THE NEW PHOTOINJECTOR FOR THE FERMI PROJECT

G. D'Auria, D. Bacescu, L. Badano, F. Cianciosi, P. Craievich, M. Danailov, G. Penco, L. Rumiz, M. Trovo', A. Turchet.
Sincrotrone Trieste, Trieste, Italia
H. Badakov, A. Fukusawa, B. O'Shea, J.B. Rosenzweig
UCLA Department of Physics and Astronomy, 405 Hilgard Ave., Los Angeles, CA 90095

Abstract

FERMI@elettra is a single-pass FEL user facility covering the spectral range 100-10 nm. It will be located near the Italian third generation Synchrotron Light Source facility ELETTRA and will make use of the existing 1.0 GeV normal conducting Linac [1]. To obtain the high beam brightness required by the project, the present Linac electron source will be substituted with a photocathode RF gun now under development in the framework of a collaboration between Sincrotrone Trieste (ST) and Particle Beam Physics Laboratory (PBPL) at UCLA. The new gun will use an improved design of the 1.6 cell accelerating structure already developed at PBPL, scaled to 2998 MHz. We expect that the new gun design will allow a beam brightness increase by a factor 3-4 over the older version of the device. Some technical choices of the new design, including the enhancement of the mode separation, removal of the RF tuners, full cell symmetrization to limit the dipole and quadrupole RF field as well as an improved solenoid yoke design for multipole field corrections, will be discussed.

OVERVIEW

The efficiency of a FEL process is strictly related to the normalize brightness of the electron source, $B_n=2I_p/\varepsilon_n^2$. In the X-ray region, the required brightness is in excess of 10^{14} A/m^2, which must be achieved simultaneously with a low energy spread. These very demanding values cannot be achieved with the present linac electron source at ELETTRA, consisting of a standard DC triode and a bunching section [2]. To reach this level of performance it is necessary to use a high performance photoinjector.

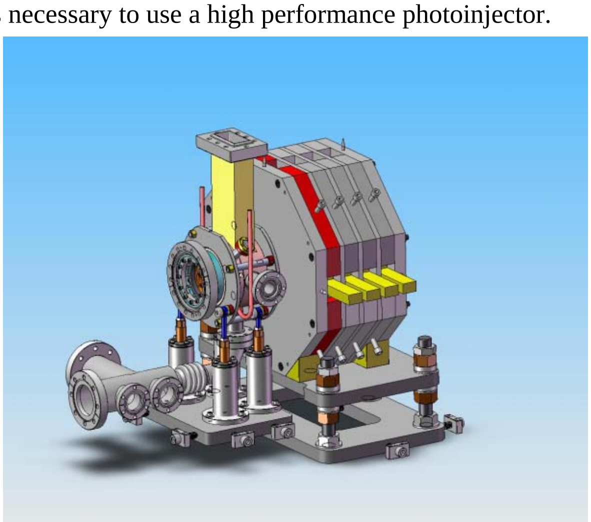

Figure 1. FERMI photoinjector: gun, solenoid, supports.

For this purpose a collaboration agreement, aimed to develop this high brightness source, has been recently signed between ST and UCLA. Indeed, UCLA has proven experience in this field and has developed several recent photoinjectors as component of the SPARC project (high brightness beam and visible FEL) [3,4] and, most recently, the FINDER (ICS) [5] collaborations.

In the FINDER experiment, low emittance performance is paramount, and the requirements on the photoinjector are nearly identical to those of the FERMI project. As the FINDER photoinjector is the most advanced design developed at UCLA, we have based the FERMI design upon it. Figure 1 shows the FERMI photoinjector with solenoid and mechanical supports. The key features added to the FINDER/FERMI 1.6 cell S-band photoinjectors in comparison to the SPARC generation are as follows:

- the full cell tuner penetrations have been removed, as they were demonstrated to cause arcing at moderate field values [6]. In the SPARC case, as well as a previous UCLA-built injector for the E-163 experiment at SLAC, with tuners retracted from the cell, fields in excess of 120 MV/m have been achieved [7].
- The full cell has been symmetrized by addition of the two extra ports, identical to the waveguide coupling port and the dipole symmetrizing port opposing it. This feature ensures that the quadrupole component of the RF field, which can lead to emittance growth through its combination with the solenoid field, is cancelled.
- The 0-π mode separation has been greatly increased in order to avoid partial excitation of the 0-mode which leads to increased energy spread and chromatically derived emittance growth. In the FERMI photoinjector, the mode separation is 14 MHz, leading to a 0-mode excitation of 2.1% relative to π mode amplitude.
- The RF gun structure design was adapted from the 2854.5 MHz (FINDER case) to 2998 MHz (FERMI standard) by simple scaling of the gun interior dimensions as well as adjustment of the external coupling.
- The emittance compensation solenoid has been designed with a strict quadrupole of symmetry in the yoke, as well as the capability of running with much higher currents/fields, which allow flexibility in the operation of the device.

