STATUS AND PLANS FOR THE LBNL NORMAL-CONDUCTING CW VHF PHOTO-INJECTOR*

K. Baptiste, J. Corlett, R. Kraft, S. Kwiatkowski, J. Qiang, F. Sannibale#, J. Staples, R. Wells, L. Yang, A. Zholents, LBNL, Berkeley, CA 94720, U.S.A.

Abstract

At the Lawrence Berkeley National Laboratory, a high-brightness high-repetition rate photo-injector is under fabrication. The scheme is based on a normal conducting 187 MHz RF cavity operating in CW mode and capable of generating an electric field at the cathode plane of ~ 20 MV/m. The electron bunches will be accelerated to ~ 750 keV with peak current, energy spread and transverse emittance suitable for FEL and ERL applications. At the same time, the presence of a vacuum load-lock mechanism jointly with a vacuum system designed to operate in the 10 picoTorr range, will make of this injector a flexible cathode test facility. In particular, it will allow to use "delicate" high quantum efficiency cathodes to generate nC bunches at MHz repetition rate with present laser technology. Construction status and future plans are presented.

INTRODUCTION

The photo-injector described in this paper is being developed at the Lawrence Berkeley National Laboratory (LBNL) in the framework of a broader activity proposing the construction of 4th generation light sourced equipped with an array of independently tunable free electron lasers (FELs) [1, 2]. The project is science driven and 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].

Particularly challenging are the requirements for the electron photo-injector. The minimal design parameters simultaneously required to operate with such a facility are:

- repetition rate of up to ~1 MHz,
- beam energy at the gun exit > ~500 keV,
- electric field at the cathode > ~10 MV/m,
- charge per bunch from few tens of pC to ~1 nC,
- sub 10^{-6} m normalized beam emittance,
- bunch length control to minimize space charge effects,
- 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 would allow achieving two main goals, the generation of the high brightness beam required by the FELs, and the 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.

None of the existing gun technologies can meet the above listed set of parameters simultaneously. DC, super-conducting and normal-conducting high frequency (> ~1 GHz) guns all fail to satisfy one or more of the requirements [5, 6]. The scheme developed and under construction at LBNL is capable of simultaneously fulfilling all the requirements and is based on reliable and mature mechanical and RF technologies [5-7]. The core of such a gun is a normal-conducting RF cavity resonating at 187 MHz in the VHF band. Figure 1 shows a cross section of the VHF cavity with the main components, while Table 1 includes its main parameters. Because of the low frequency, the structure body is large enough to withstand the heat load present when operating in continuous wave (CW) mode with the high electric fields required by a high brightness photo-injector. Additionally, the long RF wavelength allows for the large high-conductance vacuum ports necessary for achieving the desired vacuum pressure. The 187 MHz frequency choice is compatible with both 1.3 and 1.5 GHz, the two presently dominant super-conducting linac technologies.

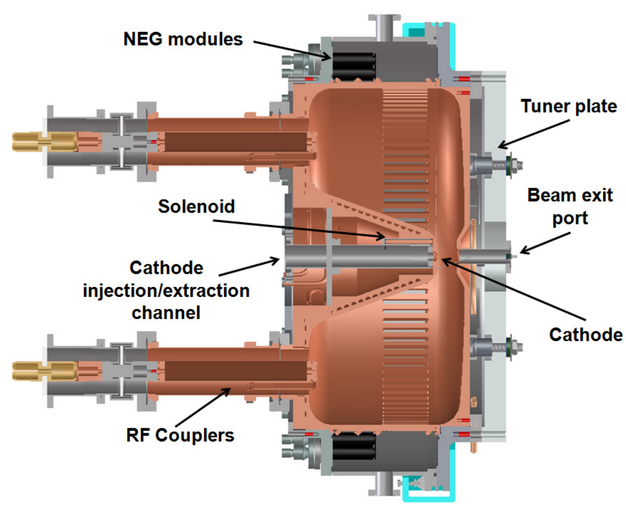

Figure 1: VHF cavity cross-section, showing some of the cavity main components.

Beam dynamics simulations are still in progress but already showed the capability of the gun to operate in a FEL scheme [5, 6].

*Work supported by the Director of the Office of Science of the US Department of Energy under Contract no. DEAC02-05CH11231
#FSannibale@lbl.gov

In this paper we present the status of the photo-injector fabrication and the future plans for a test facility based on such an injector.

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

PHOTO-INJECTOR FABBRICATION STATUS

VHF RF Cavity

Figure 2 shows a CAD 3D view of the VHF cavity assembly, the core of the photo-injector system.

