PROFILE MONITORS FOR THE SwissFEL INJECTOR TEST FACILITY

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Abstract

The SwissFEL Injector Test Facility consists of an RF gun, an accelerating section for a final energy of 250 MeV, and two diagnostics sections. Transverse profiles of the electron beam can be recorded at 27 locations by imaging fluorescent crystals that can be inserted into the beam. At 21 of these, the fluorescent screens are complemented by optical transition radiation monitors and wire scanners. Here, we will evaluate the performance of transverse profile monitors. Profile monitors are used in conjunction with a slit and a pepper pot to determine the transverse phase space distribution of the bunches at low energy. Experimental results from the SwissFEL Injector Test Facility are presented.

INTRODUCTION

The Paul Scherrer Institute is currently commissioning [1] the SwissFEL Injector Test Facility [2], a linear accelerator for a nominal particle energy of 250 MeV that is designed to study the generation of electron bunches suitable for the SwissFEL X-ray free electron laser (XFEL) [3]. The slice emittance of the electron bunches is of particular interest, as it determines the saturation length in the undulators. As a compact XFEL, the SwissFEL project foresees an emittance of 0.4 μm, which is a factor of two lower than the nominal emittance traditionally planned for XFELs.

A time-integrated, or *projected* emittance can be measured by observing the transverse distribution of the particles at different phase advances in (x, x') and (y, y') phase spaces. There are several possibilities to measure the transverse particle distributions: the observation of fluorescence in a crystal, optical transition radiation on a metallic surface and the scattered particles induced by scanning a wire through the beam. These three methods have been integrated into detector units that are installed at 27 locations along the SwissFEL Injector Test Facility(Fig.1).The setup of these monitors will be described in this paper, along with measurements of the performance and first data acquired during the commissioning phase of the SwissFEL Injector Test Facility. Data analysis methods, phase space reconstruction and the measurement of emittance are described in [4].

To measure the time-dependent, or *slice* emittance in the bunch, it is foreseen to streak the bunches vertically by a deflecting RF cavity installed upstream of the monitors. Such a RF deflector is installed in the SwissFEL Injector Test Facility, and commissioning of this device is foreseen for early 2011.

The transverse profile monitors can also be used for momentum spectrum measurements in the dispersive sections behind the spectrometer dipoles.

TRANSVERSE PROFILE MONITORS

The transverse profile monitors combine three devices: (1) A scintillating crystal, consisting of cerium doped yttrium aluminum garnet (Ce:YAG) or cerium doped lutetium aluminum garnet (Ce:LuAG), the latter offering a factor of two more visible photons. Different thicknesses (20, 200 and 1000 μm) are used, balancing detection efficiency with optical resolution. (2) An aluminum-coated silicon mirror to generate optical transition radiation (OTR). (3) Three wires that can be scanned through the beam. The wires are made from tungsten and have a thickness of 25 μm. One horizontal, and two diagonal wires at 45 degrees are installed. The wires are stretched by small springs to maintain the tension during UHV bakeout.

In the first sections of the accelerator, up to an energy of 87 MeV (i.e., the gun section and the detector after the first accelerating cavity), only scintillating crystals are installed, because the other systems would not generate sufficient signal-to-noise ratio. Here, the scintillators are positioned at 90 degrees to the beam and viewed through a mirror. At higher energies, the scintillating crystals and OTR screens are installed at an angle of 45° to the beam.

An RF shield continues the beam pipe when the monitors are not in use. The in-vacuum piece that holds the scintillator, the OTR screen and the wire scanner is shown in Fig. 2.

Two cameras are set up to image the scintillating crystal and the OTR mirror: an overview system that images an area covering 28×37 mm^2 and a system that covers the central 5×8 mm^2. The overview camera is used during initial commissioning and covers an area large enough to detect unfocused or mis-aligned beams. It has a projected pixel size of 23 μm. To image the screens installed at an angle of 45° to the optical axis, the lens is tilted according to the Scheimpflug criterion [5]. For the given magnification, this corresponds to a tilt of 8.5°. A commercial perspective control lens is used[1].

