POSSIBILITY OF ADOPTING SOLENOID IN DC-SC PHOTOINJECTOR*

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Abstract

Solenoid is an efficient element in the beam line to control the transverse rms emittance in normal conducting injectors. However, for the case of superconducting photoinjector the extra magnetic field can not exist in the area of SC cavity. By calcultaing and simulating, this paper presents the possibility of applying solenoid emittance compensation in the DC-SC photoinjector, a new type of superconducting gun developed at Peking University.

INTRODUCTION

Because the superconducting cavity can work in the CW mode and the photocathode is the best emitter with low emittance, the photo injectors based on superconducting cavity become the popular choice to produce the high average current electron beams for the high average power FELs and ERL. At Peking University, a new FEL facility (PKU-FEL) based on superconducting linac is on building, which is designed as high average power infrared (5~10μm) and THz (100~3000 μm) light source [1]. As the new electron source, DC-SC photoinjector has been developed in the last years.

DC-SC photoinjector is a novel design different from the SC injectors in Rossendorf [2], BNL [3] and Jefferson lab [4]. By integrating a small DC Pierce gun with the superconducting cavity, it is free of the compatibility of the superconducting cavity and the normal conducting photocathode, which makes the production and operation easier compared with other designs. In 2004 the first beam loading has been successfully performed in the test facility of 1+1/2 cell DC-SC injector. Up to now, the gradient of 6 MV/m has been achieved at 4.4 K. The rms emittance about 5 mm-mrad has been measured in the beam test with the beam energy of 1.1 MeV and current of 270 μA [5].

In parallel to the prototype test of 1+1/2 cell gun, the simulation of the 2+1/2 cell photoinjector has been already done [6]. The goal of this new design is to produce the beams with the energy around 4 MeV, the bunch charge of 60~100 pC and the transverse emittance about 1 mm-mrad. For the idea of DC-SC photoinjector, the main open question was the relative large transverse emittance compared with the normal conducting RF gun. To further control the transverse rms emittance, the solenoid magnetic field compensation, which is an effective method in normal conducting gun, will be consided in the DC-SC injector case.

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2+1/2 CELL GUN DESIGN

In the design of 2+1/2 cell DC-SC injector, DC gun and superconducting cavity are the main parts. The geometry of the 2 full cells is based on the TESLA design; the first cell and the DC Pierce gun are optimized to provide good focusing to low energy electrons. The parameters of DC gun and the first cell are presented in figure 1 and table 1. The voltage applied on the cathode is -70 kV, and the maxmum field on the cathode surface is 6 MV/m. There exists a hole in the anode with the diameter of 8 mm through which the electrons enter the half cell cavity. To prevent the RF power loss caused by this hole, the distance between the anode of the Pierce gun and the wall of the half cell is designed to 13 mm. The first cell is optimized to a 0.6 cell with a slope wall of 5 degree, so that the RF field near the entrance of the cavity has the focusing force on the electrons. The electron field pattern can be found in [6].

In the dynamic simulation of this design without solenoid, the minimum normalized emittance is 3.4 mm-mrad when the bunch charge is set as 100 pC. This result is much worse than the requirement, so the further control to greatly decrease the normalized emittance is necessary.

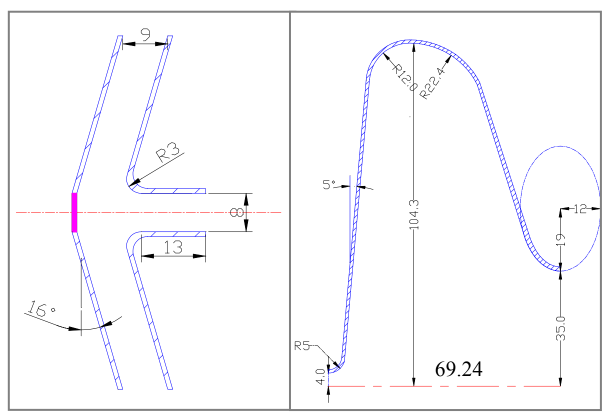

Fig. 1: The geometric parameters of DC gun and the first cell (umit:mm)

Table 1: The parameters of the new injector

Cavity	Temp.	2 K
	E_{acc}	15 MV/m
	B_{max}/E_{max}	2.4561 mT/(MV/m)
	E_{max}/E_0	2.1841
	Q_0	8.62×10^9
DC gun	$E_{cathode}$	6 MV/m

SOLENOID APPLICATION IN DC-SC GUN

In order to improve the normalized transverse emittance, the solenoid compensation is considered. As is known already, the superconducting cavity is sensitive to the magnetic field. However, there is a safe work mode: only after the cavity has been cooled down to 2 K, the solenoid begins to work. Because of the Meissner effect, externally appllied magnetic field less than the critical field will not penetrate into the niobium wall. That means the solenoid cannot be installed around the cavity cells as in the normal conducting gun cases, but only in the beam line. Another safety principle is that the DC magnetic field in the cavity area should be less than the critical field: H_{c1}~2600 Gauss[7]. From the following analyse, it will be clear that the magnetic field required by the electron dynamics is absolutely safe for the SC cavity operation.