RF STRUCTURE SCALING AND DESIGN

The RF gun structure was designed using the FINDER gun as a point of departure. The RF design was then adapted to 2998 MHz operation by first scaling the interior wall dimensions and then making adjustments to compensate for the frequency difference. These adjustments were guided by SUPERFISH (2D) and HFSS (final 3D, see Table 1) simulations.

Frequency	2998 MHz
Internal Q_0	12326
R_s/Q	207 Ω
Shunt Impedance R_s	2.55 MΩ (31.89 MΩ/m)
Peak E field @ 10 MW	125 MV/m
External coupling β	1.09
External (loaded) Q_L	5898

Table 1. Results of HFSS simulations of FERMI gun.

The enhancement of the mode separation is accomplished by widening the inter-cell iris aperture and narrowing its thickness. The resulting structure gives a maximum field on the cathode approximately equal to that found on the inter-cell iris, as well as the beam tube iris. The accelerating field leaks slightly into the beam tube with this enhanced aperture; this has negligible effect on the beam quality. Figure 2 Shows the RF fields as computed with HFSS.

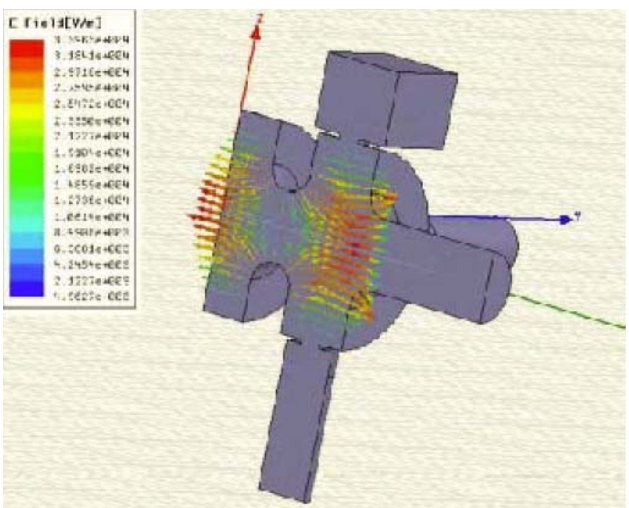

Figure 2. Fields in HFSS simulation of FERMI RF gun.

The final dimensions of the waveguide coupling slot have been specified using HFSS. The gun is chosen to be overcoupled to allow for possible RF phase adjustments. The three symmetrization slots can be used as pumping ports to improve the vacuum; enhanced vacuum levels also result from the using larger pumping holes in the cathode plane. The outside envelope of the gun has not been scaled down in size from that of the FINDER design, as we desired to preserve the thermal mass and allow for wider water cooling passages. With these changes, thermally stable operation of the gun is foreseen up to 20 Hz, at a nominal input power of 8 MW.

SOLENOID DESIGN

The solenoid design has been chosen to give emittance compensation in a scenario close to the Ferrario operating point [8]. Small changes are noted, however, in the gun's electrical length, and in a slightly larger distance (165 cm) from the cathode to the first booster travelling wave linac.

The solenoid has four coils of the "pancake" design introduced in the SPARC case, each separated by an iron field stiffener. The pancake design has a cooling scheme that uses an internal water manifold instead of hollow water-carrying coils. This more efficient cooling allows the overall field level to be operated 80% above the nominal design value (3.1 kG).

The symmetry allows the mitigation of both dipole and quadrupole field components. The quadrupole contribution to the emittance has been found in the SPARC injector studies to be potentially serious, due to coupling between x and and y phase planes. To deal with any residual multipole field errors, we will employ a printed circuit dipole/quadrupole array.

GUN INTEGRATION AND PHOTOINJECTOR LAYOUT

The RF gun and the emittance-compensation solenoid, described above, will be integrated in the FERMI linac accelerator. The technical design of this injector area is under final refinement. The guide lines, which we have followed so far in the process of mechanical component definitions, are mainly:

- to arrange a stable support able to align the gun with a good accuracy by introducing a girder based on a concrete block;
- to provide a vacuum system able to reach a good level of ultra high vacuum (few 10^{-10} mbar) close to the photocathode. This vacuum equipment makes use of all gun ports and is also versatile for different operation modes;
- to place necessary diagnostics in the short room between the Gun and the first booster section [9, 10].

Figure 3 shows the injector area in a 3D cad rendering. Many components are hidden in the drawing in order to simplify the view.

In order for the laser injection to meet the pulse shape requirements we will use a normal incidence scheme; moreover an innovative laser input port, with an out of vacuum mirror, will be used.

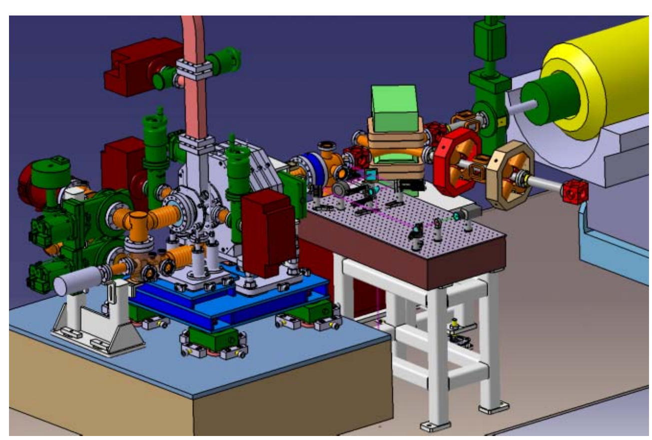

Figure 3: Photoinjector Layout. Valves are represented in green, pumps in red and some supports are hidden.