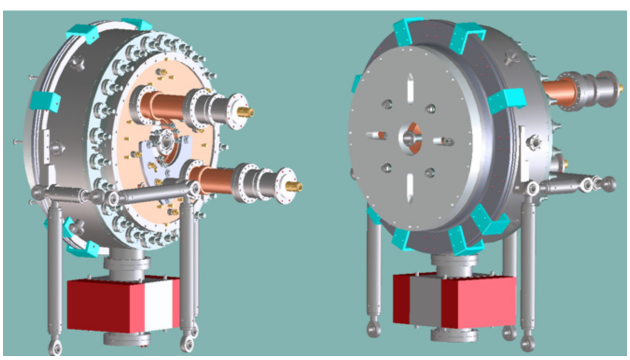

Figure 2: VHF cavity cross-section, showing the cavities main components.

Figure 3: VHF cavity backplane wall with the cathode cone temporarily assembled for mechanical fitting test.

The RF structure is in solid OHFC copper with an external stainless steel shell that ensures the necessary rigidity of the assembly. Also visible in Figures 1 and 2 are the two RF couplers used to feed the RF power into the cavity, and the vacuum pumping system composed by 24 commercial NEG pump modules from SAES and by a large speed ion pump. NEGs are very effective in pumping oxygen and water molecules (dangerous contaminants for several types of cathodes), while the ion pump takes care of noble gasses and hydrocarbons.

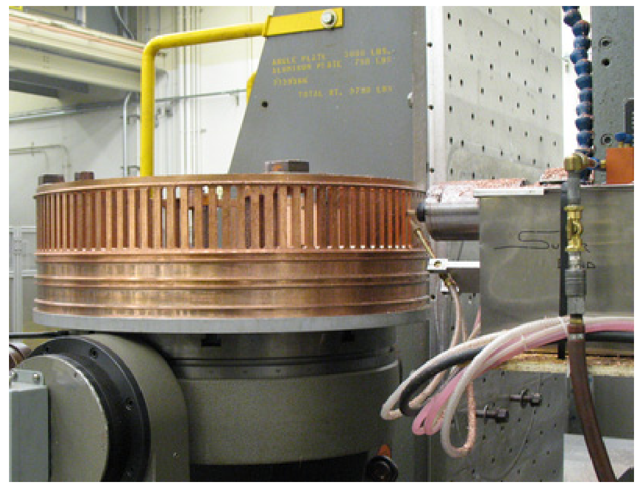

Figure 4: The "coliseum", the side wall of the RF cavity being machined.

Frequency tuning of the cavity is obtained by mechanically "distorting" the cavity wall on the beam exit side. The range of distortion is well within the elastic limit of copper and allows a frequency tuning range of about 0.6 MHz.

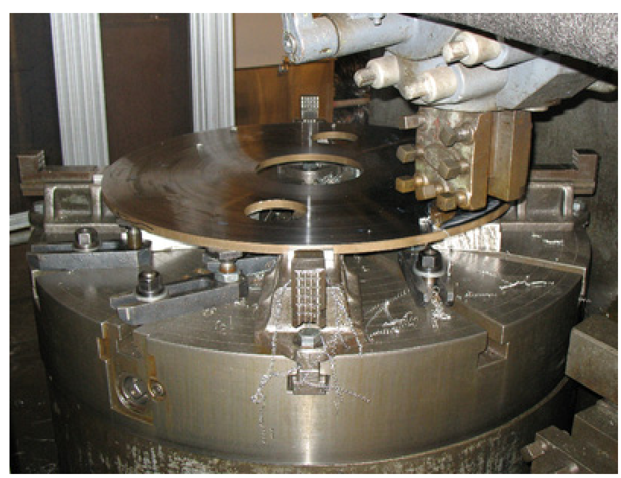

Figure 5: The stainless steel cavity shell backplane wall under machining.

With the exception of few large brazings, the whole cavity system is being fabricated at the LBNL mechanical shops. Figures 3 to 5 show examples of some of the parts under fabrication. In Fig. 3, the cavity backplane with the cathode cone is visible. The cone part is already machined within tolerance, while the backplane will be machined to the final measures after completion of the brazing and electron beam welding of all the connected parts. Figure 4 shows the side wall of the cavity during machining. Visible are the vacuum slots and the guides at which copper cooling pipes will be welded. In parallel to the copper structure fabrication, the stainless steel shell parts are also being manufactured. Figure 5 shows for example the backplane wall of the shell during machining.

The fabrication completion for the cavity system is expected to happen in early spring 2010.

RF Power Source

With the theoretical quality factor shown in Table 1, the cavity would require ~ 90 kW to generate the desired field intensity. The actual quality factor after fabrication is expected to be somehow lower, and for reliability reasons the power source should not operate at its maximum power. Accounting for these two factors, we specified the source for a maximum power value of 120kW.

