BEAM PROFILE MEASUREMENTS AND ANALYSIS AT FLASH

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Abstract

FLASH (Free Electron LASer in Hamburg) is a SASE FEL user facility at DESY, Hamburg [1]. It serves also as a pilot project for the European XFEL.

Although the slice emittance is a more appropriate parameter to characterize the SASE process, the projected emittance is a good indicator of the electron beam quality which can be measured in an easy and fast way.

In this paper we present measurements of the projected emittance along FLASH. We also analyze the effect of the dispersion on transverse electron beam profiles.

INTRODUCTION

Figure 1 shows a schematic layout of FLASH. A laser-driven RF gun generates electron bunches with a nominal charge of 1 nC. The electrons are accelerated up to 700MeV in five TESLA superconducting modules, each of them containing eight accelerating cavities. The required longitudinal compression of the beam is done in two bunch compressor chicanes. In order to protect the undulator permanent magnets against radiation damage, the electron beam passes through a collimator before entering the undulator section. The undulator consists of six segments with a length of 4.5 m each.

Emittance measurements

For the emittance determination, the transverse beam distribution is measured at different positions. Using the transport matrices between the different measurement points, the emittance and the Twiss parameters are obtained by fitting the measured beam sizes. A detailed description of the emittance measurement procedure is in [2].

At FLASH, there are two dedicated places for measurements of projected emittance. The first one is after the first bunch compressor (~130 MeV), and consists of a FODO lattice with 4 OTR screens and wire-scanner stations. In this paper we refer to it as BC section. The second one is placed between the collimator and the undulator (full beam energy). In this location, referred here as seed section, there is a FODO lattice with 4 OTR monitors. In addition, a fifth OTR monitor placed upstream of the FODO lattice can be used for the emittance measurements. The different emittance measurement locations are indicated in Figure 1. In addition, seven wire-scanner stations placed between the undulator segments allow multi-monitor emittance measurements in this section. Figure 2 shows a sketch of the undulator section.

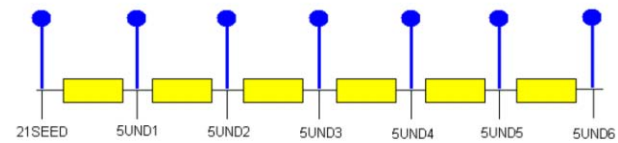

Figure 2: Undulator section sketch. The wire-scanner stations are indicated.

EMITTANCE TRANSPORT

At different times, the projected emittance has been measured in the BC and seed sections and inside the undulator. Since the interest was focused in the transport of the emittance through the machine, not much time was spent on optimizing the initial emittance. A detailed description of emittance measurements and results in BC section can be found at [3]. Nominal normalized projected emittance is 2 μm.

Table 1: Results of projected emittance measurements at FLASH. The values shown are normalized rms emittances for 100% and 90% (in brackets) beam intensities

Day / Area	21-01-2007		17-02-2007	
	ε_x [μm]	ε_y [μm]	ε_x [μm]	ε_y [μm]
BC	3.7 (2.0)	3.2 (2.0)	3.7 (2.4)	3.8 (2.5)
Seed	3.7 (2.2)	4.7 (3.2)	2.7 (2.0)	3.0 (2.2)
Undulator	4.4	4.1	4.3	4.4

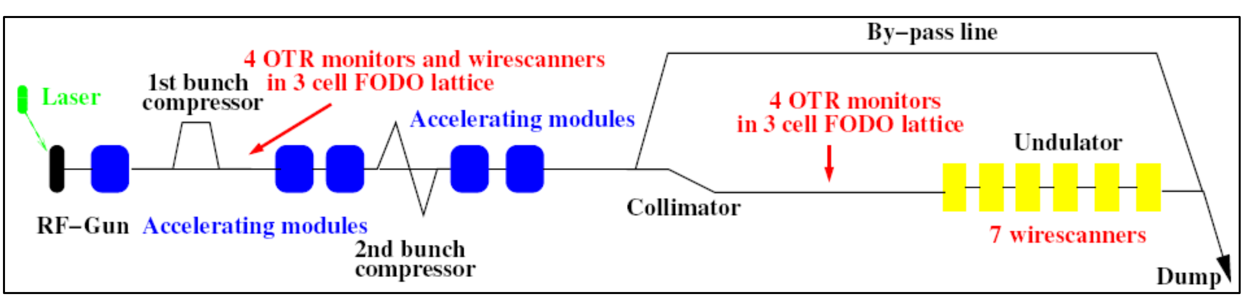

Figure 1. Schematic layout of FLASH (not to scale). Total length is about 250 m. Locations of the diagnostic sections for emittance measurements are indicated.

