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Design Studies For The LCLS 120 Hz RF Gun Injector

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Abstract

A preliminary design studies were carried out at Brookhaven National Laboratory for a photocathode RF gun injection system for LCLS 120 Hz operation. The starting point for the design is 50 Hz BNL Gun IV developed by a BNL/KEK/SHI collaboration. The basic parameters of the 120 Hz gun is discussed in this report. The complete photocathode RF gun injection system is described for a 120 Hz operation. The injector system includes photocathode RF gun, emittance compensation solenoid magnet, laser system and laser beam delivery system, and electron beam diagnostics. The basic design parameters, mechanical modification and the performance will be presented in this report.

I. Introduction

The X-ray SASE free electron laser (FEL) project - LCLS now under development by a SLAC/ANL/BNL/LANL/LLNL/UCLA collaboration requires high-brightness photocathode RF gun capable of operating at 120 Hz. BNL RF gun IV developed by a BNL/KEK/SHI collaboration now operating at APS LEUTL FEL, BNL SDL and Tokyo University was designed to operate at 100 Hz, and has demonstrated capability of operating at 50 Hz with 4 μs RF pulse. The BNL Gun IV (Fig.1) was based on the experience of the BNL Gun III by a BNL/SLAC/UCLA collaboration. Major modifications Gun IV relative to Gun III are:

1. Water channels was added to improve the operating stability and for a 50 to 100 Hz operation.
2. Improve the Helical flex seal joint to avoid possible RF break down problem. This was realized by reduce the helical flex seal exposure to the RF field.
3. Instead of just a photocathode RF gun, we have developed an integral design of photocathode RF gun injection system, which consists of RF gun, solenoid magnet, laser and electron beam diagnostics stations. All basic parameters of the photocathode RF gun, such as the field on the cathode, charge, laser performance and laser relative to RF gun phase, can be determined within the injection system [1].
4. A better support structure was designed for easy installation and alignment of RF gun relative to the emittance compensation solenoid magnet.

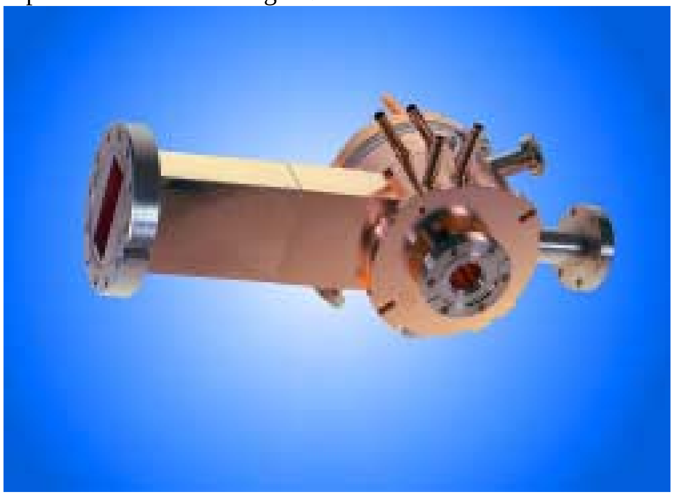

Fig.1: BNL photocathode RF gun IV.

The basic parameters of the 120 Hz Photocathode RF gun injection system will be discussed first. We then present the modification required to operate the photocathode RF gun at 120 Hz. We will also present the simulation carried out for the performance of the photocathode RF gun injection system. A brief discussion the laser system and its beam optics will be included.

II. Photocathode RF Gun Parameters

Base on the almost ten years experience of operating photocathode RF gun at the Brookhaven Accelerator Test Facility, we will present a complete set of parameters for the 120 Hz photocathode RF gun injection system.

I. *Photocathode RF gun:* The photocathode RF gun is designed for operating at the 120 Hz, table I list the basic parameters for the RF gun. Two parameters have been not considered in previous design are vacuum and operating temperature. The operating temperature was lowered from 45 C traditionally for the linac to 30 C, which reduces the resistivity by about 10 %. This is important for 120 Hz RF gun development. Another important parameter is the vacuum inside the RF gun. Based on the experience we had at the ATF, vacuum is important metal cathode quantum efficiency and its life-time. With better vacuum, 0.5% quantum efficiency (QE) of Mg cathode was measured with life time more than 30 days. Another advantage of good vacuum is that, QE can be restored using vacuum based laser cleaning technique [2].

