DC HIGH VOLTAGE PHOTOEMISSION ELECTRON GUN FOR CAEP FEL

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Abstract

The research on high average power FEL-THz requires more demanding specifications of electron source. A DC high voltage electron gun with photoemission cathode is a natural choice for generating the critical beams considering the condition of technology. Field emission from the electrode structures limits the operating voltage and cathode field gradient in these guns. A ceramic insulator determines the level of operating voltage. The photocathode operational lifetime is limited by the gun vacuum and ion back-bombardment. The design thoughts and the technical solutions to forementioned issues are presented. The results of the beam dynamic simulation based on the design are displayed; normalized emittances at the entrance of booster are X 1.335 π·mm·mrad, Y 1.364 π·mm·mrad, Z 4.81 π·keV-deg, using the following initial beam parameters: the laser spot 4mm in diameter, the laser pulse length FWHM 12ps, the charge per bunch 35pC and the accelerating voltage 350kV.

INTRODUCTION

THz radiation lying in the region between the microwave and the infrared, with the property of high spatial resolution and low quantum energy, has wide applications in condensed matter, physics, chemistry, biology and so on. However, lacking of proper THz source has greatly delayed the related THz science and technology development. CAEP plans to construct a facility of high peak power and high average power THz source be based on FEL. The primary matter of FEL is the electron source. There are many options for a high brightness electron source, but the DC gun is a economical choice for high average beam intensity.

The very successful Jlab IR FEL is based on a photocathode dc gun operating. The gun design started as a 500 kV gun with a peak electric field of 10 MV/m at the surface of the cathode in the beginning of 1990's. Due to field emission from the electrode structures encountered during the 1kW IR Demo's commissioning the gun has been modified to a lower gradient at the cathode achieved by lowering the operating voltage to 320kV and by increasing the cathode-anode gap (6 MV/m at 500 kV)[1]. The 500kV operation is realized until 2011[2]. High voltage operation should circumvent many obstacles. In the following sections, we describe the component solutions adopted and explain the CAEP DC gun status and plans.

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GENERAL DESIGN SPECIFICATIONS

FEL requires a electron source of very high brightness, and then the technology must be realized to control the emittance decay and achieve electron beam of higher energy. Therefore, the design should consider the physical requirements and the state of the art. The parameters of the DC gun are preliminary operation voltage 350kV and vacuum less than 2×10^{-8}Pa, then can be upgraded to 500kV and XHV.

The main gun chamber is a four-way 316L stainless steel cross of 500mm in inner diameter and its characters are shown in Fig 1. The upside is insulating part and downside is vacuum achieving part. The two ceramic insulators are stacked in a pressure vessel holding 0.6MPa of SF_6. The vacuum achieving part includes one three-pole ion pump and three CapaciTorr B 1300-2 MK5.

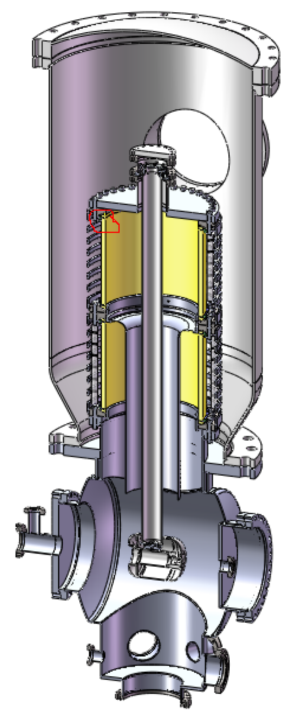

Figure 1: The cutway of the DC gun.

DESIGN OF ELECTRODE AND SUPPORT STRUCTURE

Field emission, originating at electrode and its support structure, is the principal effect limiting the high voltage and high electric gradient operation in DC electron guns.

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It is the source of undesirable phenomena, such as charging of ceramic insulators, localized melting in areas struck by field-emitted electrons, and vacuum degradation from both heating and electron stimulated desorption. These problems can lead to voltage breakdown of the cathode-anode gap, electrode surface damage, and punch through of the ceramic insulator. The engineering design should focuse on solving field emission.