Alignment

The alignment quality and the stability of the photoinjector are relevant for the performances of the whole system; the e-beam brightness can be drastically deteriorated by a small misalignment of the solenoid with respect to the gun cavity. A rigid translation of the solenoid with respect to the gun of only 100 µm produces a trajectory deviation of 0.8 mm after just 1 m, exciting transversal wakefields which strongly affect the emittance. The worst case occurs when the solenoid is tilted with respect to the gun and/or to the beamline axis: as shown in figure 4 a tilting of about 1 mrad in one plane produces an emittance growth of about 10% without any trajectory correction. Thus the solenoid is required to be aligned with the gun to better than 100 µm and with a tilt angle less than 100 µrad in both planes.

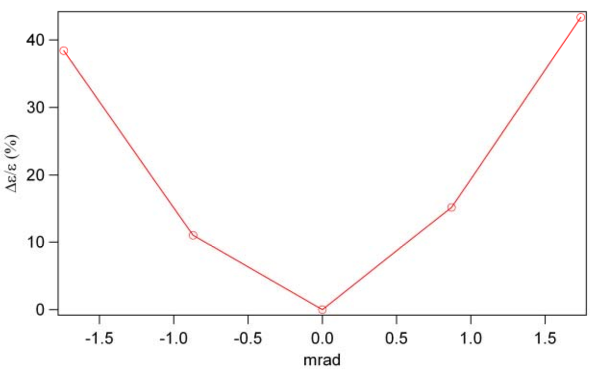

Figure 4: Emittance growth at the end of the injector due to a tilting of the solenoid in the horizontal plane.

Vacuum system

The vacuum system makes use of different pumps in order to produce, maintain, and quickly recover UHV conditions: a turbo molecular pump, three ion pumps and a non evaporable getter pump. Multiplicity of ion pumps allows operation of the gun even in the case of a power failure in a single pump. NEG pump helps to pump efficiently in the very low pressure range and it could also act as "emergency" pump in case of mains failure. All pumps can be isolated from the main chamber by gate valves. This choice allows a more efficient bake-out procedure and also makes the system suitable for sputtering operation, optionally foreseen for cathode cleaning and conditioning. In case of cathode maintenance, the removal of one single elbow allows free access to the cathode flange and a venting valve is used to allow dry N_2 to continuously flow through the cavity.

STATUS AND TIME SCHEDULE

The gun, solenoid and support structures designs have been completed. Machining of all these components is now underway at UCLA. The solenoid will be finished in July 2007 and tested at UCLA and SLAC for multipole purity. The RF gun will undergo first braze at SLAC in August 2007, with final joining in September. Delivery of the injector components and supports to Sincrotrone Trieste is scheduled for October 1, 2007.

CONCLUSIONS

The importance of the electron source for a successful operation of a FEL facility is universally recognized. With this assumption the strategies and guidelines adopted for the new photoinjector of the FERMI project have been discussed. We are now finalizing the integration of the UCLA gun into the FERMI layout, before starting with the detailed technical design of all the components. We plan to have all the components ready for installation at the beginning of next year. Meanwhile, the laser system is already at ST and is now under testing to verify its performance and reliability.

The photoinjector installation is planned for the beginning of 2008 when the new buildings will be available and the plant can be installed. The first half of next year will be widely used for hardware tests and beam characterization.

REFERENCES

[1] FERMI@Elettra Conceptual Design Report, Jan. '07
[2] G. D'Auria et al., "Linac upgrading program for the FERMI project: status and perspectives", this Conference.
[3] J. Rosenzweig et al., "RF and Magnetic Measurements on the SPARC Photoinjector and Solenoid at UCLA" Proc. 2005 Particle Accelerator Conference.
[4] D. Alesini et al., "The SPARC Project: A High Brightness Electron Beam Source at LNF to Drive a SASE-FEL Experiment", Proc. 2003 Particle Accelerator Conference.
[5] S. Anderson et al., this Conference.
[6] A. Cook, et al, "Mitigation of RF Gun Breakdown by Removal of Tuning Rods in High Field Regions", in Physics and Applications of High Brightness Electron Beams, World Scientific, 2007.
[7] D. Alesini et al., "Status of the SPARC project", Proc. 2006 European Particle Accelerator Conference.
[8] M. Ferrario et al., "HOMDYN study for the LCLS Photoinjector", in "The Physics of High Brightness Beams", World Sci., 2000.
[9] S. Lidia et al., "Technical Design and Optimization Study for the FERMI@elettra FEL Photoinjector", ST/F-TN-05/13, August 2005.
[10] L. Badano et al, "The Beam Diagnostics System for the FERMI@elettra Photoinjector", Proceedings of DIPAC, Venice, 2007.