Table 1: Photocathode RF Gun Specification.

RF gun rep. Rate (Hz)	120
Field on the cathode (Mv/m)	100 - 140
Cathode material	Cu or Mg
Vacuum inside the gun	$< 3x10^{-10}$ with RF on
Operating Temperature (°C)	30

II. *Photocathode RF Gun Laser System:* There are many studies which specified the performance requirements for the photocathode RF gun injection system. We felt different way of specify the laser system performance is required based on the operation experience we had at the ATF. One particular example is the timing jitter required for the laser system. Both our experiment and recent simulation shows much more strict requirements for a reliable performance. Most LCLS design requires 0.5 ps (rms) timing jitter, which corresponding to about 2 ps (p-p) timing jitter. The new specification should be 0.1 ps (rms), and 0.5 ps (p-p), which we have demonstrated at the ATF most time. Another depart on specify the laser system is that, we think it is important to specify both rms and peak to peak value. Table II listed the laser parameter required for the 120 Hz RF gun.

Table 2: Photocathode RF Gun laser system specification.

Rep. Rate (Hz)	120	
Laser energy on cathode (UV,uJ)	30 (Mg)	200 (Cu)
Laser pulse length (ps, FWHM)	5 to 20	
Laser spot (radius, mm)	0.5 – 1.5	
Laser energy stability (%)	1.5 (rms)	6 (p-p)
Timing jitter (ps)	0.1	0.5 (p-p)
Point stability (%)	0.25	1

III. Mechanical Design of 120 Hz RF Gun

A detail thermal analysis was performed for the BNL Gun IV (figure 2). For a 1 kW average input power, the temperature distribution of the RF gun is plotted in Fig.3. The maximum temperature gradient is about 5 °C. The thermal mapping also has shown that, hot spots are the iris between two cells and the center portion of the cathode. Several preliminary modifications on the gun IV were made to improve the cooling capability. A water channel on the RF gun power input wave guide was added(Fig.4). To reduce the hot spot near the iris, the diameter of the water channel near the iris was increased, and it was pushed further close to the iris (Fig.5, and 6). We are also investigating the possibility of increase more cooling for the cathode surface. More detailed thermal mapping of the 120 Hz RF gun will be performed in next couple months if funding available.

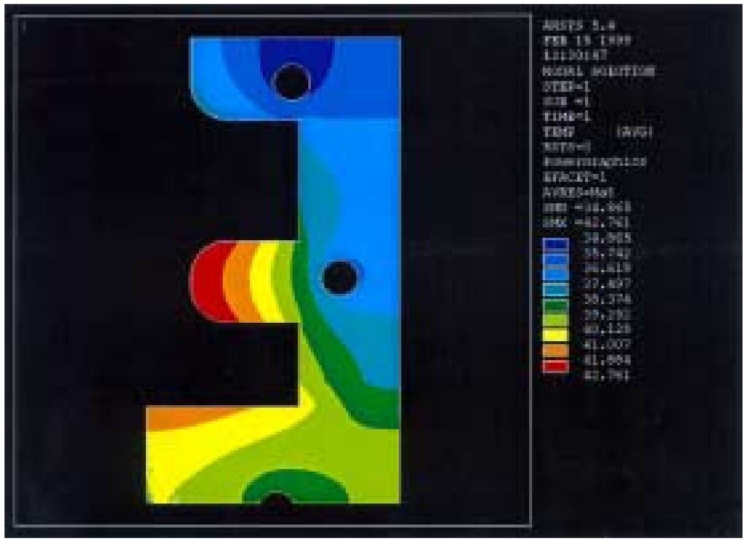

Fig.3: Thermal mapping of BNL Gun IV for 1 KW CW power.

