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MEASUREMENT OF TRANSVERSE PROFILE IN ELECTRON LINACS: RECENT ADVANCES IN SwissFEL

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Abstract

The measurement of transverse profiles of the electron beam is key to measuring and optimizing the emittance of a linear accelerator. Also, transverse profile monitors are used in conjunction with an RF transverse deflecting structure (TDS) to measure bunch length and slice emittance. An RF deflector and a profile monitor behind the undulator can furthermore be used to reconstruct the FEL pulse profile. Here, we give an overview on recent advances in beam profile measurements at SwissFEL, including scintillating screens as well as wire scanners. The goal of these advances is the improvement of the resolution in both screens and wire scanners, both by improving the optics, and by improved data processing. Furthermore, we are exploring the possibility to do non-invasive wire scans with micrometer-size wires.

INTRODUCTION

When setting up and operating an accelerator, one needs to measure and optimize the phase space distribution of the electron beam. No tool exists to directly measure the 6-dimensional (x, x', y, y', E, t) phase space distribution of the particles. Instead, we use beamline elements to rotate the phase space and subsequently make projections on one-dimensional or two-dimensional subspaces. Examples for such beamline elements are:

- A dipole magnet to map the the energy axis onto a transverse dimension.
- Quadrupoles and skew quadrupoles for transverse phase space transformations.
- An RF transverse deflecting structure or a corrugated wakefield structure to map the time axis onto a transverse dimension.

We use transverse profile monitors, for example, wire scanners, or screen monitors, to measure the distribution in the x, y, or (x, y) sub-spaces. The performance of these monitors is therefore at the core of phase space measurements, and the present manuscript will focus on accurate transverse measurements. For emittance-measurement methodologies at SwissFEL, see Prat et al., [1] and Prat and Aiba, [2]; for TDS-based longitudinal diagnostics, see Craievich et al., [3]; for wakefield-based longitudinal diagnostics, see [4] and [5]. We have established 5-dimensional phase space reconstruction at SwissFEL, following a method demonstrated at DESY [6], and we are working on the full 6-dimensional reconstruction.

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CONTINUED DEVELOPMENT OF BEAM PROFILE MONITORS IN SwissFEL

The instrumentation developed for the commissioning of SwissFEL was continuously improved during its operation in recent years. The goal is to improve resolution, reliability, and to make progress towards minimally invasive measurements.

Wire Scanners

Wire scanners at SwissFEL were designed as high-resolution, quasi-non-destructive beam diagnostics. These systems employ a beam-synchronous data acquisition system to mitigate the effects of shot-to-shot jitter by correlating the scattered particle signal with the wire position, as determined by an encoder, and the beam charge and root-mean-square (rms) position measured by beam position monitors (BPMs) [7].

Improved resolution and reduced beam impact can be achieved through the use of wires fabricated via electron beam lithography and photolithography [8]. By combining measurements from wires positioned at multiple angles, a reconstruction of the four-dimensional (x, x', y, y') phase space distribution is possible [9].

Screen Monitors

Screen monitors in SwissFEL utilize a cerium-doped yttrium aluminum garnet (Ce:YAG) crystal imaged onto a CMOS image sensor via an objective lens. An angled screen insertion minimizes depth-of-field blur and avoids contamination from coherent optical transition radiation [10].

The sensitivity of these monitors is adjusted by inserting neutral density filters into the optical path. Initially, gelatin filters were used. These were found to unnecessarily degrade optical resolution. This degradation was most severe when the beams were most dense and therefore smallest. The gelatin filters of the screen monitors at the most relevant locations in SwissFEL have thus been replaced with glass filters. These filters do require re-focusing after each filter change, but they result in an improved resolution of 14.3 µm [11].

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ONGOING WORK TO IMPROVE BEAM PROFILE MONITORS IN SwissFEL

Wire Scanners

Current research focuses on optimizing wire scanner performance through material studies and investigations into beam invasivity (see Fig. 1). Aluminum and tungsten wires are currently employed in standard wire scanners, while gold and silicon nitride wires are utilized in nano-fabricated test configurations. The robustness of these materials during accelerator operation is being evaluated, revealing that wire destruction can occur not only from direct electron beam interaction, but also from induced currents generated by radio frequency (RF) fields from the accelerating cavities. The thin wires act as antennas, and identifying locations with sufficiently low RF field strength is crucial.

The development of wire scanners with a wire diameter below 5 micrometers is pursued, with the goal of enabling non-invasive measurements for routine verification of beam optics and emittance during user operation. Preliminary results indicate that minimizing the effect on FEL performance is achievable through the use of such thin wires, and various materials and manufacturing techniques are under investigation.

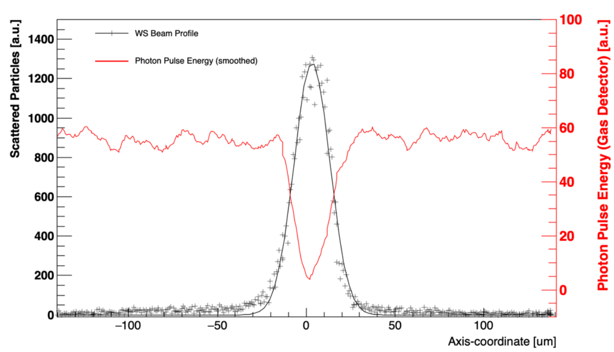

Figure 1: Beam-synchronous measurements of FEL pulse energy (red line) and electron beam profile (black crosses) reconstructed using a 12.5 µm diameter Al wire.

