FIRST COMMISSIONING EXPERIENCE AT THE SwissFEL INJECTOR TEST FACILITY

T. Schietinger, M. Aiba, B. Beutner, M. Dach, A. Falone, R. Ganter, R. Ischebeck, F. Le Pimpec, N. Milas, P. Narang, G.L. Orlandi, M. Pedrozzi, S. Reiche, C. Vicario
Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland

Abstract

The Paul Scherrer Institute is commissioning a 250 MeV injector test facility in preparation for the SwissFEL project. Its primary purpose is the demonstration of a high-brightness electron beam meeting the specifications of the SwissFEL main linac and undulator complex. At the same time it is advancing the development and validation of the accelerator components needed for the realization of the SwissFEL facility. We report the results of the first commissioning phase, which includes the gun section of the injector up to 7 MeV electron energy. Electrons are generated by a 2.6-cell laser-driven photocathode RF gun operating at 3 GHz followed by an emittance compensating focusing solenoid. The diagnostic system for this phase consists of a spectrometer dipole, a series of screens and beam position monitors and several charge measuring devices. Slit and pinhole masks can be inserted for phase-space scans and emittance measurements. The completion of the entire injector facility proceeds in three stages, culminating with the integration of the magnetic compression chicane expected for early 2011.

INTRODUCTION AND MOTIVATION

The SwissFEL project at the Paul Scherrer Institute (PSI) foresees the realization of a SASE Free Electron Laser (FEL) operating at 0.1–7 nm photon wavelength based on permanent-magnet undulator technology by 2016 [1]. To minimize the facility length, and therefore cost, the concept aims at minimum electron beam energy (5.8 GeV in the baseline design). For the extensive study of the generation, transport and compression of high brightness electron beams and for developing the necessary components, PSI is presently commissioning the SwissFEL injector test facility, a highly flexible 250 MeV linear electron accelerator [2]. The injector is conceived as a split photoinjector operating at S-band frequency, followed by a magnetic bunch compression chicane including a harmonic X-band cavity for phase-space linearization.

The commissioning of the test facility proceeds in three stages: in a first step (phase 1), the gun section with additional diagnostics is put into operation. For phase 2, the full accelerator will be assembled with the exception of the bunch compression chicane, which will be added in 2011 for phase 3. In this paper we report on the results of the phase 1 commissioning period, which lasted from March to June 2010.

BEAMLINE SETUP

The setup for phase 1, schematically shown in Fig. 1, essentially consists of a laser-driven RF gun with focusing solenoid followed by a diagnostic beamline for the characterization of the ensuing drift, in which the beam undergoes emittance compensation and is matched into the first traveling-wave structure of the booster linac. Since no accelerating structures beyond the gun were installed in phase 1, an additional diagnostic section was implemented at the location of the first booster cavity to characterize the envelope of the unaccelerated beam in this region. The commissioning of this configuration proceeded in parallel with the installation of the remaining beamline further downstream, with a concrete shielding wall separating the two areas.

Laser system: The laser used to drive the electron gun during phase 1 commissioning is based on a compact, turnkey Nd:YLF amplifier adapted to the stability requirements of FEL electron guns [3]. The laser oscillator delivers 2.2 mJ, 10.4 ps pulses (FWHM, Gaussian profile) at 1048 nm wavelength. Sequential frequency doubling in a 3 mm and 2 mm BBO crystal, respectively, and transfer to the beamline results in an available pulse energy at the cathode of about 70 μJ at 262 nm wavelength. The pulse length at this wavelength is significantly shorter, a direct measurement using cross-correlation gave a UV pulse length of about 6 ps. The laser beam is sent through a 50 cm long capillary of 300 μm diameter to suppress higher-order spatial modes. Transverse pulse shaping is performed by expanding the Gaussian-like intensity profile transversely and selecting the central part (≈50%) with an aperture mask. A lens is used to image the profile at the mask position onto the cathode. The horizontal (vertical) rms laser beam pointing stability at the cathode is 3.6 (5.5) μm. In Fig. 2 we show the longitudinal and transverse profile of the laser beam, measured via cross-correlation and with a UV camera, respectively.

In the future, a more powerful and more sophisticated Ti:Sapph amplifier will be used as a gun laser [4].

RF gun and solenoid: In its initial phase, the injector test facility uses the CTF3 gun number 5, originally developed for high-current operation at the CLIC test facility at CERN [5]. (In 2011 it is planned to replace this gun with a new PSI-developed RF gun optimized for FEL operation.)

