STATUS OF THE LBNL NORMAL-CONDUCTING CW VHF PHOTO-INJECTOR *

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Abstract

A high-brightness high-repetition rate photo-injector based on a normal conducting 187 MHz RF cavity design capable of CW operation is under construction at the Lawrence Berkeley National Laboratory. A field at the cathode of ~ 20 MV/m accelerates electron bunches to 750 keV with peak current, energy spread and transverse emittance suitable for FEL and ERL applications. A vacuum load-lock mechanism is included and a 10 picoTorr range vacuum capability allows most types of high quantum efficiency photo-cathodes to operate at a MHz repetition rate with present laser technology. The status of the project is presented.

INTRODUCTION

The work described in this paper is part of a broader activity at the Lawrence Berkeley National Laboratory (LBNL) with the goal of designing and building a facility with an array of independently tunable free electron lasers (FELs) [1, 2]. The project addresses the interest of a large scientific community in the XUV and soft x-rays requiring extremely high brightness sources with photon energies ranging from about 10 eV to 1 keV [3, 4].

The minimal design parameters required to an electron gun to operate with such a facility are:

- repetition rate of up to ~ 1 MHz,
- beam energy at the gun exit $\gtrsim$ 500 keV,
- electric field at the cathode $\gtrsim$ 10 MV/m,
- charge per bunch from few tens of pC to ~ 1 nC,
- sub 10^{-6} m normalized beam emittance,
- variable bunch length,
- 10^{-11} Torr operation vacuum,
- compatibility with magnetic fields in the cathode and gun regions (mainly for emittance compensation),
- “easy” cathode installation capability,
- high reliability compatible with a user facility.

Such requirements when simultaneously satisfied allows achieving two main goals, i) production of the high brightness beam required by the FELs, and ii) capability of operating with high quantum efficiency photo-cathodes requiring extremely low vacuum pressures. This last requirement is necessary for operating at the high repetition rate with present laser technology.

To the best of our knowledge, none of the existing gun technologies can meet the above listed set of parameters simultaneously. For example, DC guns have proven reliable operation at ~ 350 kV [5], but show severe voltage breakdown issues at higher voltage [6, 7]; super-conducting guns are very promising but still in R&D phase and field exclusion from the super-conducting walls makes difficult to apply magnetic fields in the gun area; normal-conducting high frequency ($\gtrsim$ 1 GHz) guns have already proven excellent performances and match almost all the requirements, but because of the high power density on the cavity walls cannot operate at repetition rates higher than ~ 10 kHz [8].

We have developed at LBNL a gun scheme capable of simultaneously fulfilling all the requirements and that is based on reliable and mature mechanical and RF technologies [9, 10]. The core of such a gun is a normal-conducting RF cavity resonating at 187 MHz in the VHF band. Because of the low frequency, the structure is larger and the power density on the walls becomes compatible with CW operation. Additionally, the long RF wavelength allows for the large high-conductance vacuum ports necessary for achieving the desired vacuum pressure. The initial phase of the project has been funded and the gun cavity is presently under construction at LBNL.

In this paper we present the main characteristics of the electron gun and preliminary beam dynamics studies showing the capability of the gun to operate in a FEL scheme. The present status of the project and future plans are also briefly discussed in the last part of the paper.

THE LBNL VHF PHOTO-INJECTOR

Figure 1 shows a cross section of the VHF cavity, and Table 1 contains its principal parameters.

The re-entrant geometry of the structure allows achieving the desired resonance frequency while maintaining a reasonably small size.

The cavity geometry was optimized to maximize the shunt impedance, to minimize the wall power density, to reduce the mechanical stress, simplify fabrication, maximize vacuum performance and facilitate photocathode replacement.

The frequency choice is compatible with both 1.3 and 1.5 GHz super-conducting accelerating section technologies, the most probable candidates for the main linac.

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Most of the cavity is in solid OFHC copper externally supported by a brazed stainless steel shell with cooling channels in the interface between the two materials.

