THE FABRICATION AND EXPERIMENTAL INVESTIGATIONS OF THE SC PHOTOINJECTOR AT PEKING UNIVERSITY*

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Abstract

An important application of superconduting RF technology at Peking University is the development of the SC photoinjector, which is built to provide electron source for future free electron laser—PKU-FEL [1]. This is the first photocathode electron gun to integrate Pierce DC gun with 1.3GHz superconducting cavity, which has been installed in Peking University. In this paper the fabrication of the 1+1/2 Nb cavity is introduced, and the test results of the injector prototype are summarized.

INTRODUCTION

The new project of PKU-FEL [1] based on superconducting accelerators started in 2002. For this program, a new design of DC-SC photoinjector was worked out [2]. The major goal is to produce minimum transverse emittance beams at a high average current (~1mA).

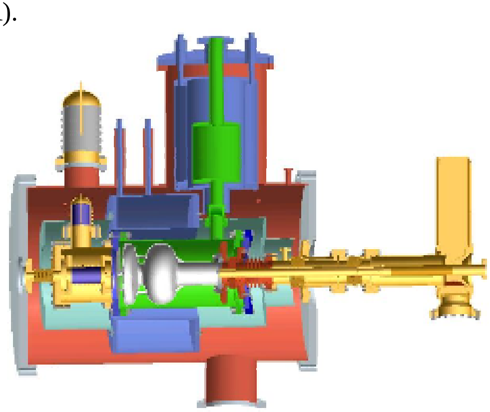


Fig. 1: 3D view of the test facility of DC-SC photoinjector

The basic idea of DC-SC photoinjector is to integrate a DC Pierce gun with a superconducting 1+1/2 niobium cavity. Figure 1 shows the 3D view of the test facility, including the DC pierce gun, the module housing the superconducing cavity and the power input coupler. Details of the hardware components are described elsewhere [3].

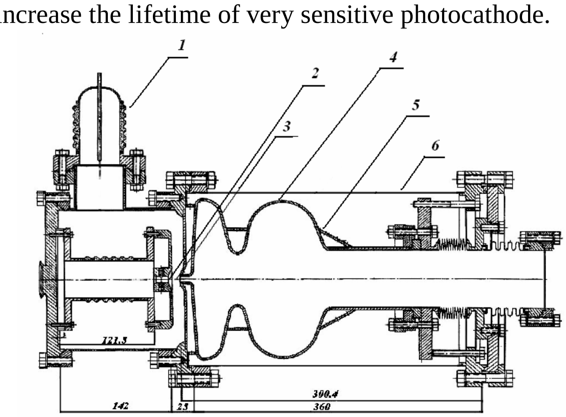
The prototype of the 1+1/2 cell cavity has been fabricated and treated, and all of the subsystems have been assembled at our lab. The cavity test has been finished and the first test of the injector is in process.

DC PIERCE GUN AND 1+1/2 CELL SC CAVITY

Design Considerations

This is a compact structure, and the cores of DC-SC photoinjector are the DC Pierce gun and the 1+1/2 cell superconducting cavity. The photocathode is placed at the cathode of the Pierce structure (as shown in the figure 2).

The attracting advantage of DC- SC injector is that the effect of the photocathode to the SC cavity can be avoided because the photocathode is placed outside the SC cavity. It will require neither vacuum break nor cavity warm up to change the cathode. The cathode plug with the photolayer will also be operated at low temperature, and the good vacuum conditions should increase the lifetime of very sensitive photocathode.



(1) Ceramic insulation (2) Photocathode
(3) Pierce DC gun (4) Nb cavity
(5) Stiffening ring (6) LHe tank

Fig. 2: Draft of the 1+1/2 cell cavity

It is impossible to apply an external magnetic field in the SC situation, so a conical geometry of the back wall of the half-cell has been designed to lead to an RF focusing of the electron bunch. Code PARMELA [4] is used to simulate the performance of the whole injector. The optimized results at the exit of the injector are listed in Table 1.