Screen Monitors

Efforts are underway to improve the reliability of screen monitor focusing and to enhance the reconstruction of the particle distribution from the acquired images. Initial screen monitors were equipped with fixed focus mechanisms adjusted manually during installation. Newer monitors, incorporating glass filters, feature motorized focus control. However, a more robust and reliable focusing method is required, particularly following maintenance procedures that necessitate removal of the camera boxes (e.g., during vacuum chamber bakeout). This is especially critical for the new screen stations, located at the end of the accelerator, where high resolution is paramount for optimization and operation.

The spectrometer screens at the end of the accelerator were found to need a larger field of view for the observation of the streaked electron bunches, necessitating a new design of the screen monitor that preserves the high resolution, but also increases the screen area (See Fig. 2). This design has recently been implemented and is now in standard use at the Athos beamline. It is very helpful for the characterization of new beam modes that are being developed at the SwissFEL soft X-ray branch. The new set-up necessitated the redesign of the scintillator holder, a longer optical path to a larger mirror, while preserving the overall optical path to the lens-and-camera setup.

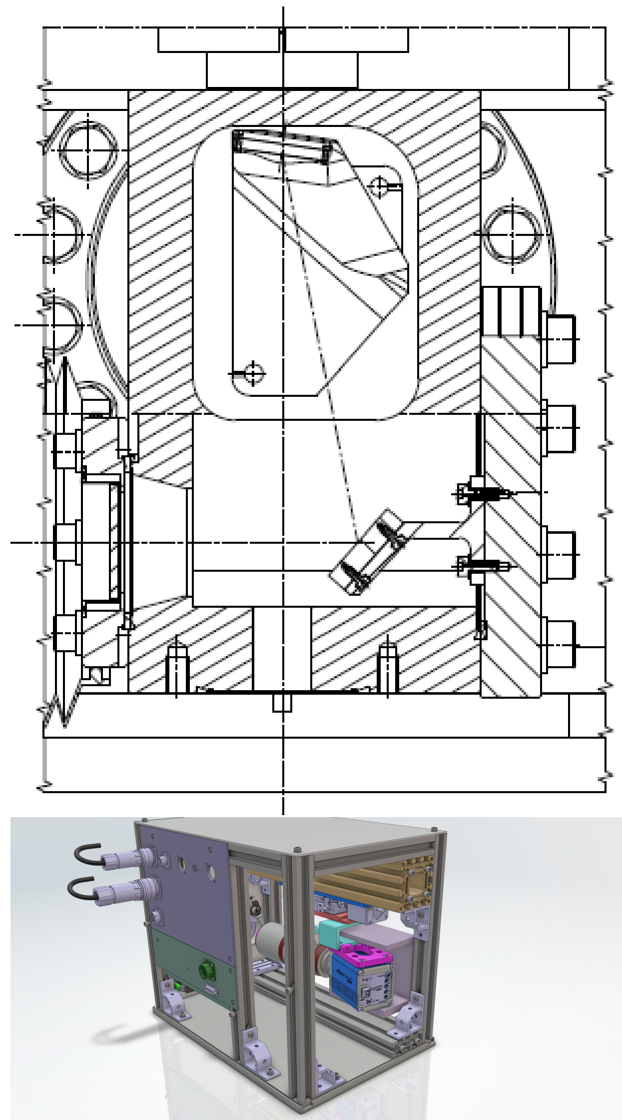

Figure 2: A screen monitor with a larger field of view, featuring a different scintillator/mirror geometry, and a redesigned optics box setup.

We are aiming at further improving the resolution of the screen monitors. To this goal, a neural network is being trained to reconstruct the electron distribution from images affected by the limited resolution of the system. This reconstruction will account for both the contribution from

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the scintillating crystal and the visible light optics, utilizing the resolution determined in [11] and assuming a Gaussian point spread function. A system with an additional camera, featuring smaller pixels, has been installed in SwissFEL, allowing to test the limits of the reconstruction (Fig. 3). The deconvolution of the optical resolution with a neural network has been shown to be superior to classical deconvolution algorithms [12].

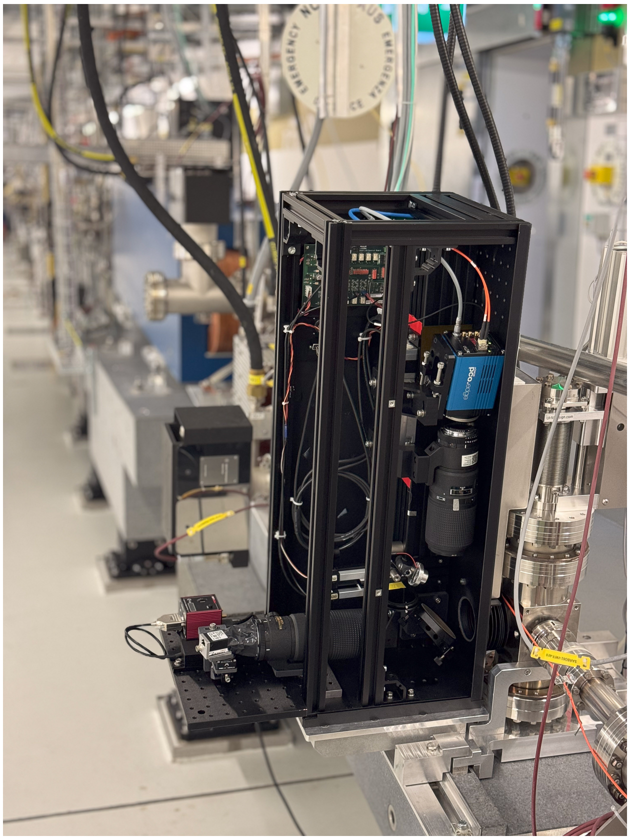

Figure 3: A second camera with smaller pixels was installed in one screen monitor to assess the performance of neural networks for image deconvolution.

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