

## STATUS OF THE WISCONSIN SRF GUN\*

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### Abstract

Superconducting RF electron guns hold out the promise of very bright beams for use in electron injectors, particularly in light source applications. The University of Wisconsin has started a multi-year program to demonstrate a low frequency electron gun based on a quarter wave resonator (QWR) cavity. The design includes active tuning and a high temperature superconducting solenoid. We will report on the status of the Wisconsin SRF electron gun program.

### INTRODUCTION

The University of Wisconsin (UW) is in the process of building a superconducting radiofrequency (SRF) electron gun for the U.S. Department of Energy. The program is in response to a demand for a very bright electron source which can be used for the next generation of light sources and colliders which are being contemplated. SRF guns hold the promise to produce very bright, CW beams because of the linear correlation between the magnitude of the electric field on the cathode and brightness[1]. Modern SRF cavities routinely produce peak electric fields in excess of 65 MV/m with over 110 MV/m as the present record [2]. The goal for the UW gun was to achieve a more modest peak field of 40 MV/m. This allowed the gun to produce bunches with less than 1 micron normalized transverse emittance which could be compressed to 1000 A amplitude with sufficient bunchlength such that they could overlap a 30 fsec long seed laser with 30 fsec of jitter for EEHG or HGHG up conversion in an FEL. The specified current and bunchlength set the bunch charge at 200 pC. The WiFEL design uses blow-out mode bunches[3] in which a charge pancake is produced on the surface of the cathode and allowed to expand under its own space charge into an elliptical bunch with constant charge density. This renders a potentially less modulated bunch for use in the FEL frequency up conversion process at the expense of slightly increased initial transverse emittance. The gun itself has been modelled [4] with a 200 pC bunch to produce less than 1 micron normalized transverse emittance at the design cathode field of 40 MV/m when mated with a TESLA style cryomodule. The gun has also been modelled using 20 pC bunches for a lower emittance configuration. In that mode simulations indicate a projected normalized transverse emittance of 0.3 mm-mrad and an output slice energy spread of 0.6-0.8 keV under the assumption that the initial transverse emittance is 0.2 mm-mrad, which is consistent with a 20 pC bunch

produced by a  $K_2CsSb$  cathode. The gun is scheduled to produce first beam during the fall of 2012, with commissioning to continue through August of 2013.

### DESCRIPTION OF SYSTEM

The UW design uses a 199.6 MHz, quarter wave resonator geometry at a peak cathode gradient of 40 MV/m. A low frequency design was chosen for several reasons; the dynamic heat loss goes as the frequency squared, allowing the gun to operate at 4 K, dramatically lowering the operating cost. The QWR geometry was selected to reduce the size of the cavity compared to an elliptical structure of the same frequency and the long rf wavelength is much greater than the cathode to anode distance. That means that close to crest, during the initial acceleration process, there is little phase slip and the electric field is close to constant while the electron transits the accelerating gap, greatly reducing the rf curvature on the electron bunch. In the UW design [5], the electrons pass from the stem (cathode), along the axis of the gun and exit the cavity through the inner conductor of the rf coupler, Fig. 1. This cavity geometry also has a very low ratio of peak magnetic field vs. electric field, reducing the possibility of magnetic quench from high fields. Table 1 contains key parameters for the gun.

Table 1: Cavity Parameters

| Parameter                     | Calc Value      | Units |
|-------------------------------|-----------------|-------|
| Temperature                   | 4.2             | K     |
| Cavity Frequency              | 199.6           | MHz   |
| Unloaded Q (Q0), Nominal      | $3 \times 10^9$ |       |
| Surface electric field, Pk    | 53              | MV/m  |
| Integrated Electric Field     | 3.96            | MeV   |
| Dynamic heat loss at $E_{pk}$ | 39.2            | Watts |
| Static Heat Loss at 4.2K      | 7.5             | Watts |

### STATUS OF THE SYSTEM

#### Cavity

The mechanical details of the He vessel and cavity can be seen in Fig. 1 [6]. A frequency map [7] for the cavity construction was used to track the cavity frequency through the fabrication process. The cavity underwent final welding in October 2011 followed by a buffered chemical polish (BCP) etch and a vacuum bake at JLAB.