The camera that images the central part of the screens has a projected pixel size of 4.5 μm. For the required imaging ratio, perspective control lenses are not commercially available. Instead, a regular macro lens is installed[2]. There-

[1] PC Micro Nikkor 85 mm f/2.8
[2] Micro Nikkor 200 mm f/4

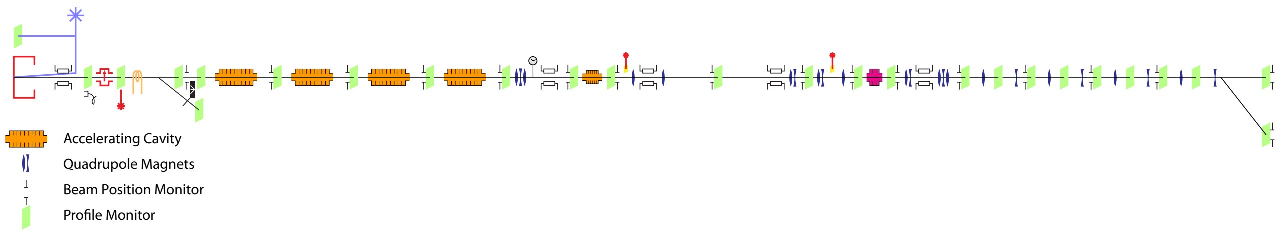

Figure 1: Overview of the profile monitors installed in the SwissFEL Injector Test Facility.

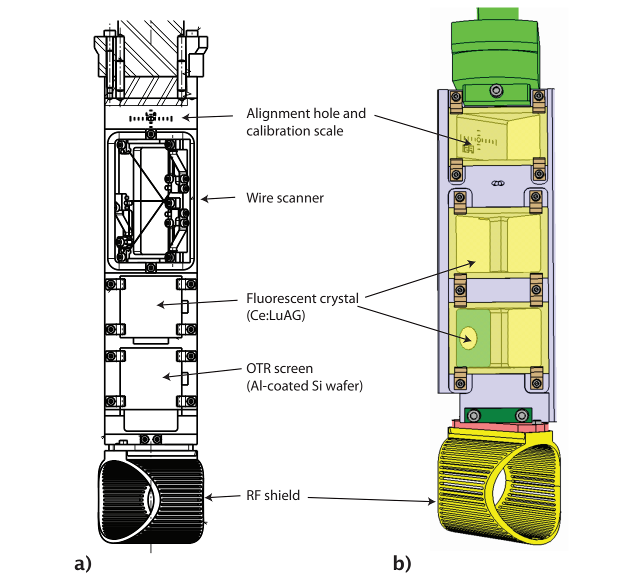

Figure 2: Holder for the fluorescent crystal, the OTR screen and the wire scanners.

fore, only the central part, corresponding to a field of view of about 1 mm, achieves reasonable resolution. Vertically, the field of view is 7.5 mm, suitable for use with the RF deflector.

The radiation is detected with a room-temperature monochrome CCD sensor[3], digitized with a 12-bit ADC. The readout noise precludes the usage for OTR at low bunch charges; consequently, the detectors of the most important monitors will be replaced by cooled CMOS devices in 2011 (Fig.3).

CHARACTERIZATION OF THE OPTICS

The two optical systems have been characterized with a target according to ISO 12233, illuminated by incoherent white light, to evaluate the achievable resolution. A tilted knife edge, located on this test target, can be used to measure the optical transfer function of the Heaviside step function with sub-pixel oversampling. From the transfer function of the step function, the point spread function and hence the spatial frequency response (SFR), also known as modulation transfer function (MTF) can be calculated with the code sfrmat2 [6]. The SFR for the two optical systems is shown in Fig. 4. The limiting resolution of the two sys-

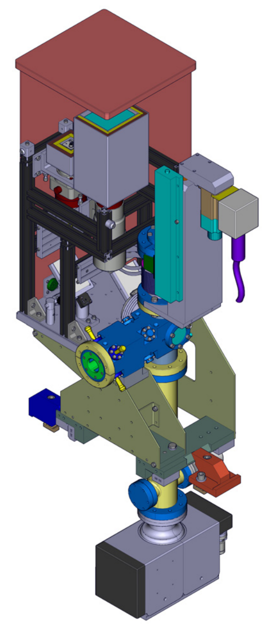

Figure 3: Readout unit for the screen monitors, consisting of two cameras and filters that can be inserted into the optical axis.

tems, according to the ISO 12233 standard [7], is 30 and 150 line pairs per mm, respectively.

