the gradient of 13 MV/m and the transverse emittance is minimized. After the solenoid compensation and consideration of the thermal effect, the total rms transverse emittance is 1.4mm·mrad. The rms pulse length is 3 ps. For THz mode, the cavity operates at 15MV/m and it works as a buncher and accelerating cavity. By velocity modulation of the beam produced by the 3.5-cell cavity, the bunch length of the electron beam is compressed to 0.55 ps, which is suitable for THz generation.

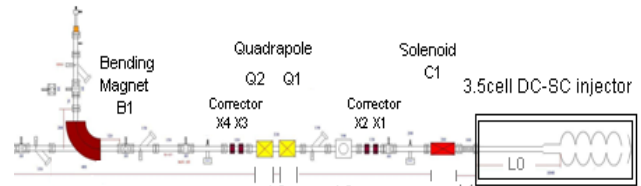
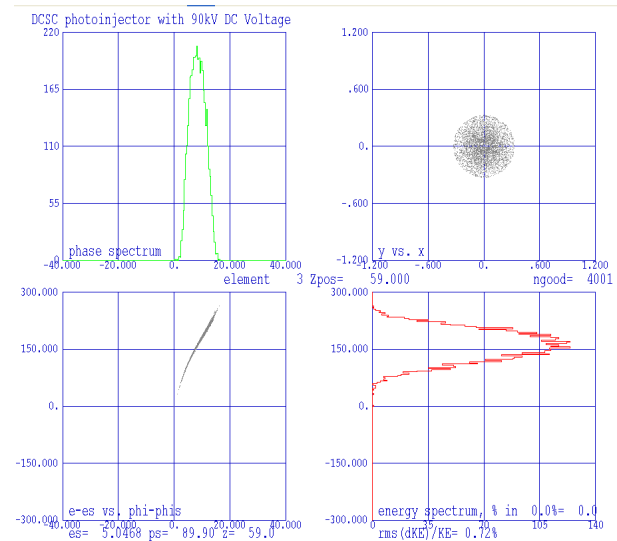


Figure 5: Layout of the photoinjector and its beam line.



(a) ERL mode

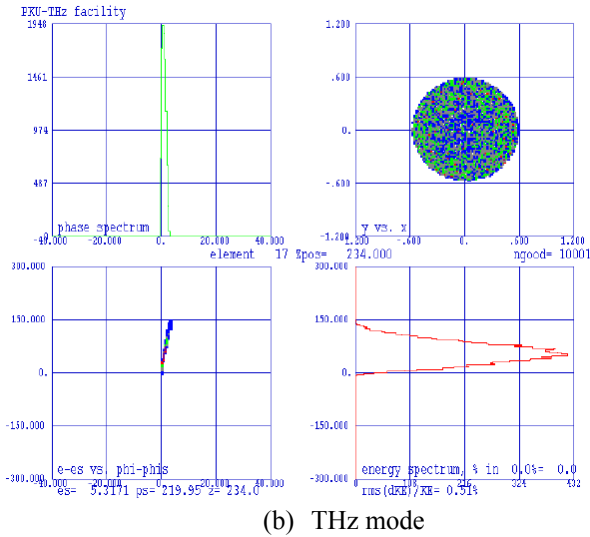


Figure 6: The four diagrams are: longitudinal bunch shape, transverse bunch shape, energy-phase relation and energy spectrum of the electron beam.

Table 1: Design parameters of the DC-SRF injector at two operation modes (DC voltage = 90 kV)

Drive laser		
Pulse length /	8ps	
laser spot / FWHM	3.0mm	
Repetition rate	81.25MHz	
Bunch shape	uniform transverse distribution, Gaussian longitudinal distribution	
Injector	ERL mode	THz mode
gradient	13 MV/m	15MV/m
Bunch charge	100 pc	20pc
energy	5MeV	<5MeV
Transverse emittance	1.4mm·mrad	2.1 mm·mrad
Longitudinal	15 deg - KeV	3.0deg - KeV
Bunch length / rms	3ps	0.55ps
Rms beam spot	0.3mm	1.7mm
Energy spread	~ 0.5%	0.55%

We also consider the impact of DC high voltage on transverse emittance. When the injector is for ERL mode, higher DC voltage causes lower transverse emittance, seen from Fig. 7. But when the voltage is higher than 60kV, the emittance decreases slightly.