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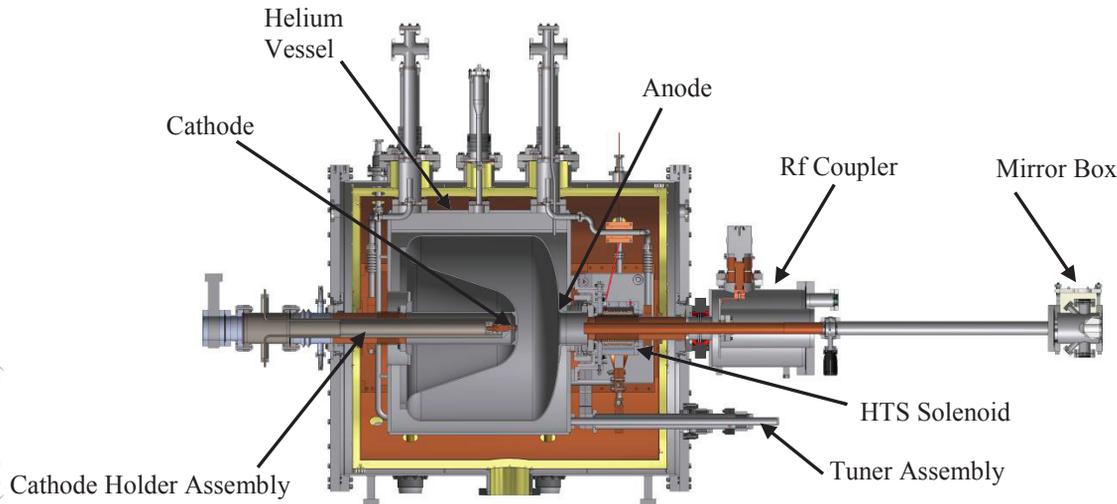


Figure 1: Mechanical Layout of Cavity, He vessel, HTC Solenoid, Cathode Holder, Rf Coupler and Mirror Box.

The cavity was baked at 600 C for 8 hours in the vacuum oven to remove hydrates and mitigate “Q” disease concerns. NbTi alloy conflat vacuum flanges were used to prevent the knife edges of the flanges from softening during the vacuum bake. The helium vessel was then fabricated of titanium in order to allow weldments between the cavity flanges and the helium vessel. Titanium also closely matches the thermal expansion of the niobium cavity, reducing thermal stresses in the cavity during cool down.

In February 2012 the cavity was assembled into a temporary cryostat for the cold test at Niowave. The cold test, which was to determine the low level Q0, was limited to one day of testing. The low level Q0 was easily determined to be  $3 \times 10^9$  in agreement with the models. Multipactor barriers were encountered during the test, Fig. 2, but showed a steady improvement during the

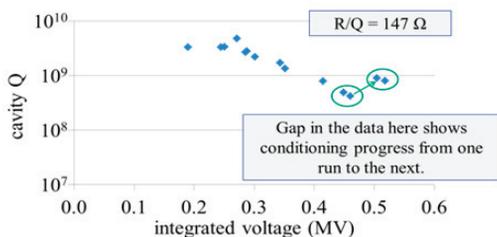


Figure 2: Day One Q0 vs Integrated E Field.

day of testing. After the cold test, the titanium helium vessel was attached to the cavity and the assembly shipped to Wisconsin for integration into the cryostat. Additional conditioning of the cavity will be done at the University after installation into the cryostat there. UW is exploring a new technique, plasma processing [8], as a means to further process the cavity. This technique has shown it can virtually eliminate multipactor and greatly reduce field emission.

The cavity tuner, Fig. 1, uses a ‘scissors jack’ driver similar to the one used by Michigan State University and JLAB [9] to actuate a teeter-totter which pulls on the

cavity flange on the anode end. The tuner uses the helium vessel as a strong back to work against in pulling on the cavity flange. Lengthening the cavity produces a frequency change of  $\sim 110$  kHz per mm, which was verified experimentally during the cavity fabrication. The tuner has the capability to adjust the cavity by  $\sim 60$  kHz for an 800 lb. load. Integration of the tuner is expected to occur in summer 2012.

The load lock / cathode holder is based on the HZDR system[10]. It uses a copper slug as a carrier for the cathode and a twist lock system to mount the cathode holder inside the cathode tube. The tube itself is double walled to allow liquid nitrogen flow to cool the cathode and reduce the radiative heat load from the cathode tube to the liquid helium cooled cavity.