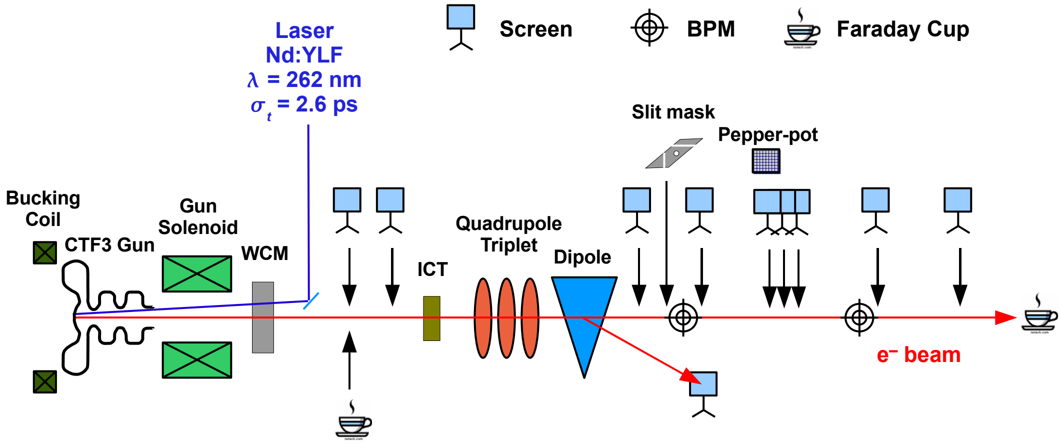

Figure 1: Schematic view of the phase-1 setup comprising RF gun and diagnostics.

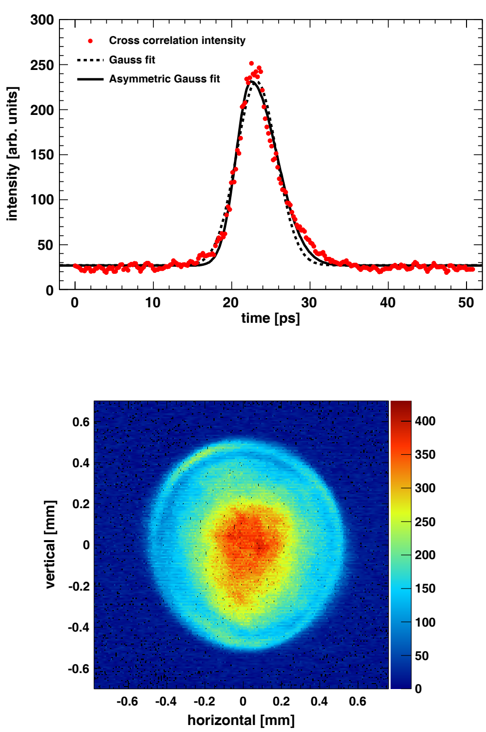

Figure 2: Laser longitudinal (top) and transverse (bottom) profile measurements.

The 2.6-cell standing wave S-band cavity runs at a nominal gradient of 100 MV/m with 21 MW of peak power at a repetition rate of 10 Hz. The measured pulse-to-pulse jitter is below 0.02° in phase and less than 0.019% in amplitude. A solenoid located immediately after the gun focuses the beam while optimizing the projected emittance. It is mounted on a movable platform to allow alignment with respect to the electron beam. Two small quadrupole magnets (regular and skew) are integrated into the solenoid to correct possible quadrupole terms in the solenoid field.

Diagnostics: The transverse beam envelope is monitored by a set of 10 screen monitors [6]. The screens consist of YAG:Ce crystals of 20 µm and 200 µm thickness (high-resolution and overview, respectively). Additional information on the transverse phase space is obtained by intercepting the beam with a pinhole-array ("pepper-pot", at 3013 mm from the cathode) or horizontal and vertical slit masks (at 2662 mm) while recording the resulting beamlet pattern on a subsequent screen to derive the local divergence [7]. The pinholes have a diameter of 25 µm and are separated by 150 µm, the slits have widths of 20 and 50 µm. Two 500 MHz resonant stripline beam position monitors provide information on the beam trajectory with a position resolution of 7 µm (rms) between 5 and 500 pC (20 µm at 2 pC) and a charge resolution of 1.5% down to 2 pC. Two coaxial Faraday cups, a wall current monitor (WCM) as well as an integrating current transformer (ICT) are used to monitor the bunch charge and the charge profile within the gun RF pulse. The momentum and momentum spread of the electron beam is measured through dispersion created by a dipole magnet (30° bending) in a spectrometer arm.

BEAM CHARACTERIZATION

In Fig. 3 we show a Schottky scan (bunch charge as a function of laser launch phase). The corresponding momentum and momentum spread curves, shown in the same figure, indicate a minimal momentum spread at a launch phase of about 38°. At this phase, our regular gun operating phase, electrons are emitted from the copper cathode with a quantum efficiency of 4×10^{-5} as determined from the linear rise in bunch charge when increasing the laser pulse energy. The gun was operated at bunch charges varying between 10 and 200 pC.

In Fig. 4 we show an example measurement of the beam envelope for a charge of 200 pC, together with a matched 3D particle simulation [8].

