PHOTOCATHODE STUDIES FOR THE SPEAR3 INJECTOR RF GUN*

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Abstract

The electron gun for the SPEAR3 injector operates with a warm thermionic dispenser cathode immersed in a 1.5-cell RF structure. At each injection cycle the gun accelerates several thousand electron bunches up to ~3 MeV during a 2.5us rf pulse. The individual bunches are then compressed by an alpha magnet and a travelling-wave chopper selects 3-5 bunches so they don't cause beam loading to the linac, where the accelerated bunches reach 120 MeV for subsequent capture in a single booster synchrotron bucket. Tests are underway to operate the dispenser cathode as a cold electron photo-emitter driven by an external laser system. Eventually, without the chopper, this will enable multi-bunch injections to the Booster and SPEAR3. In parallel, tests are underway to evaluate quantum efficiency and beam emittance for a beam emitted from a CsBr photocathode with ns- and ps-pulses of UV laser light. In this paper we report on both the cold cathode electron gun operation studies for SPEAR3 and the CsBr research aimed at developing advanced cathode materials for future applications.

INTRODUCTION

In November 1990 a new linac system[1] began to inject 120 MeV electron bunches to the Booster, where the beam energy was ramped up to 2.3 GeV for injection to SPEAR2 storage ring, and the stored beam energy was further ramped up to 3.0 GeV for the user service.

With the commissioning of SPEAR3 in 2004, Booster ejection energy was raised to 3.0 GeV. The injector linac, however, has not been changed: Presently it consists of one thermionic cathode RF gun and 3 10-foot linac sections driven by two 2.856-GHz klystrons by SLAC.

RF Gun and Linac Configuration

The previous configuration was that one klystron drove the entire linac system[2] including RF gun and 3 linac sections. One of the two klystrons thus freed up drove an LCLS photocathode gun test facility (GTF) and the second a linac section that followed the SSRL gun.

With the Linac Coherent Light Source (LCLS) project in full swing, the GTF linac was finally removed, and the klystron for that linac now powers the 3rd section of the injector linac.

Since the gun and the first 2 linac sections are driven by one klystron, the RF power and phase relative to the linac sections are set by the high-power waveguide attenuator and phase shifter. The relative RF phase between the two klystrons at set by a phase shifter in low-level RF.

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RF Gun with Thermionic Cathode

While thermionic cathode RF gun[3] generates low emittance beam and is compact, heavy beam loading and back bombardment are drawbacks. The gun beam also has a broad energy spectrum, from which low energy parts are removed by a scraper, the bunch length is compressed by an alpha magnet, and a beam chopper allows only a few bunches to enter the linac, rendering the linac beam loading negligible.

The current toroids GT1 (after the gun), GT2 (after the alpha magnet) and GT3 (after the chopper) waveforms are shown in Fig. 1 below.

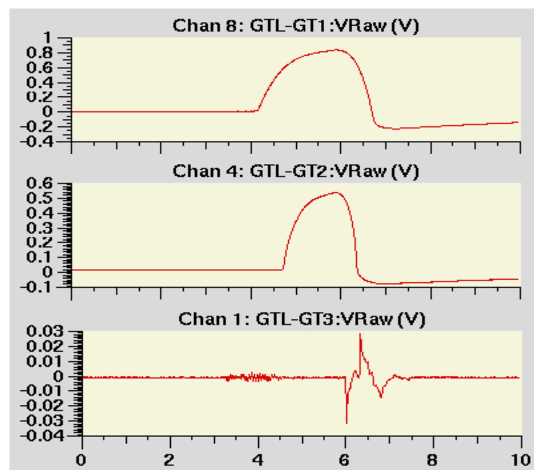

Figure 1: The electron bunch waveform in the Gun-to-Linac (GTL) transport line. Horizontal time axis in µs. Sensor voltage is converted to bunch charge, averaged over a 1 second period, and stored in the data acquisition system every 2 seconds.

Issues with Thermionic Cathode

The cathode is subject to back-bombardments of the electrons emitted when the RF phase is reversed, which can inflict damage to its surface and shortens its lifetime. The operational issue is that the bunch charge available to the linac for acceleration is rather limited: It can be increased only by raising the cathode temperature, thus inflicting further damage to the cathode.

Another limiting factor is that it can generate a bunch train that is only enough to fill only one Booster RF bucket in any Booster cycle of 100 ms, thus limiting the Booster performance in terms of injection efficiency to the SPEAR3.

One practical alternative to this thermionic cathode gun is to operate as a photocathode, eventually replacing it with a photocathode of high quantum efficiency (QE) and long service life.

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PHOTOINJECTION

For photoinjection to be successful the laser beam must be stable and stay focused onto the cathode over a period of SPEAR3 user run, which stretches out to two weeks between the scheduled accelerator maintenance.

We characterized the laser, along with all the optical components for the beam control and diagnostics. The response of the cold cathode to the 266 nm UV pulses has also been tested.