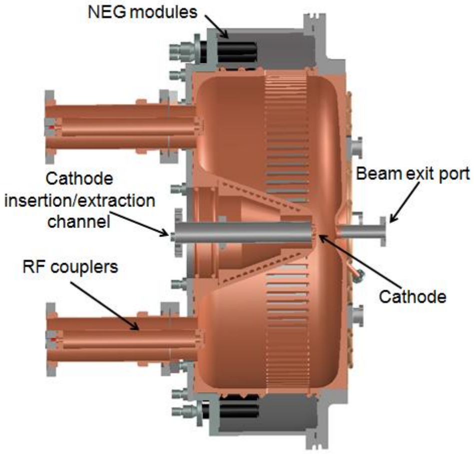

Figure 1. VHF cavity cross-section, showing the cavities main components.

The accelerating gradient and voltage at the gap are comfortably above the minimum required values, and the modest peak power density at the walls, allows the use of relatively conventional cooling techniques.

Table 1. VHF cavity main parameters.

Total length [m]	0.35
Cavity internal diameter [m]	0.694
Accelerating gap [mm]	40
Frequency [MHz]	187
Q_0	30877
Operation mode	CW
Gap voltage [MV]	0.75
Electric field at the cathode [MV/m]	19.5
Peak surface electric field [MV/m]	24.1
Stored energy [J]	2.3
Shunt impedance [MΩ]	6.5
RF power for 0.75 MV at Q_0 [kW]	87.5
Peak wall power density at 0.75 MV [W/cm^2]	25.0

The relatively small peak field value of ~ 24 MV/m should not represent an issue in terms of field emission and voltage breakdown.

Extensive multipactoring simulations with several different codes have been performed showing that a broad region around the operating voltage is free of multipactoring resonances.

Figure 2 shows a detailed view of the cathode area. The embedded solenoid in the cathode nose can be used as “bucking” coil to nullify the magnetic field on the cathode surface, or for generating the correlation in the beam transverse plane required by some emittance exchange techniques.

The actual photo-cathode will be located on the top of a cathode “plug” (in blue color in Fig. 2), part of the load-lock vacuum system that will allow for an “easy” replacement of the cathodes. The load-lock system will be based on the present design operating at the FLASH FEL in Germany, and now under further development at Fermilab.

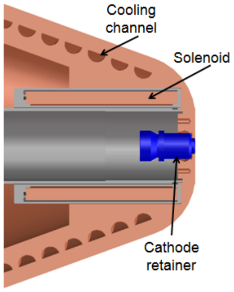

Figure 2. VHF cavity cathode area detail.

The vacuum system is designed to achieve a pressure down into the low 10^{-11} Torr range when operating at the nominal RF power. The long wavelength allows for large pumping ports with negligible RF field leakage into the pump plenum. Commercial NEG pump modules located in equatorial anti-chamber are used. Such pumps are very effective in removing H_2O and O_2, the most dangerous for cathode contamination. Such an arrangement will allow testing a variety of cathodes including "delicate" multi-alkali and/or GaAs. An ion pump will take care of the noble gasses and hydrocarbons not pumped by the NEG modules.

No sliding mechanical tuner is used. A mechanical "ssqueezer" will allow tuning the frequency within a ~ 0.5 MHz range by compressing the beam exit wall within the elastic limit of the wall material.

Operating the gun with 1 nC at 1 MHz repetition rate using available laser technology requires using photo-cathodes with quantum efficiency of at least several percent. One option under consideration uses the relatively robust Cs_2Te cathode combined with a Ti:Sapphire laser with ~ 1 W power in the infrared converted in 3rd harmonic (~ 5% conversion efficiency is asumed). Another option under investigation is to use alkali antimonides photo-cathodes, eg. SbNa2KCs, combined with a ~ 100 mW average power Nd:YVO4 laser frequency doubled to 532 nm. The photoemission in the green permits the use of a relatively low power inexpensive and simple laser system, and for a more effective and easier laser pulse shaping required for improving the beam dynamics performance. The drawbacks are that such cathodes are still in R&D phase, and require operation pressures down to ~ 10^{-11} Torr for acceptable lifetimes.

PRELIMINARY BEAM DYNAMICS SIMULATIONS

Here we present the results of preliminary beam dynamics simulations with the goal to demonstrate that the VHF gun is compatible with the design requirements for the LBNL FEL facility, i.e. a sub-micron normalized emittance beam with a peak current of at least 40 A at the exit of the injector. The work is still in progress, and different injector configurations are presently under study.

