

MODELING OF A LOW FREQUENCY SRF ELECTRON GUN FOR THE WISCONSIN FEL*

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Abstract

The Wisconsin FEL project is a 2.2 GeV, HHG seeded, FEL designed to provide six individual beamlines with photons from 5 to 900 eV. The FEL requires electron bunches with 1 kA peak bunch current and less than 1 mm-mrad normalized transverse slice emittance. To meet those requirements a low frequency, SRF electron gun is proposed which uses "blow-out" mode bunches [1]. Blow-out mode produces ellipsoidal bunches which are easily emittance compensated [2]. They also have a very smooth density and energy distribution. Results of the modeling of the injector and a diagnostic beamline are presented.

INTRODUCTION

The Wisconsin FEL (WiFEL) project is a 2.2 GeV, HHG seeded, FEL designed to provide six individual beamlines with photons from 5 to 900 eV. The FEL requires electron bunches with 1 kA peak bunch current and less than 1 mm-mrad normalized transverse slice emittance. The injector for the WiFEL must supply the continuous stream of electron bunches which have the necessary transverse and longitudinal properties to support the compression system while minimizing the collective effects in the accelerator to the FEL. The bunch longitudinal profile must be optimized to avoid current spikes at the front and rear of the bunch charge density profile from wakefields [3]. At the same time, it must provide a bunch which reaches the kilo-amp level needed by the FEL for long enough to ensure overlap between the bunch and the seed laser in the undulator. It also must have a very smooth current density profile to prevent CSR or resistive wakefield microbunching in subsequent compressors. The 3D bunch profile which meets this requirement is a uniform ellipsoid [4].

To create an ellipsoidal bunch with uniform charge density, an ultra-short laser pulse with a hemispherical transverse profile is directed onto the photocathode. The charge pancake generated expands dynamically to form an ellipsoidal bunch under space charge forces. The limit on the dynamically formed bunch approach is that the charge density of the bunch is dependant on the peak electric field applied to the cathode. For a greater peak bunch current, either the electric field on the cathode must be increased or the emission radius must be enlarged with a consequent increase in thermal emittance; the limit for the FEL to operate, 1 mm-mrad, is reached at 1 mm rms radius for Cs₂Te [5]. Twenty is about the maximum bunch compression ratio which can be easily achieved with two magnetic chicanes while preserving the beam parameters

* This work is supported by the University of Wisconsin-Madison and MIT. SRC is funded by the US NSF under award No. DMR-0537588
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necessary to lase in a seeded FEL [6]. With that compression ratio 1 kA at the FEL requires 50 A peak from the gun. At the 1 mm rms emission radius the electric field on the cathode necessary to achieve 50 A peak is about 40 MV/m [7]. Such a CW field is too great for either a DC gun (field emission) or a CW normal conducting rf gun (thermal load), but is well within the reach of an SRF electron gun. For this reason, an SRF gun optimized to produce the smoothest maximum field on the cathode was selected.

The gun is to be built as part of the WiFEL R&D program along with a diagnostic beamline which can measure the bunch parameters. ASTRA [8] simulations of the beamline provided guidance in selection and placement of the diagnostic suite.

ELECTRON GUN DESIGN

Table 1: Electron Gun Parameters

Pulse frequency, MHz	10
Charge per bunch, pC	200
Average current, mA	<2
I_{peak} at first bunch compressor, Amps	50
Peak field in gun, MV/m	41
σ_x at 100 MeV, mm	0.34
σ_z at 100 MeV, mm	0.34
Transverse ϵ at 100 MeV, mm-mrad	0.9
Longitudinal ϵ at 100 MeV, keV-mm	2.2

The electron gun design [9] uses a 200 MHz SRF half wave cavity with a warm, Cs₂Te cathode mounted on a cathode stalk surrounded by a quarter-wave choke joint to

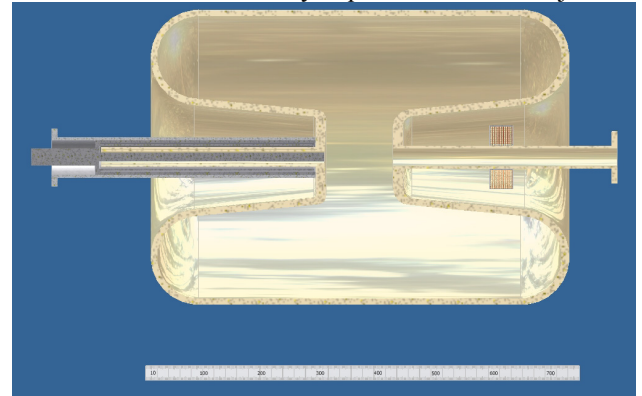


Figure 1: SRF gun cavity w/ cathode and solenoid.

isolate it from the rf in the cavity. The load lock system exploits the required choke joint with its low wall current point to mate the retractable Ti cathode stalk to the SRF

cavity. The entire assembly is contained in the nose cone of the cavity (Fig. 1). The entire cathode assembly can be retracted to an external cathode preparation chamber. The emittance compensation solenoid should be placed as close to the cathode as possible for minimum emittance. The design used is a superconducting magnet placed on the Ti tube welded to the anode of the SRF cavity in the He bath. Cavity rf is fed from couplers in the sides of the cavities, allowing greater power input to the cavity. The cryomodule entrance is placed 1.9 meters from the cathode to be at the invariant envelope working point.