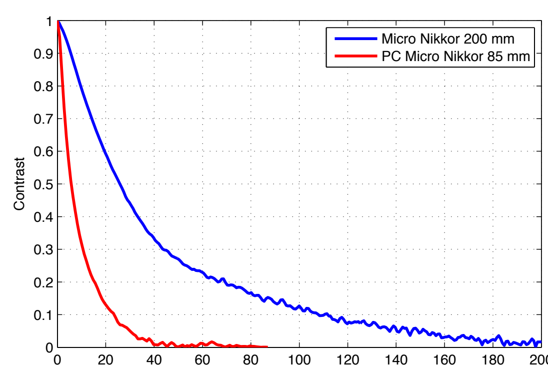

Figure 4: Comparison of the spatial frequency response curves for the two optical systems.

It should be noted that these figures have been obtained by imaging incoherent white light shining through a very thin resolution target. A lower resolution is expected for the measurement of electron beams in the accelerator, based on

[3] Sony ICX274AL

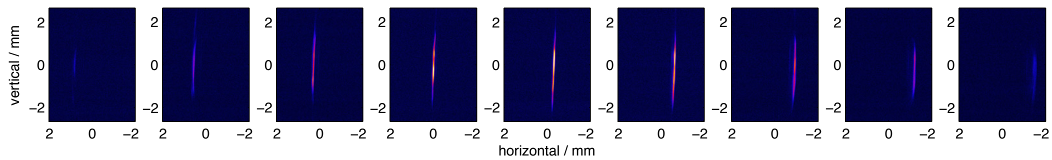

Figure 5: Propagation of a beam through a slit. The slit is scanned across the beam to measure the emittance.

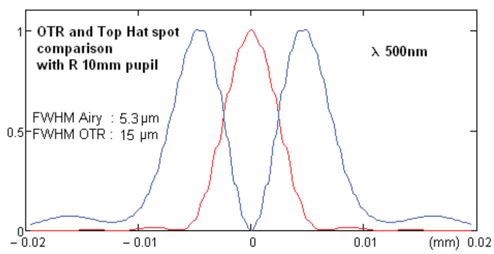

Figure 6: Comparison of the resolving power of an ideal lens, when illuminated by optical transition radiation (blue) and by uniform light (red). The resolution of the uniformly illuminated lens is about a factor of three better.

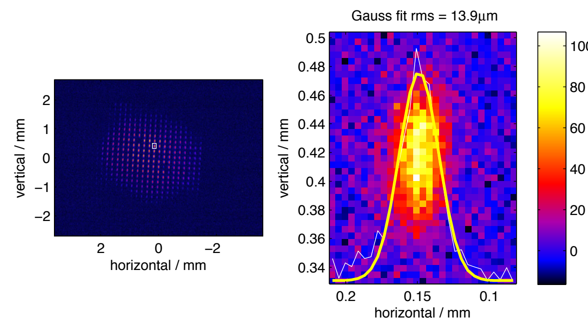

Figure 7: Image of the electron beam after a pepper pot, i.e., a pinhole array that separates the beam into small beamlets for emittance measurement at low energies.

two effects: (1) the finite thickness of the scintillator, seen under an angle of 45°, and (2) the angular distribution of OTR light.

To evaluate the consequence of the emission characteristics of the light on the resolution, an ideal lens was modeled numerically, both with a uniform illumination and with incoherent radiation that has an angular distribution according to the Ginzburg-Frank theory, using particle energies, beam sizes and imaging equivalent to the present setup in the SwissFEL Injector Test Facility. The resulting image of the OTR on the detector is about three times larger than the Airy disk that is expected for a uniformly illuminated lens (Fig. 6).

For SwissFEL, beam sizes around 10 µm are expected. We have therefore started development of an optical system that images OTR screens onto a detector according to the Scheimpflug criterion. Coherent emission of optical transition radiation is expected for compressed bunches. The effect is predicted to be strongest at long wavelengths. To maintain a maximum flexibility in the observation wavelength, we are designing a mirror system based on Schwarzschild optics, employing an electron multiplying CCD that is sensitive in the wavelength range of 200 to 1000 nm.

ELECTRON BEAM MEASUREMENTS

A few example images acquired during the initial commissioning of the SwissFEL Injector Test Facility have been presented. These include an image of an electron beam intercepted by a slit (Fig. 5). The slit, with a width of 20 µm, is made from 1 mm thick tungsten and achieves good stopping power at an energy of 7 MeV. An image of the electron beam passing through a pinhole array (pepper pot) indicates that resolutions below 14 µm rms are achievable in practice (Fig. 7). The analysis of these images is presented in [4].

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