The Laser System and Optics

A Nd:YAG laser is used in the photoinjection study. It has a 10 ns fwhm pulse length with output wavelength of 532 nm, which is converted to 266 nm by a second thin harmonic generator BBO (beta barium borate) crystal. In the process the pulse energy of 150 mJ in green is converted to 480 μJ in UV with a conversion efficiency of 0.3%. The UV pulse energy jitter is up to several percent over the pulse duration, and also from pulse to pulse.

In order to maintain the operational laser stability at its best, the flash lamp to the lasing medium is pulsed at its maximum at the repetition rate of 10 Hz at all times. It is in synchronism with the linac RF when the White Circuit is active. The Q-switch, however, is triggered only when the UV beam is needed at the cathode, to minimize the integrated fluence and thus preserve the cathode surface condition.

UV Pulse Energy Control and Monitoring

The UV pulse energy to the cathode is controlled by a combination of a wave plate and a polarizing-cube beam splitter, where the main beam energy is chosen by rotating the wave plate, and reflected beam at 90 degree is sent to a beam dump.

After passing through a number of mirrors and irises, and a pair of collimating lenses, the UV beam arrives at a small optical bench near the RF gun in the linac vault. A set of mirrors (some of them remotely steerable) and irises on the bench steer and shape the UV beam to the cathode. To deliver 25-μJ UV beam to the cathode, the beam energy downstream of the beam splitter must be 180 μJ to compensate for the losses.

Also on the bench are two pellicles. Each couples out about 1.6% of the UV beam energy at 266 nm. One coupled beam forms a two-dimensional 'virtual cathode' image on a CCD camera. The image is displayed on a monitor outside the vault. The beam from the other pellicle falls onto a UV photodiode, of which output is numerically converted to monitor the UV beam energy to the cathode. This data is logged in the data acquisition system.

Laser and RF Timing Control

For routine thermionic injection, the two S-band amplifiers are triggered on and drive the klystrons. After a 6.5 μs delay the klystron modulators are also triggered on, followed by a chopper trigger 3.405 μs later. For photo-injection, all these trigger sequence and delay values remain constant except the master trigger to the entire linac system is delayed by 181.192 μs, which is an integer multiple of the Booster revolution period.

The lasing medium of the Nd:YAG laser is pumped by a flash lamp, reaching the saturation in about 180 μs. For optimal lasing, the Q-switch trigger is delayed by this amount from the flash lamp trigger. This delay being a constant, the flash lamp trigger time delay is adjusted so that a train of photoelectron bunches arrives at the chopper when it is triggered to pass 3-5 S-Band bunches.

The RF System Setting for Photoinjection

The operational requirement is that the linac provide 3~5 S-band bunches at 120 MeV. As shown in Fig. 1, the RF gun is heavily beam loaded during the thermionic injection, thus reducing the beam energy at the gun exit. When this is switched over to a photoinjection, the lack of beam loading introduces an RF phase change between the first linac section and the gun, and the beam energy out of the gun is increased, leading to higher than 120 MeV linac beam energy.

For the photoinjection, the heater power is reduced to the dispenser cathode to the extent that the cathode is still warm but does not emit. To keep the gun beam energy unchanged, the RF power to the gun, which is coupled from the klystron K2 forward power by -8.5 dB, must be reduced. It results in reduction of the linac beam energy.

Photoinjection Test

The cathode heater voltage is lowered from 10 to 6 V. When the cathode is cooled in about 10 minutes there is no measurable gun beam at toroid GT1. The RF power at both half-cell and full-cell of the gun are lowered to the values at the time of thermionic injection by reducing klystron K2 RF output. Then klystron K3 RF output is increased slowly in small steps. The first bending magnet B1 downstream of the linac bends the beam and the beam energy distribution can be seen on a diagnostic phosphor screen located after B1 magnet that serves also as an electron energy spectrometer. The K3 RF output is fine tuned to recover the beam position on the screen and at a set of beam position monitors (BPMs) to assure correct beam energy.

After adjustments, the final RF parameters are: the waveguide phase shifter to the gun is set at 152.4 degrees (down from 159.2), K2 RF output is 31.31 MW (down from 36.50), K3 RF output is 13.30 MW (up from 9.75) and the cathode heater voltage is 5.870 V (down from 9.155) as tested at 00:00 June 14, 2011. The klystron RF output is controlled by RF input power attenuator.

With the linac RF and laser systems adjusted, aligned and timed, a beam-based fine tuning is done on the UV pulse energy, the UV spot position and the laser timing to optimize the bunch charge at the current toroid GT3 (after the chopper) and linac average current monitors (ACMs). Photoinjection test results to date are: 51 mA/min injection rate, stored current of 96mA from 56mA in 45s.

CAESIUM BROMIDE PHOTOCATHODE

At the LCLS injector RF gun, the photocathode is pure copper (Cu). It may also be employed as a SPEAR3 injector gun in the future. The LCLS-II project is moving forward. All these warrant further studies of cathode materials so we coated a Cu cathode with caesium bromide (CsBr). Photoemission data from uncoated Cu and CsBr-coated Cu have been analyzed and compared.