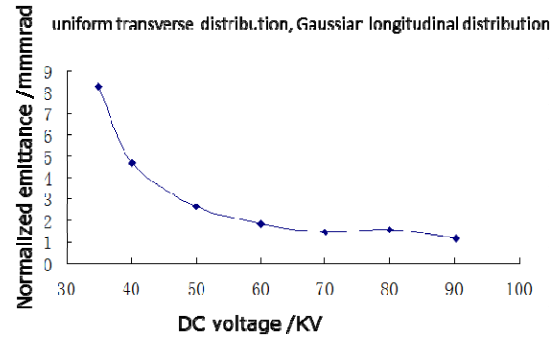


Figure 7: Transverse emittance changes as the DC high voltage.

HORIZONTAL RF TEST OF THE 3.5-CELL SUPERCONDUCTING CAVITY

The cryogenic system and the cryo-module of the injector were installed during 2010 as a collaborative effort between PKU, Linde, and Technical Institute of Physics and Chemistry of CAS (TIPC). The liquefier and 2K cold box are from Linde. The 2K cooling capacity is 58W. The pipes and the transfer lines are from TIPC. The heat load of the 2K transfer lines is about 0.5 W/m. The cryomodule of the injector is made by PKU. The static heat load of the cryostat at 2K is lower than 10W. After commissioning, the cryogenic system can provide 2K liquid helium for the injector successfully and the pressure stability is 30 ± 0.2 mbar.

The 3.5-cell superconducting cavity was tested horizontally inside the injector cryomodule at both continuous and pulsed modes. Figure 8 gives the reflection and pickup signals when the cavity was under superconductivity at 2K. Q_{ext} is measured to be 5×10^6 . Limited by our present amplifier which can output 2.3kW RF power, the gradient of the cavity only reaches 11.5MV/m. Multipacting barrier was encountered around 6.5MV/m and could be processed through.

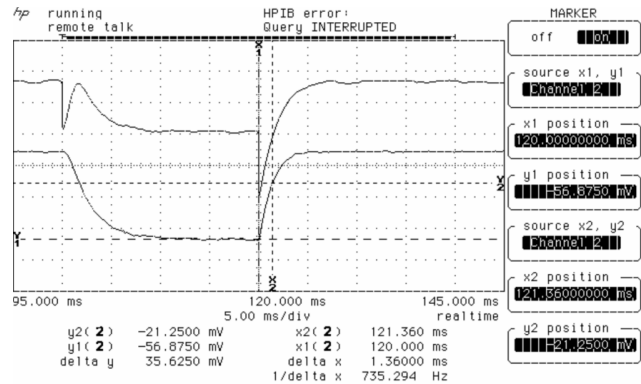


Figure 8: The reflection and pickup signals at 2K at pulsed mode.

BEAM TEST PREPARATION OF THE INJECTOR



Figure 9: Layout of the DC-SRF photoinjector facility.

Figure 9 is the layout of the injector facility. It includes laser driven photocathode system, 2K cryogenic system, DC high voltage system, injector cryomodule, RF power transportation system and beam diagnostic system, etc.

The drive laser is based on a commercial picosecond laser (Time-Bandwith GE-100), delivering 5 W at 1064 nm wavelength. The lasing medium is diode-pumped neodymium yttrium vanadate (Nd:YVO₄), mode-locked to generate 8 ps FWHM pulses at a repetition rate of 81.25 MHz, this being the 16th sub-harmonic of the 1.3 GHz RF frequency. Recently this commercial drive laser has been modified and upgraded. After being amplified, the output of the seed laser is 40W. After frequency multiplication, the green laser at 532 nm wavelength is 10 W. After fourth harmonic generation, the UV laser at 266 nm wavelength is higher than 1 W.

A film thickness monitor is set inside the preparation chamber, so we can automatically control the deposition rate of the cesium film and the tellurium film. After preparation, the Cs₂Te photocathode is moved to the transmission chamber, transported into the cryostat and fixed at the cathode of the pierce structure by a rod. To decrease the heat load, the transfer rod was taken back to the transmission chamber. Then the cavity starts to cool down.

CONCLUSION

Beam dynamic simulation shows the 3.5-cell superconducting cavity DC-SRF photocathode injector can provide high average current, low emittance, short pulse length electron beam. This injector facility has been installed and is under commissioning now. The horizontal test of the injector 3.5-cell superconducting cavity has been carried out. The accelerating gradient of the cavity is 11.5MV/m limited by our present RF power source. Preparation of the beam test is almost done, and the electron beam will be extracted and accelerated by the injector soon.

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