Field emission from large area electrodes is a poorly understood phenomenon [3]. It is well known that the voltage supported by a vacuum gap increases more slowly than linearly with the gap dimension. Even in the condition of very small gaps, the field emission current from large area electrodes is observed to be much greater than that predicted by the Fowler–Nordheim equation. Many ideas have been put forth to explain these observations, but to date there is no way to know with confidence how well a particular high-voltage vacuum gap will perform, but cathode electrodes, if they are more smooth and harder, can work better shown in many experiments.

The choice of materials is a very important ingredient for high gradient and UHV operation of DC gun. In the foregone experiments, the titanium alloy exhibits better high voltage performance than stainless steel[4], but the electrodes is still made of 316L stainless steel for lack of machining experience of titanium. In a pierce gun, the peak field on the electrode is two to three times higher than the field on the cathode. The field emission electrons from stainless steel electrode typically become unacceptable at the electric filed approaching 10MV/m, which varies with turning technology and surface condition, and so we adopt flat cathode surface, which produce a high degree of electric field uniformity over the emitting area and have lower peak electric field than pierce type cathode electrode ensuring the emitting field.

To lower the peak electric field of the support tube, a meso-potential electrode is adopted in DC gun, and the peak electric field on the support tube is just 70 percent of field strength without meso-potential electrode, which can effectively decrease the field-emitted currents in the high voltage operation.

DESIGN OF INSULATION

The DC gun insulator works in high voltage, high vacuum and high pressure. The voltage holdoff capability of a high voltage ceramic insulator in vacuum is poor compared to that of the ceramic material or the vacuum itself.

Field emission originating at the triple junction of ceramic-metal-vacuum is a well-understood cause of internal surface flashover, and is controlled by reducing the field on the junction with electrostatic shields. The external ceramic surface is usually corrugated to inhibit flashover. Nevertheless, it is unavoidable that the inner surface of ceramic intercepts electrons field-emitted from support tube or meso-potential electrode. Aiming at former problem, the ceramic adopts charge-dissipative type, which provides some surface conduction to bleed off accumulated surface charge and to suppress the surface flashover.

The field uniformity can improve the stability and reliability of the DC gun on the surface of a ceramic insulator. We adpoted shielding rings which distibution is non-proportional spacing to obtain comparatively equal electric field on the insulator surface, and the potential between rings is controlled by a high-Ohmic divider.

DESIGN OF ULTRA-HIGH-VACUUM

The operation of high average power FEL-THz requres higher quantum efficiencies photocathodes, but to date they are readily poisoned by small quantities of chamically active gases such as water, oxygen and carbon dioxide [5]. Relatively inert gases such as hydrogen, methane, nitrogen and carbon monoxide have small to negligible poisoning effects on these cathodes, but they can be ionized by electrons traversing cathode-anode gap, and are accelerated back to the photocathode to cause quantum efficiencies degradation. Therefore, we must take measures to achieve ultral high vacuum. The vacuum pump scheme is with triple ion pump and non evaporable getters which are well suited for pumping CO, CO_2 and greatly enhanced the jpumping speed for hydrogen [6], the dominant gas species in the ultal high vacuum systems.

In the condition of specific vacuum pumps, the ultimate pressure in a gun vacuum chamer correlates with the material and the manufacture technics. The electrode and chamber walls are made of 316L stainless steel which outgassing rates can be up to very low level after air bakeout at 400-450℃[7]. Considering machining, the left and right port of the gun chamber are 380mm in outer diameter, and so the structure permits melt welding on the vacuum side, which can gain lower leakage rate.

BEAM DYNAMICS SIMULATION

The high average power FEL-THz asks the DC gun to provide 1-5mA average beam currents, which is a 54.167MHz train, ans so a corresponding bunch charge is about 20-100pC.

Design simulation has been carried out with GPT, PARMELA supplemented by POISSON. Initial electron bunch produced at cathode by a laser spot of 4mm in diameter is round with a uniformly distributed charge distribution transeversely. Logitunally, the bunch is a Gaussian distribution whose FWHM is taken to be 12ps. Optimizing cathode-anode spacing and emittance compensation solenoid field for various charges ranging from 20 to 100 pC. The cathode-anode voltage 350kV and a bunch charge 35pC is the most frequently used setup presently. The 350kV cathode-anode voltage corresponds to emitting area field 4MV/m, and the gun operates in source-limited region. Correspondingly, at the entrance of booster, the beam spot and phase-space distribution are shown in Fig 2, Fig 3, and Fig 4, and the normalized emittances are: x 1.335 π·mm·mrad, y 1.364 π·mm·mrad, z 4.81 π·keV-deg.