Figure 6 shows a simplified block diagram of the system. The low level RF part will be developed at LBNL while the high power amplifier is under development and fabrication at the company ETM Electromatic. Two independent final stages based on Thales TH571B tetrodes will each generate 60kW CW RF power at 187 MHz. The system is scheduled to be delivered at LBNL in February 2010.

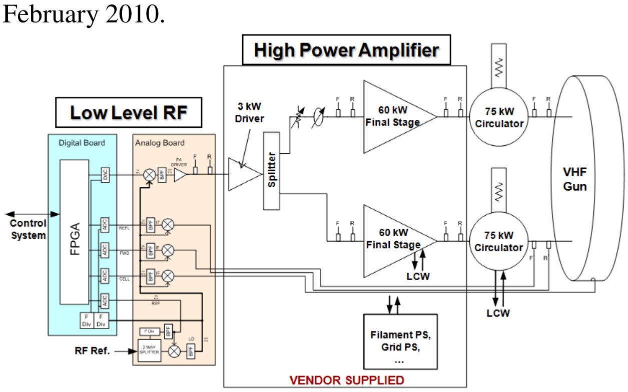

Figure 6: RF power source block diagram.

Beam Test Facility Preparation

The photo-injector will be installed and tested in the Beam Test Facility (BTF), an existing shielded area at the Advanced Light Source at LBNL. The BTF, visible in a CAD representation in Fig.7, is under preparation and will be ready to accept the photo-injector in early spring 2010. The footprint of the area is large enough to accommodate also accelerating sections to bring the beam energy to few tens of MeV, and the diagnostic beamline required for characterizing the electron beam quality.

ADDITIONAL ACTIVITY AND FUTURE PLANS

The tests with the photo-injector will be performed in two phases. In the first one, already funded and planned for the second part of 2010, the full RF test, the tests with the electron beam at the gun operation energy, and the characterization of different photo-cathodes will be all performed. In the second phase, that requires funding continuation, the beam will be accelerated up to few tens of MeV and a full characterization of the 6-D beam emittance at different charge per bunch will be performed.

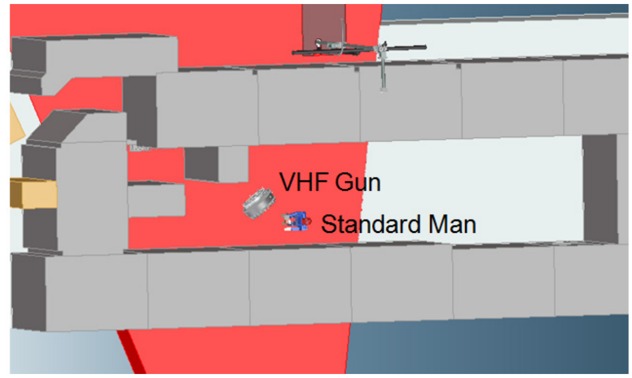

Figure 7: BTF CAD view.

In order to perform all such tasks, several activities have been carried out in parallel. Among those, we want to mention the work that another LBNL group is presently doing for the development of the first generation of photo-cathodes that will be tested in the VHF photo-injector [8]. These cathodes are based on multi-alkali antimonides and are potentially capable of more than 10% quantum efficiency with photo-emission driven by photons in the visible (~550 nm). Such cathodes are very sensitive to contamination and require the low vacuum pressures that the VHF gun should be able to generate. If successful, the use of these cathodes will dramatically reduce the requirements on the photo-cathode laser and will significantly facilitate the laser pulse shaping required for generating high brightness electron beams.

ACKNOWLEDGEMENTS

We acknowledge contributions by D. Colomb, L. Dolittle, R. Donahue, T. M. Huang, D. Li and R. Muller.

REFERENCES

[1] A. Belkacem, *et al.*, Synchrotron Radiation News, Vol. 20, No. 6, 2007, pag. 20.
[2] A. Zholents, *et. al.*, to appear in Proc. of Linac 2008 conference.
[3] Workshop on "Science for a New Class of Soft X-ray Light Sources", Oct. 8-10, 2007, Berkeley, USA.
[4] Science and tech. of future light source, ANL-08/39, BNL-81895, LBNL-1090E, SLAC-R-917, (2008).
[5] K. Baptiste, *et al.*, NIM A **599**, 9 (2009).
[6] K. Baptiste, *et al.*, *Status of the LBNL normal-conducting CW VHF photo-injector*, Proceedings of the 2009 Particle Accelerator Conference, Vancouver, Canada, May 2009.
[7] J. Staples, F. Sannibale and S. Virostek, "VHF-band Photoinjector", CBP Tech Note 366, Oct. 2006.
[8] H. Padmore, private communications.