For the DC-SC injector case, the solenoid will be placed outside the cryostat in the beamline, so the position depends mainly on the size of cryostat. The nearest position for a 20 cm solenoid to the cathode is 86.7 cm, or 42 cm away from the exit of SC cavity. When the solenoid is inserted and the optimized emittance is attained, the maximum magnetic field applied on the cavity is only 0.4 Gs (figure 2). The simulation shows that the solenoid goes further from the cathode, the optimized emittance becomes worse, and the distance between the cathode and the beam waist soon after injector is also much longer. Thus in the following discussion the solenoid is set at 86.7 cm away from cathode surface.

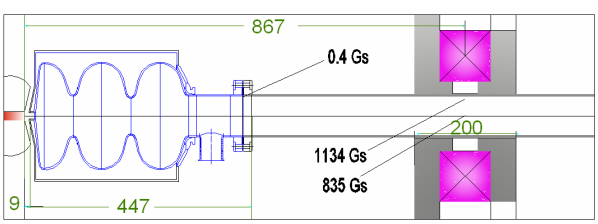

Figure 2: The position of the solenoid and the magnetic field (unit: mm).

From figure 3, when a solenoid field is applied and varies in a certain range, after drifting a certain length the electron beam always reaches a status, where the emittance is the minimum (also the point “B” in figure 4). This emittance valley depends on the phase and naturely on the magnet field. When the field is stronger, the valley goes nearer to the injector. But a best value always exists for every accelerating phase, and among them there is an optimized one. After scanning the phase and the magnetic field, figure 4 is the best beam profile with 835 Gauss solenoid field and 225° phase.

Actually, from figure 4, a beam waist “A” appears before the emittance valley “B”: this waist position could be the best place for the entrance of next accelerating element, where simultaneously 1.4 m forward from the solenoid. The room between the solenoid and the main accelerator is suitable for the the beam diagnostic, the laser input port and the other engineering arrangement.

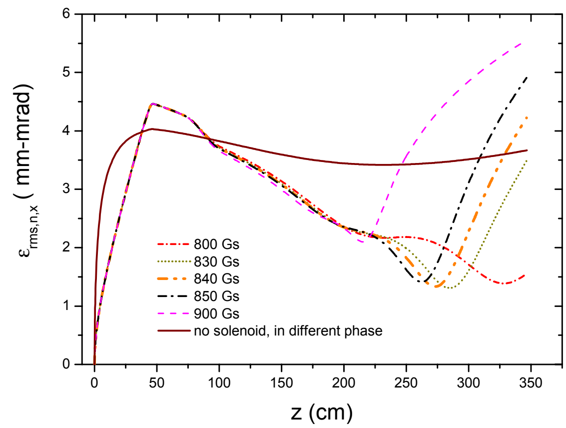

Figure 3: The effect of solenoid compensation.

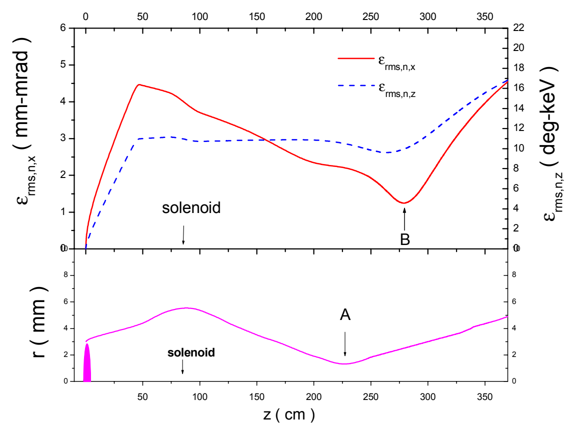

Figure 4: Rms emittance and the beam profile along the z axis. The solenoid field is chosen as 835Gs.

Table 2: The parameters of the new injector

Laser	$\varphi_{simul.}$	225°
	r_{edge}	uniform，3 mm
	L_{FWHM}	Gauss，8 ps
Bunch	Charge	100 pC
	E	4.225 MeV
	ΔE/E	0.60%
	$\varepsilon_{rms,n,x}$	1.134 mm·mrad
	r_{edge}	2.5 mm
	L_{FWHM}	5.6 ps

The beam dynamics simulation has been done while the solenoid magnetic field is chosen as 835 Gauss. Table 2 presents the main parameters of the beam quality in the position "B" where the minimum emittance in the figure 4. The transverse normalized emittance is as small as 1.1 mm-mrad, much less than 3.4 mm-mrad in the situation without compensation: the adoption of solenoid in the DC-SC photoinjector is greatly helpful and makes the new design one of the potential electron sources for the PKU-FEL facility.

SUMMARY

DC-SC photoinjector has been developed and tested for the high average power PKU-FEL project. To provide the beam with 4 MeV energy and low transverse normalized emittance, a new DC-SC photoinjector with 2+1/2 cell cavity has been designed. In order to control the emittance increase, the emittance compensation technique is considered in the safe work mode. The simulation shows that the idea of adopting solenoid in the DC-SC gun is safe for SC cavity and the transverse rms emittance as low as 1.1 mm-mrad can be attained.

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