Table 1 shows the results of emittance measurements performed along the FLASH linac in two different days. The measurements at BC were done using OTR screens. The beam sizes are the rms values of the entire beam intensity. In addition, to reduce the influence of a beam halo, rms values of ninety percent of the beam intensity are quoted in brackets. The intensity cut is performed in the (two-dimensional) image by removing the lowest intensity tails. In all the cases, the electron beam charge was 1 nC, the beam went on-crest through all the accelerator modules and the final beam energy was around 500 MeV.

An analysis taking into account errors in the beam size, in the energy and in the transfer matrices leads to an error estimation of the measured emittance of about 0.5 μm.

As indicated in Table 1, similar normalized emittances were obtained along FLASH for the two measurement days. No substantial change in emittance along the linac is observed. Similar results have been obtained in other measurement days when the machine has been well-tuned.

Notes about the measurements in the undulator

The calculation of the emittance and Twiss parameters in the undulator is bad conditioned. For typical operation settings, the matrix condition number in the undulator section is an order of magnitude larger than at BC. As a consequence, the same error of the measured beam sizes leads to one order of larger errors in the determination of the second moments of the beam (used for calculation of emittance and Twiss parameters) [4]. This makes the optics matching in the undulator difficult. Matching works better when the beam sizes for the emittance and Twiss parameters calculation are obtained doing a Gauss fit to the transverse beam distribution (i.e. instead of using rms beam sizes). Using more quadrupoles with smaller gradient changes and cycling the magnets after each iteration also help to improve the matching in the undulator.

Three different wires can be used for each of the seven wire-scanner stations in the undulator section: 50 μm tungsten, 10 μm tungsten and 10 μm carbon. The photon shower generated when an electron hit the wire is proportional to the square of the wire diameter d and to the square of the atomic number of the wire material A; i.e., proportional to $d^2 \cdot A^2$. Therefore, the input light going to the photomultiplier for the 50 μm tungsten wire is 25 times larger than for the 10 μm tungsten wire and 950 bigger than for the 10μm carbon wire. Due to this fact, the photomultiplier has a non-linear behaviour when Tungsten wires are used, leading to an increase of the measured beam sizes and therefore to an increase of the calculated emittance. A filter with an attenuation factor of 32 has been recently placed in front of the photomultipliers in order to overcome this problematic. Note that emittances in the undulator presented at Table 1 correspond to measurements using the 10 μm carbon wire. In former measurements using the 50 μm tungsten wires (without filters) we have typically measured emittances between 20 and 30 μm.

DISPERSION EFFECTS

Dispersion generation

In order to generate horizontal dispersion in the undulator, the current of the quadrupoles in the collimator section was decreased by 10%. That resulted in an R_{16} of 140 mm rms in the undulator section. Figure 3 shows the measured and simulated R_{16} in the undulator. The measurement was performed by changing the gradient of the last two accelerator modules (ACC45). A good agreement except at the BPM 5UND4 is observed. Simulations have been done using elegant [5].

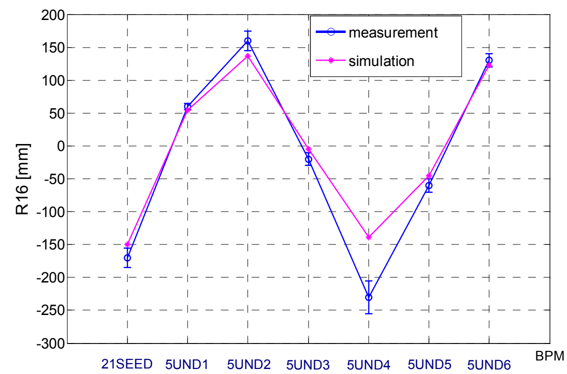

Figure 3: Measured and simulated R_{16} in the undulator.

In general, an increase of the transverse beam size proportional to the dispersion increase was observed. For instance, while the beam size was strongly increased at 5UND2, 5UND4 and 5UND6 – where dispersion was large; the beam size remained approximately constant at 5UND3 – where the dispersion did not increase.

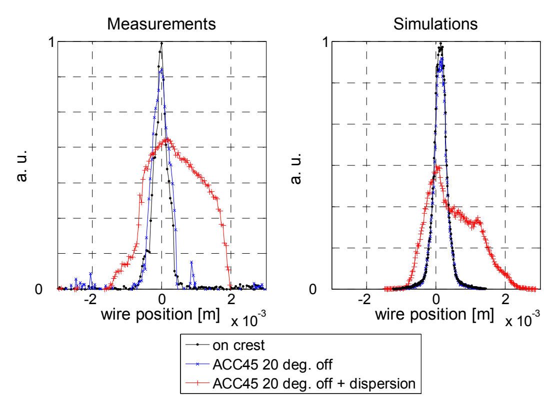

Figure 4: Measured (left) and simulated (right) beam profiles at the wire-scanner 5UND6.