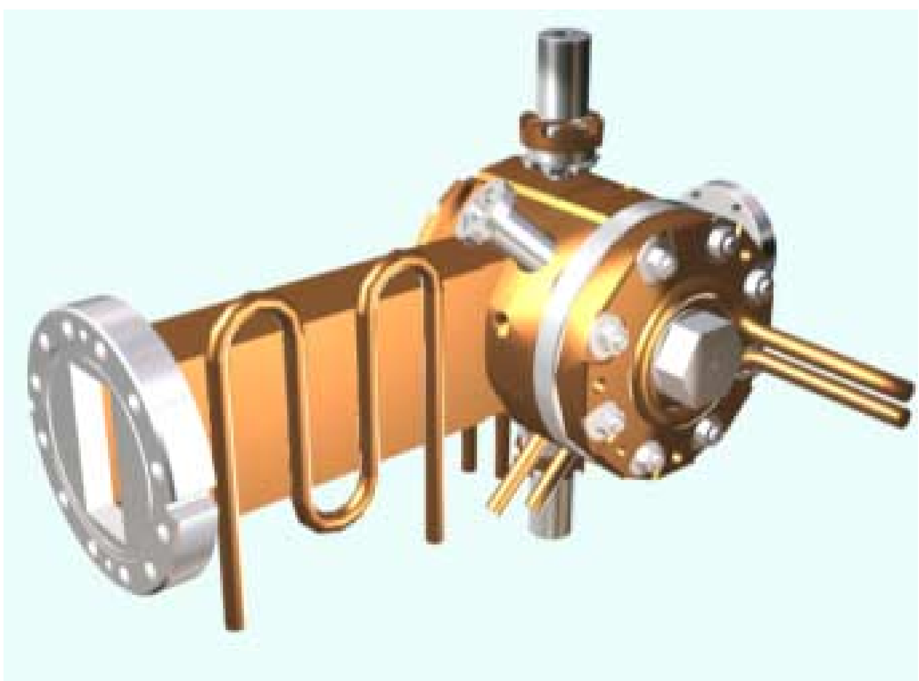

Fig.4: The schematic of 120 Hz RF Gun

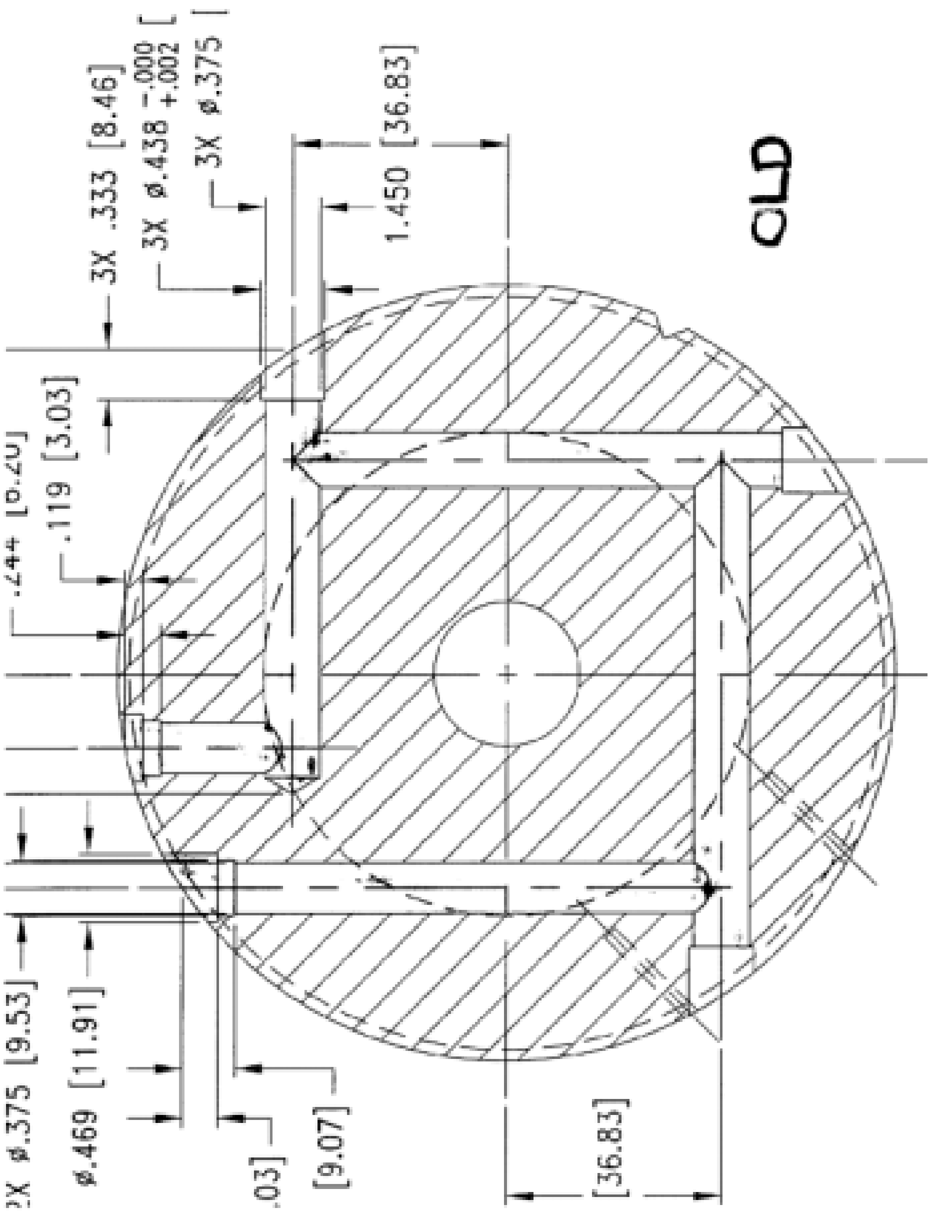

Fig.5: Water channel for BNL gun IV.

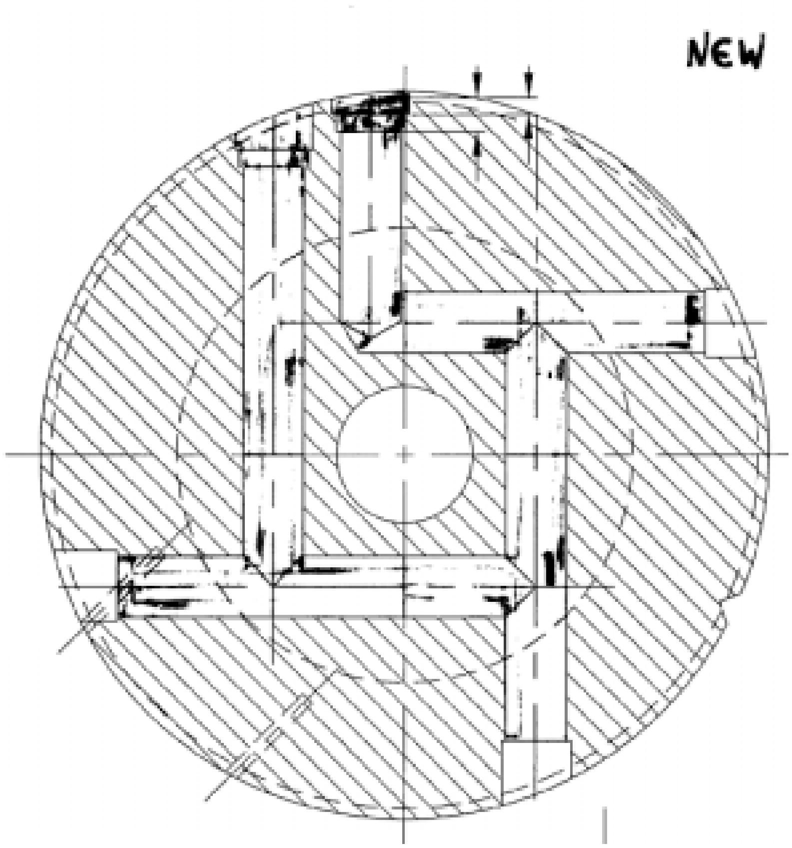

Fig.6: Water Channel for 120 Hz RF gun.

IV. Simulation of 120 Hz Photocathode RF gun Injection System

A systematic study of the performance of the photocathode RF gun for 120 Hz operation was carried out using computer program PARMELA. Official version of the PARMELA program was used for the study. In order to better understanding, we added some minor capabilities of the program for both pre-processing and post-processing the data. For pre-processing, we can generate any electron beam distribution, which is important for studying the Schottky effect on the electron beam distribution. For post-processing, we can calculate electron beam parameters of any faction of the electron beam, such as slice and 90% of best beam

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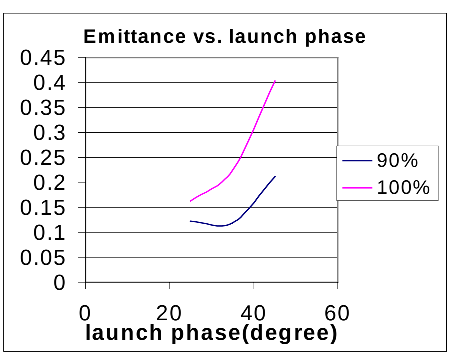