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Table 1: Simulation results of the DC-SC injector

Electron bunch	
Length	7.8 ps
Energy spread (rms)	1.16%
Energy	2.61 MeV
I_{ave}	1mA
Emittance (rms)	3mm-mrad
Radius	2.8 mm
Charge	60pC
SC cavity	
E_{acc}	15 MV/m

The disadvantage of this design is its slender neck with a length of 15mm between the DC Pierce gun and the half cell SC cavity. The space-charge effect increases the emittance of the low energy electron bunch. But we found that before the charge per bunch increases to 100pC, the simulation results show good promise to our requirements. The RMS emittance in table 1 is as good as 3mm-mrad at the end of the whole injector.

The Preparation of the Prototype of 1+1/2 Cell Cavity

The whole prototype are composed of four half cells, two tubes and the Pierce anode. Two flanges made from NbTi are used to connect to the LHe tank and the beam tube (Figure 3).

Fig. 3: The parts of the cavity prototype

The 2.6mm thick sheet niobium (RRR=250) are annealed at 800~850°C in the vacuum of 10^{-5}~10^{-6}mbar for 2~3 hours.

The four half cells are made by spinning, and the Pierce anode is made by deep drawing. After forging and sheet rolling, the Nb cups and tubes are thoroughly cleaned by chemical etching and ultrapure water rinsing. The EB welding is carried out at a pressure of less than 5×10^{-5}mbar. The weld parameters are chosen to achieve full penetration according the results of a lot of tests. Figure 4 shows the smooth weld seam with a width of about 4mm at the equator.

Fig. 4: Weld seam (4mm wide) at the equator

A layer of Nb has been removed from the inner cavity surface to obtain good rf performance in the superconducting state. The cavity undergoes mechanical polishing, high pressure ultrapure water rinsing and heat treatment at 1100°C in vacuum with Ti sheet for 4 hours. A layer of 120μm is removed by buffered chemical polishing (BCP) and the cavity is rinsed with ultraclean water. The next step is electric etching of 29μm and ultraclean water rinsing.

At last the cavity (figure 5) is mechanically tuned to adjust the resonance frequency to the design value in the 100 class clean room. The frequency of the cavity under normal conducting state is 1297.7MHz.

Fig. 5: Picture of the 1+1/2 cell Niobium cavity

Test Results

The cold RF-test of the SC cavity has been carried out up to date. The cavity was tested without the cathode in it to evaluate the cavity and to prove the compatibility of the superconducting cavity and the DC Pierce gun. A resonant at 1300MHz at 4.2K is achieved. The first test showed that the unloaded Q value of 1+1/2 cell was ~10^8 and the average gradient was about 4~5MV/m, limited by multipacting.

The first test on the DC gun has been done, in which the current reached 100μA.

THE DESIGN OF THE BEAM LINE

Cs_2Te photocathode will be adopted to produce electrons. One layer of Cs_2Te on a stainless plug is excited by 266nm UV laser, and its quantum efficiency is above 5%. A high power mode-locked and diode-pumped Nd:YVO_4 picosecond laser provides average output power is 10.4W@1064nm with the repetition of 81.25MHz. The pulse duration is 10ps. After frequency doubling and quadrupling, it is able to generate 1W@266nm.

The cavity is powered by a 4.5kW solid-state power amplifier via a coaxial input coupler. To decrease the thermal loading and RF loss, the inner conductor is made of thin stainless, coated with copper outside, and the metal of outer conductor is stainless coated with copper inside too.

A beam diagnostic system has been commissioned in the beam line. A new measure of electron beam emittance with Cerenkov radiation 'duo image pattern', has been researched newly [5].

SUMMARY

DC-SC photoinjector is a new type of electron gun to get moderate average currents at low charge per bunch but at very high repetition rate. To prove the compatibility of the superconducting cavity and the Pierce DC gun, the prototype of 1+1/2 cell cavity has been fabricated and the test facility has been developed.

The performance in our current test shows good promise as an injector for the electron source of PKU-FEL. First results from the cold test of superconducting cavity have been presented. The beam test on the DC gun has been done. The next step is to prepare all the equipment for the beam tests.

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