### Solenoid

The high temperature superconducting solenoid provides emittance compensation for the gun. The predicted integrated B field required for emittance compensation at 40 MV/m cathode field is  $31 \text{ kG}^2\text{cm}$  and are derived from simulations of the gun. To specify limits on dipole and quadrupole terms, a 10% emittance dilution budget was allowed. Simulations were run to predict the allowable magnitude of the magnetic terms within that budget. Further simulations were made to verify that downstream skew magnets could theoretically undo the effect to first order [4]. The solenoid also had to limit the physical extents of the field so it could be placed as close as possible to the cavity without the use of a bucking solenoid. Finally, the design was limited by the fixed minimum bore size dictated by the co-axial rf coupler it encircles. Fortunately, a similar design had been built by BNL [11] and they provided guidance and suggestions in developing a specification. Danfysik was contracted to build the solenoid and is in the process of fabrication and testing. Delivery is expected in June 2012.

### *Cryostat and Thermal Management*

The cryostat which contains the cavity and solenoid and provides thermal management, magnetic shielding, mechanical support and alignment for all the assembled systems is in final design. The cryogenic design and modelling effort looked at not only how the He vessel kept the cavity cold, but how helium boil off gas was managed, how the HTS solenoid was cooled, how pressure was stabilized and how alignment tolerances were maintained during cool down. The magnetic shielding addressed concerns of stray field from the solenoid in addition to earth's field. Electrically the cryostat provides the connections for the solenoid, the rf probes and rf coupler. Finally, the entire system is a cryostat and must be cooled and evacuated which places mechanical stresses on all the aligned parts.

### *Rf System*

The rf system utilizes a commercial, 30 kW, solid state transmitter as a high power amplifier (HPA) driving coaxial waveguide through a high power circulator and load to the rf coupler. The HPA has been tested to 33 kW CW. The low level rf controller (LLRF) [12] allows self-excited cavity operation and incorporates cavity fault and tuner control. It is based on the JLAB upgrade design and is in test at UW. Although the system is presently configured for just the drive laser and gun, a booster cavity could be controlled by simply adding another LLRF chassis of the appropriate frequency and using the common LO. On-site testing of the entire system at high power will occur in June 2012.

### *Laser System*

The drive laser procured operates at a 1 kHz rep rate and is synchronized to an external 80 MHz signal phase locked to the rf master oscillator. It provides output at 800, 400 and 266 nm with a pulse one hundred and fifty femtoseconds long for blow-out bunch mode. The adjustable wavelength allows a wide range of photocathodes to be used. Energy per micropulse is approximately 4 mJ at 800 nm, enabling the use of metal cathodes. Mechanical shutters are used to provide pulse selection and fast beam shut down. The laser incorporates a polarizer and telescope imaging system similar to the one used at JLAB's FEL. The laser was delivered, installed and tested in the enclosure in February 2012. Fabrication of the optical transport beamline and associated mirror box that delivers the laser pulse to the cathode is underway with testing to occur during the summer.

### *Facilities*

The test stand requires the normal complement of electrical power, cooling water, compressed gases and instrument air. In addition there are cryogenic installations for handling the large quantities of LN<sub>2</sub> and liquid He required. Safety concerns required upgrades of the ODH, ionizing radiation and laser light interlocks and sensors. The additional heat generated by the rf system

required an upgrade of the building HVAC system to handle the HPA waste heat. Temperature controlled areas were built for the high power rf and drive laser adjacent to the beam enclosure. The new drive laser enclosure also provides a dust free location for the optical table on which the various lasers, shutters, half wave plates, combiners and optics will be mounted. Finally, a clean room has been refurbished into a class 100 area large enough to do final assembly of the cavity, cryostat, cathode holder and rf coupler. These upgrades were completed in April 2012, along with the new rf HPA and drive laser rooms.

## CONCLUSIONS

Construction of the UW SRF electron gun continues on schedule with most major systems on-site and in test. Facility work needed to support the project has been completed on schedule. Integration of the cryostat and its various pieces is scheduled to occur this summer with commissioning starting in the fall. We are planning for first beam in late fall of 2012.

First operation of the gun will be with a copper cathode which is a very robust and well characterized material in order to minimize the possibility of contaminating the cavity. Future operation of the gun may include low charge (20 pC) bunches for lower emittance operation. Once we ascertain that the cathode does not contaminate the cavity, more exotic cathode materials may be used in order to further lower emittance or increase the quantum efficiency. This could potentially allow direct operation at 80 MHz with the oscillator laser in a low charge configuration.

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