The emittance at the (future) location of the booster en-

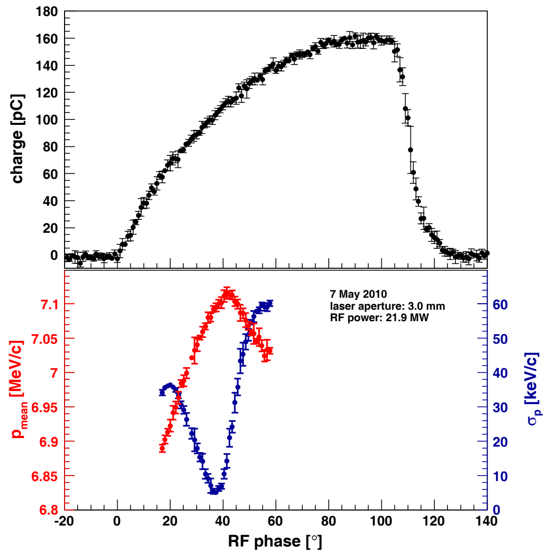

Figure 3: Schottky scan (top) and corresponding spectrometer scan (bottom) showing bunch charge, momentum and momentum spread as a function of the relative phase between gun RF and laser pulse.

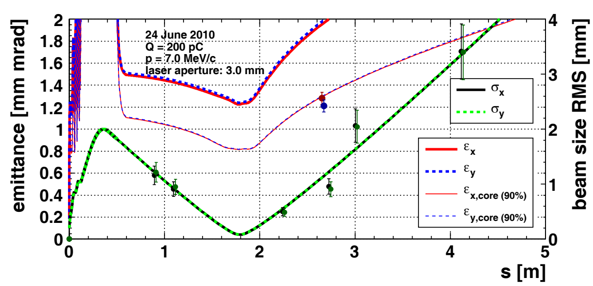

Figure 4: Beam envelope and emittance from a 3D particle simulation, matched to a particular experimental setup. The data points represent the corresponding measurements (slit scans for emittance). The 90% core emittance is determined by removing 10% of the charge in the head and the tail of the bunch.

trance is optimized by scanning the strength of the gun solenoid. In Fig. 5 we show such a scan for a bunch charge of 70 pC, with emittances obtained by slit scans (pepper-pot measurements yield consistent results). Table 1 summarizes the smallest obtained emittances at different bunch charges. The use of the quadrupole correctors integrated in the gun solenoid was essential for reaching these values.

The intrinsic emittance of the cathode was measured with the pepper-pot method and found to be 0.53 ± 0.05 mm mrad per mm rms laser spot size.

CONCLUSION AND OUTLOOK

The commissioning of the gun section of the SwissFEL injector test facility was completed in June 2010 with measured parameters approaching the design requirements. In August 2010 the facility resumed operation with two S-band traveling-wave RF structures accelerating the beam up to an energy of 162 MeV. Later this year two further structures will be put in operation to reach the booster design energy of 280 MeV. In 2011, the injector facility will be completed with the installation of the magnetic bunch compression chicane and the associated harmonic cavity.

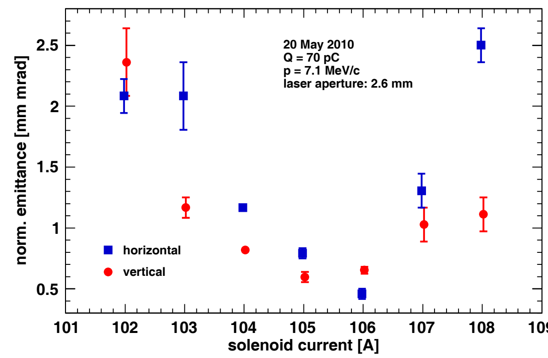

Figure 5: Horizontal and vertical emittance as measured with slit scans versus gun solenoid focusing (controlled by the solenoid current).

Table 1: Lowest Measured Emittances for Different Bunch Charges. Errors are statistical.

Q [pC]	σ_{laser} [mm]	$\varepsilon_{n,x}$ [mm mrad]	$\varepsilon_{n,y}$
$\approx$10	0.16	0.64 ± 0.06	0.56 ± 0.14
$\approx$100	0.27	0.46 ± 0.04	0.60 ± 0.04
$\approx$200	0.36	1.04 ± 0.01	0.78 ± 0.04

REFERENCES

[1] R. Ganter (ed.), "SwissFEL Conceptual Design Report", PSI Report 10-06 (2010).

[2] M. Pedrozzi et al., in Proceedings of the 31st International Free Electron Laser Conference (FEL), Liverpool, UK, 2009. M. Pedrozzi (ed.), "250 MeV Injector Conceptual Design Report", PSI Report 10-05 (2010).

[3] C. Vicario et al., in Proceedings of the 32nd International Free Electron Laser Conference (FEL), Lund, Sweden, 2010.

[4] C. Hauri et al., in Proceedings of the 31st International Free Electron Laser Conference (FEL), Liverpool, UK, 2009.

[5] R. Bossart, M. Dehler, in Proceedings of the 5th European Particle Accelerator Conference (EPAC), Sitges (Barcelona), Spain, 1996.

[6] R. Ischebeck et al., these Proceedings.

[7] B. Beutner et al., these Proceedings.

[8] A. Adelmann et al., "The OPAL Framework (Object Oriented Parallel Accelerator Library)", PSI Report 08-02 (2008).