CsBr-Coated Cu Photocathode

CsBr is a white solid material which melts at 636°C. At 25°C, 1 ℓ of water solution can contain 1.243 kg of CsBr. The purity of commercial sample is up to 99.999%. It's mainly used for making optical components in infra-red range. Its index of refraction is 1.858 at the wavelength of 266 nm.

The assembly of Cu base plate and a floating photo-electron collector is chemically cleaned and installed in a vacuum chamber, which is baked to have all moisture pumped out. When the vacuum is in low nanotorr range, the CsBr loaded in a crucible holder is electrically heated to 418°C so that its vapour migrates and gets deposited on the Cu base plate. There is no electrical bias in this process. For quantum efficiency (QE) measurements the coating is about 20 nm thick, which is measured by the change in resonance frequency of a quartz crystal that is also coated simultaneously with the cathode.

Experimental Arrangement

The collector is biased by up to +3.0 kV. It has a 1.0 cm diameter hole at its center allowing the passage of the UV laser beam to the cathode, which is grounded through a 1.0 nF capacitor. At each UV pulse this capacitor is charged up by photoelectrons. The collector and CsBr/Cu cathode planes are parallel with each other, and 5 mm apart for the QE measurements. The photocathode assembly is shown in Fig. 2 below.

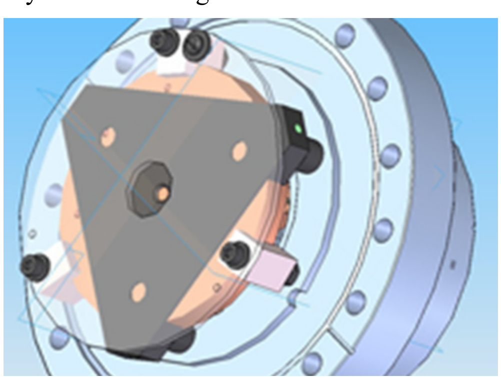

Figure 2: Photocathode assembly for QE measurements.

QE Measurement Data

With the speed of Light c, Planck constant h, electron charge e, UV wavelength λ, UV pulse energy E, capacitor voltage V and capacitance C, all in MKS units, the quantum efficiency QE in ppm is (CV/e)*(hc/Eλ)*1.e06. The QE measurement data is shown in Fig. 3 below.

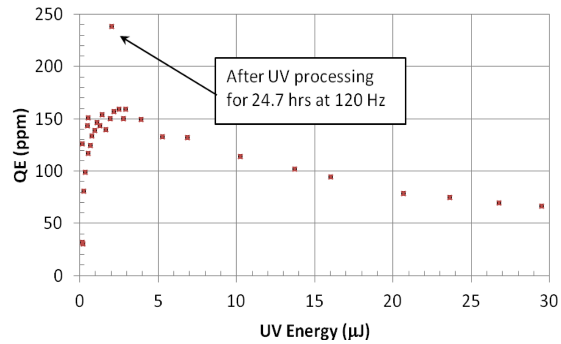

Figure 3: The CsBr/Cu QE data.

At E = 25 μJ, the photoelectron charge q_P is 400 pC. After a UV processing of the CsBr/Cu cathode over a day, although QE is substantially improved but the q_P is only 100 pC at E = 2 μJ. The beam emittance measurements on CsBr/Cu and on bare Cu were reported elsewhere. [4]

CONCLUSIONS

The tungsten dispenser cathode at the RF gun has been tested as a photocathode. Its heater power was lowered to a non-emitting temperature. Then it was excited by 266 nm UV beams of 7 to 10 ns pulse length from a Nd:YAG laser to generate sufficient photoelectron charges from the gun. With the adjustment of the RF phase and output powers from the two klystron, the rest of the injector linac functionality did not change and efficient injection was achieved. A full test of the photoinjection system will be done this year.

Compared with a uncoated Cu, the QE of the CsBr/Cu cathode is typically higher by an order of magnitude. It also produces beams of good emittance. Further tests are planned for its 2-ps UV response and long term effect on the cathode, probably at the LCLS injector gun test stand.

In both cases of bare Cu and the one with CsBr coating, laser cleaning process has been effective in raising the QE. More studies will be done to clarify this effect.

REFERENCES

[1] J.N. Weaver et al., "The Linac and Booster RF Systems for a Dedicated Injector for SPEAR," PAC'91, San Francisco, May 1991, p. 771 (1991)

[2] Sanghyun Park, "RF Power Distribution and Phasing at SSRL Injector Linac," Linac'98, Chicago, August 1998, p. 317 (1998)

[3] M. Borland, "A High-Brightness Thermionic Microwave Electron Gun," SLAC-R-402, 1991. Stanford University Ph.D. Thesis.

[4] Juan R. Maldonado et al., "Experimental verification of the 3-step model of photoemission", submitted to *Appl.Phys.Letters.*

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