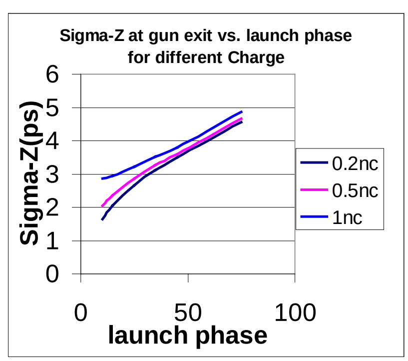

Fig.7: Emittance and bunch length as function of the RF gun phase for 10 ps (FWHM) Gaussian laser pulse. Emittance (cm-mrad) is for 1 nC charge.

The first issue we investigated is to solve the difference between the previous simulations [3,4] and experiment results. One of the major differences is the RF gun phase dependency of the transverse emittance. Both Kim's theory and earlier simulation predicted the RF gun phase for minimum transverse emittance lies between 50 and 70 degree from the zero crossing. The best emittance measured at the ATF is about 30 degree [2]. Out latest simulation has the similar result (Fig.7). Lower RF gun operating phase has immediately several important implications for 120 Hz RF gun operation. One is the timing jitter specification, other is the longitudinal laser profile for the best emittance. Due to the Schottky effect, timing jitter now will directly introduce electron beam charge fluctuation, which also cause emittance fluctuation. Another effect is that, for longitudinal uniform laser profile (beer can model), The Schottky effect will introduce 30 to 50 % charge density variation from heat to tail of the electron beam, which could lead to 20% emittance growth comparing to uniform electron longitudinal profile.

We also investigated various options shaping the electron beam longitudinal profile, specially using both electron beam and laser beam truncation. Laser beam truncation can be realized by saturable absorber, while electron beam truncation can be realized by slit at the dispersion region. We found that, the emittance achieved using truncation is about 20 % larger than uniform longitudinal distribution beam.

III. Laser and Front-end Beam Optics

Based on the latest simulation and ATF operation experience, we have been working with Sumitomo Heavy Industries (SHI) to develop a 120 Hz laser system to drive the photocathode RF gun. SHI now has a all solid state Nd: YLF laser operating at the 100 Hz satisfy the requirement set out in the earlier section [5]. The SHI PULRISR-100 is capable of produce 2 mJ @ 1047 nm, and 0.2 mJ at 262 nm, the 8 hour energy stability is 0.25% (rms), and 1% peak to peak. SHI intend to raise the repetition rate to 120 Hz in next year.

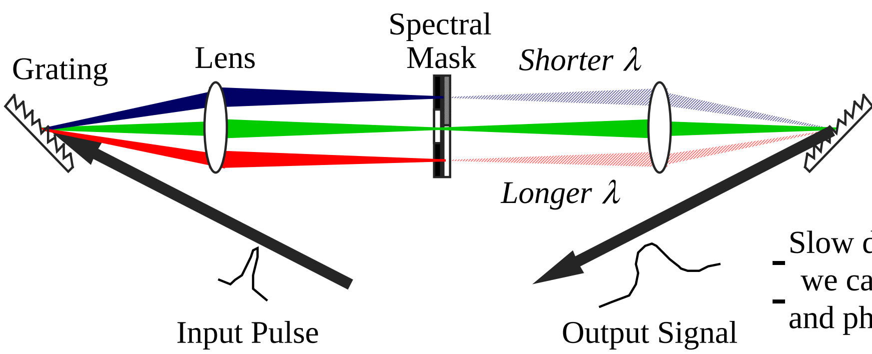

Fig.8: Longitudinal laser pulse shaping using spectral mask.

Oblique laser incident on the cathode will be the choice over the normal incident, the main reason for such laser optics is the laser beam diagnostics [6]. We plan to develop a complete laser and its beam delivery system with following capabilities:

1. longitudinal beam profile shaping based on either solid state saturable absorber, or laser phase mask (Fig.8).
2. Transverse beam profile shaping and control: Gaussian mirror will be investigated for transverse beam profile shaping. Another possibility of transverse beam profile shaping is based on the adaptive optics, which could be implemented with oblique incident optics.
3. On-line laser monitoring system: with oblique laser incident, we will develop laser optics delivery system which can measure the laser profile, energy and timing jitter.

V. REFERENCE

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