Figure 4 shows the measured and simulated beam profiles at 5UND6 for three different conditions: on-crest at all the accelerator modules, 20 degrees off-crest at ACC45 and 20 degrees off-crest at ACC45 with the extra dispersion generated. The measured profiles have been shifted in order to remove steering effects which were not completely compensated. Measurements were performed with the 50 μm tungsten wire. Simulations have been done from the exit of the first accelerator module to the end of the undulator using elegant. A distribution of 10^5 particles obtained from ASTRA [6] for standard conditions has been used as an input beam.

In both measurements and simulations, there are no significant differences between on-crest and off-crest conditions, and there is a strong increase of the beam size when the additional dispersion is generated. A qualitative agreement between measurement and simulations of the beam shapes is observed.

Dispersion correction

Figure 5 shows the R_{16} measured from the accelerator module ACC45 before and after applying a dispersion correction. In the undulator section R_{16} was reduced from 22 to 4 mm rms. Dispersion correction was done as described in [7].

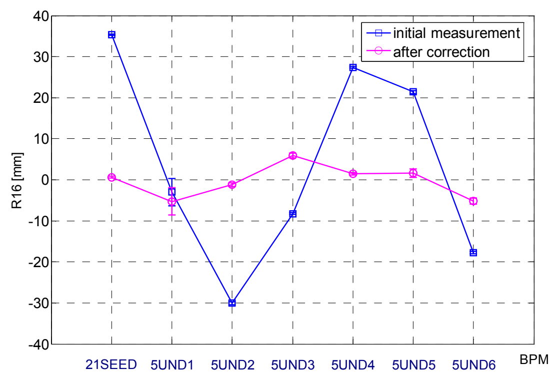

Figure 5: R_{16} in the undulator before and after dispersion correction.

Emittance was measured in the undulator section before and after the dispersion compensation. Beam sizes were measured at four different wires: 21SEED, 5UND1, 5UND2 and 5UND3. A significant decrease of the beam size was observed at the points were R_{16} was reduced (i.e. 21SEED and 5UND2) while the beam size remained approximately constant where R_{16} was not reduced (i.e. the points where initial R_{16} was already small: 5UND1 and 5UND3).

Normalized projected emittance was reduced by approximately 20%, decreasing from 5.8 μm to 4.7 μm. All the accelerator modules were operating on-crest. When FEL radiation is produced, the electron beam is accelerated off-crest leading to a larger energy spread. Therefore, in lasing conditions we would expect a larger impact of the dispersion correction on the projected emittance.

Figure 6 shows the beam profile measured at the wire-scanner 5UND2 before and after correcting the R_{16}. Due to the dispersion correction, the shoulders which appeared at the initial measurement vanished. The beam size was decreased from 252±7 μm up to 183±20 μm (i.e., a reduction of 27%)

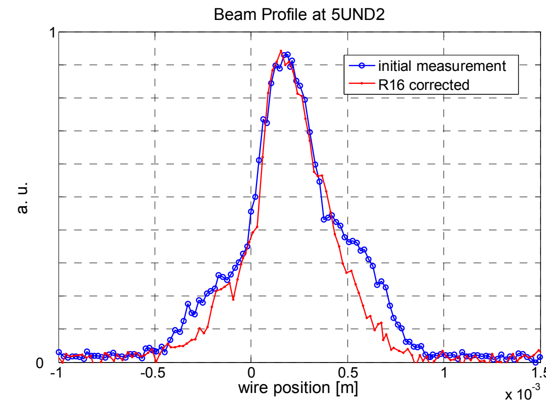

Figure 6: Beam profile measurement at wire-scanner 5UND2 before and after dispersion correction.

SUMMARY AND OUTLOOK

Projected emittance measurements along FLASH have been presented. Similar values have been obtained from the injector up to the undulator section. Effect of the dispersion on the beam profiles and emittance in the undulator section has been studied as well.

During spring and summer 2007 FLASH is being upgraded. With the installation of a new accelerator module, the electron beam will have an energy up to 1 GeV. During the shutdown, we have improved emittance measurement set-up in the seed section by replacing the OTR monitors by combined OTR and wire-scanner monitors. Attenuation filters have been installed in each wire-scanner station.

For the next measurement period, we will continue the studies on emittance transport. We also plan to analyze the impact of the wakefields and the couplers of the accelerator modules by applying trajectory bumps through the accelerator structures.

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