MODELING RESULTS

The gun was modeled using ASTRA. The cathode emission was modeled as a 200 pC, 30 fsec long bunch with a hemispherical transverse charge distribution [9]. Figure 2 plots bunch development to the end of the first cryomodule in the WiFEL injector. The longitudinal ΔE induced by space charge cannot be corrected by running the low frequency cavity off-crest, as done with high

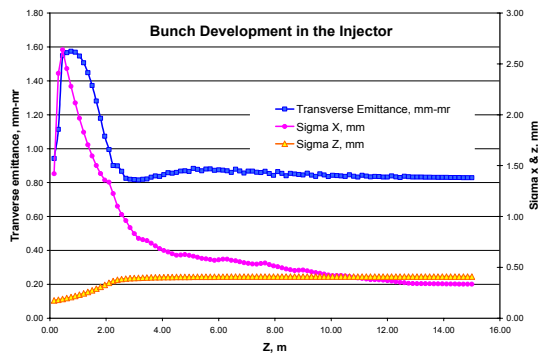


Figure 2: Space charge induced ΔE lengthens bunch.

frequency cavities [10]. Instead the module is moved closer to the cathode and the first cavity in the cryomodule is run off-crest to reverse the energy slew across the bunch and stop the blow out seen in sigma z. The phase and amplitude of the rf in the first cavity are calculated by looking at the amplitude of the energy chirp and the bunch length at the entrance to the module in the simulation and calculating the \cos^{-1} (amplitude of energy chirp / amplitude of field in cavity) \pm (the bunchlength in rf degrees) for the phase. The maximum cavity gradient is set to allow the emittance oscillation to be completed before the emittance is frozen. In practice, this value will need to be reduced to account for rf focusing in the cavity. This also converts the non-linear portion of the longitudinal energy distribution to a “U” shape (Fig. 3).

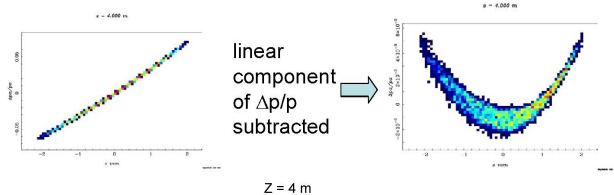


Figure 3: Longitudinal energy spread.

Figure 4 shows the simulated degradation of the transverse and longitudinal emittance at the entrance to the cryomodule versus an offset or error in field strength in the solenoid. The bunch is very sensitive to solenoid setting with a $\pm 1\%$ change causing a 30% change in normalized emittance and a 50% change in transverse sigma. This also suggests that chromatic effects in the solenoid may have a large effect on the bunch. Figure 5 shows the sensitivity of the transverse emittance to $\pm 10\%$ changes in bunch charge. Note that sigma z and the peak bunch current are also changing by $\pm 5\%$ as the charge per

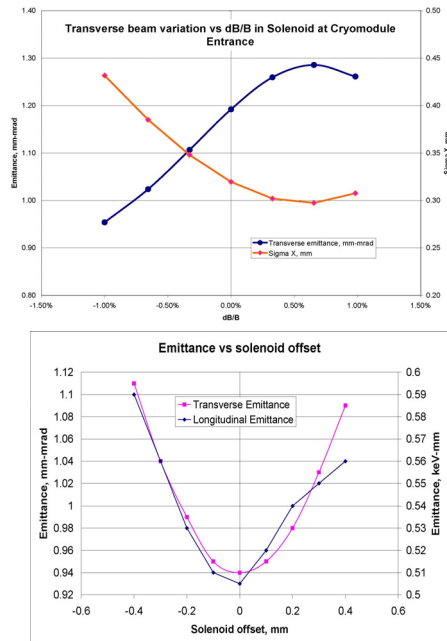


Figure 4: Sensitivity of ϵ working point to solenoid errors.

bunch is changed. This might effect subsequent compression and the lasing process.

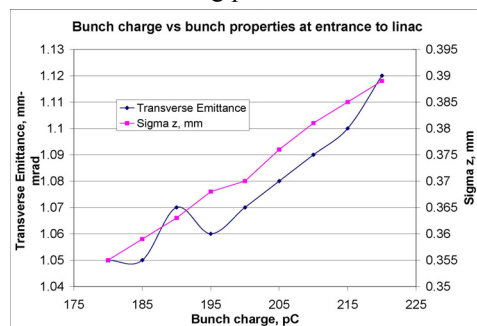


Figure 5: Sensitivity to bunch charge.