Figure 3 shows the simple injector layout used in the simulations. It includes the VHF gun operating at 750 keV, followed by a solenoid for emittance compensation and by 6 nine-cell Tesla-like 1.3 GHz cavities. The embedded solenoid used to nullify the magnetic field at the cathode plane.

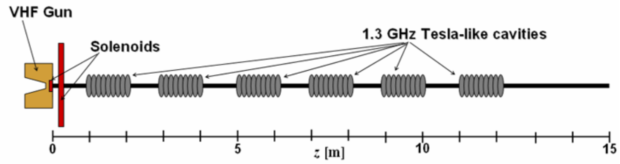

Figure 3. Injector layout used in the simulations.

The first 1.3 GHz cavity is used for acceleration but also for velocity bunching by tuning its phase off crest, while the downstream cavities are tuned to maximum acceleration with a gradient of ~ 8 MV/m approximately matching the emittance compensation condition for the beam size at the entrance of the first cavity [11].

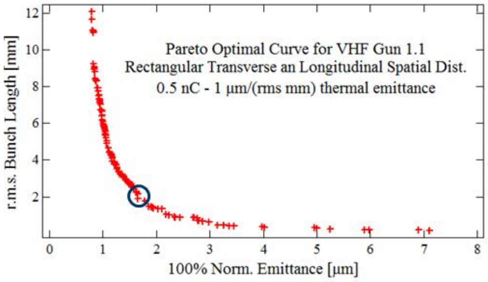

Figure 4. Pareto-optimal curve showing the best tradeoffs between final emittance and bunch length.

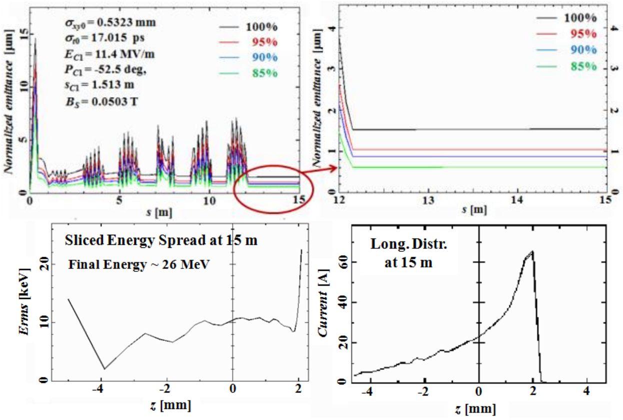

Figure 5. ASTRA simulation results from one particular optimization solution.

Because of the long RF wavelength, the dynamics of the RF gun is quite similar to that of a DC gun. Indeed, the phase of the VHF cavity is tuned very close to the peak of the field. As in DC guns, the bunch length at the cathode is relatively long to control space charge effects.

We performed a multi-objective genetic algorithms (MOGA) optimization [12], trading between normalized emittance and rms bunch length at the exit of the injector (z = 15 m). Six free parameters were used, the laser pulse length and spot radius, the main solenoid field, the first 1.3 GHz cavity phase and gradient, the distance between the VHF and the first 1.3 GHz cavity. The mutual distance between the 1.3 GHz cavities was kept constant. The thermal emittance used was from experimental data for Cs_2Te cathodes [13]. The charge per bunch was 0.5 nC. Figure 4, shows the so-called “pareto-optimal” curve [12] that represents the set of optimized tradeoffs solutions, while Fig. 5 shows one of such solutions in the region within the small blue circle in Fig. 4. The parameters value for such a case and the beam distribution used are described in Fig. 5 top part. One can see that 95% of the 26 MeV beam is contained within 1 µm emittance and that the peak current is ~ 60 A.

PRESENT STATUS & FUTURE PLANS

In the present fiscal year, the project has received funds sufficient to build the VHF cavity and to start procuring the RF power source. At the present time, the design of the cavity is completed and the fabrication has been initiated, the bid for the RF power source in under way and the preparation of the shielded area for housing the photo-injector has started. The plans for the near future include, the completion of these initiated tasks; the design, construction and installation of the RF power distribution system; the development of the laser/cathode system (work already initiated by a collaborating group); and the design and construction of a diagnostics beamline for low energy beam tests.

The completion of such tasks and next fiscal year funding continuation would allow performing the full power RF tests of the cavity, and the low energy beam tests within the first half of 2010.

Higher energy beam tests, by adding a RF booster capable of accelerating the beam up to few tens of MeV are also under consideration.

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