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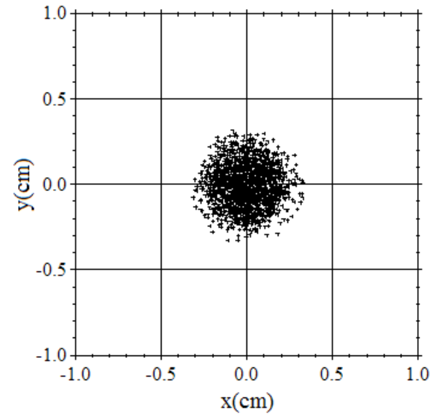

Figure 2: The beam size at the entrance of booster.

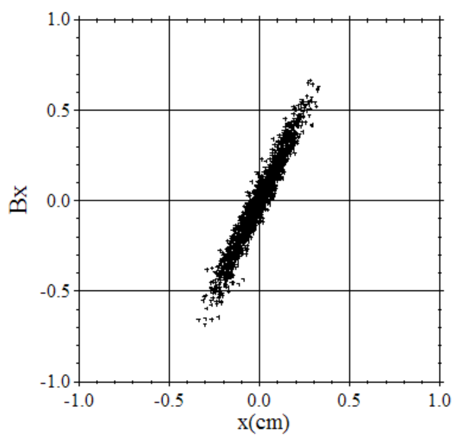

Figure 3: Particle distribution in phase-space v_x-x.

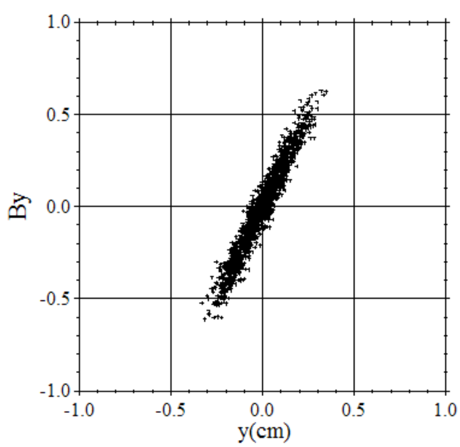

Figure 4: Particle distribution in phase-space v_y-y.

PRESENT CONDITION AND WORK SCHEDULE

Based on the forementioned design thoughts we have conducted and completed fabrication of the DC gun. Consequently, performed the vacuum test of the gun and the vacuum can be up to 1.5×10^{-8}Pa. A picture of the DC gun is shown in Fig 5.

Figure 5: A picture of the DC gun.

Now we are doing high voltage conditioning of the DC gun, for the time being, the high voltage is up to 248kV, and the test results are shown in Fig 6. At same time, the driver laser of 54.167MHz has been tested, its output power is CW 8W and direction stability meets technical requirement. The electron beam character will be tested in the end of 2011.

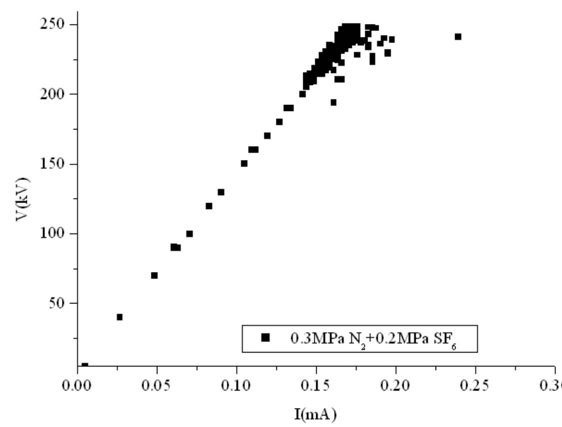

Figure 6: A high voltage conditioning plot of I-V of the DC gun.

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