WiFEL GUN TESTSTAND

The gun described above is to be built as part of the WiFEL R&D program. To test the properties of the gun and qualify it for use with the WiFEL, the diagnostic beamline shown in Fig. 6 has been proposed. The beamline is highlighted by a phosphor coated, 50 micron slit mounted between two bellows on a precision linear stage. This arrangement allows the slit to be moved plus or minus 0.5 meter from the working point of the

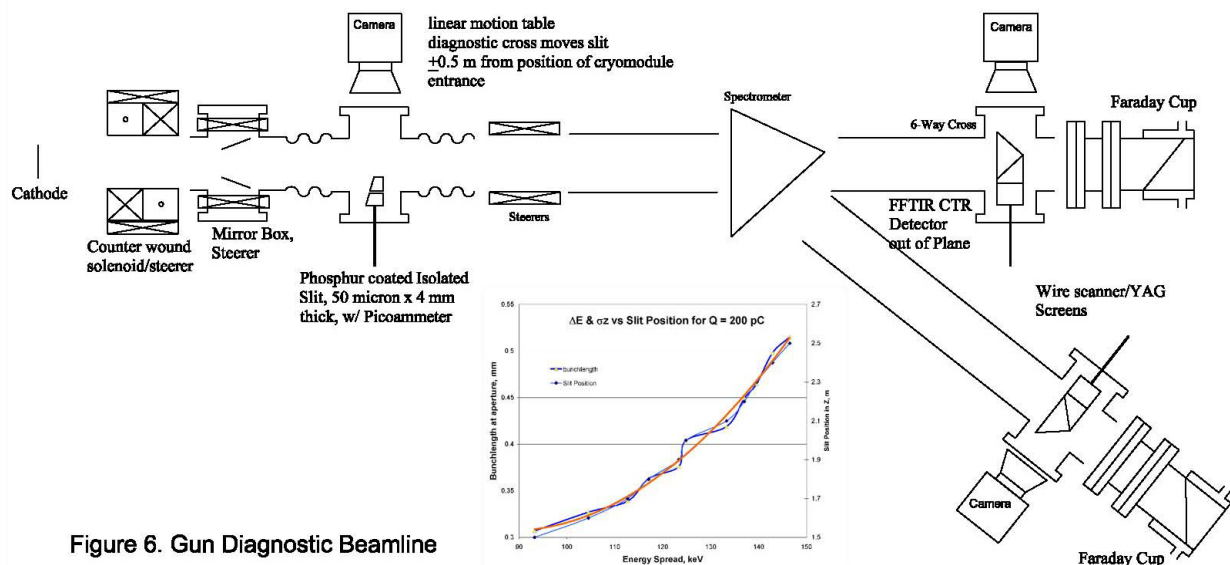


Figure 6. Gun Diagnostic Beamline

emittance compensation scheme. The slit acts to transform the bunch from a strongly space charge dominated regime to an emittance dominated regime [11] in which the development of the emittance envelope as a function of solenoid strength and position can be plotted. When the beamlet produced by the slit is allowed to drift through the spectrometer with no field, the rms emittance of the beam can be measured with the downstream slit/scanner using the technique described in [12]. Adjusting the longitudinal position of the aperture while measuring the downstream transverse emittance and beam sizes, the working point for the solenoid and placement of the linac section can be optimized experimentally.

The straight ahead line is also equipped with a Faraday cup to allow monitoring of the bunch charge throughout the measurements. Finally, an OTR (Optical Transition Radiation) screen and input to a FTIR (Fourier Transform InfraRed) detector is mounted on the other axis from the wire scanner. The FTIR allows the measurement of longitudinal modulation on the bunch by direct measurement of the 1.25 - 25 μm CTR (Coherent Transition Radiation) produced by the bunch. The FTIR diagnostic is looking for modulations on the beamlet which are of the scale to act as a seed for microbunching in compressors [6].

The spectrometer beamline after the dipole allows the momentum spread of the bunch to be measured at the wire scanner. Since the space charge increases the energy spread of the bunch as it moves away from the cathode in blow-out mode, measurements of energy spread in the spectrometer line can be correlated to a rough bunch length at the slit. To make the measurement even more precise, the slit can be moved longitudinally to vary the energy spread in the dump and the data fit to a curve of the simulated data (Fig. 6). The port on the spectrometer vacuum cross orthogonal to the harp contains a second mirror for transport to the FTIR spectrometer. The detector will measure longitudinal energy modulations converted to density modulation on the incoming bunch

by the dispersion in the spectrometer leg. This pairing of energy spread and FTIR diagnostic will yield a rough bunch length along with the longitudinal high frequency content of the bunch. Discriminating the FTIR frequency content between the dispersive and non-dispersive measurements will yield both the longitudinal energy and density modulations. Both these measurements are key to the bunch compression process.

CONCLUSIONS

A brief description of the proposed 200 MHz gun for the Wisconsin FEL and simulations showing bunch development are given. A diagnostic beamline is described. The transverse emittance and bunch sigmas will be measured to verify the solenoid strength and cryomodule placement.

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