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BEAM OPTICS MEASUREMENTS AT FLASH2

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Abstract

FLASH2 is a newly build second beamline at FLASH, a soft X-ray FEL at DESY, Hamburg. Unlike the existing beamline FLASH1, it is equipped with variable gap undulators. This beamline is currently being commissioned. Both undulator beamlines of FLASH are driven by a common linear accelerator. Fast kickers and a septum are installed at the end of the linac to distribute the electron bunches of every train between FLASH1 and FLASH2. A specific beam optics in the extraction arc with horizontal beam waists in the bending magnets is mandatory in order to mitigate effects from coherent synchrotron radiation (CSR). We performed various beam optics measurements to ensure that the conditions for FEL operation at FLASH2 are fulfilled. Here we will show results of measurements.

INTRODUCTION

The existing superconducting single-pass high-gain SASE FEL FLASH (Free-electron LASer in Hamburg) at DESY, Hamburg [1] delivers photons in the wavelength range from 4.2 nm to 52 nm. The photons generated in the fixed gap SASE undulators can be delivered to five experimental stations one at a time. A second undulator beamline was attached to the linac during the last three years and is now under commissioning [1, 2]. The FEL will continue to be referred as FLASH and the two beamlines are named FLASH1 and FLASH2. Fast kickers and a DC Lambertson-Septum, installed behind the FLASH linac, allow to distribute the beam either to FLASH1 or to the extraction arc leading to FLASH2. The final angle between FLASH1 and FLASH2 is 12°. Strong bending magnets in the extraction arc require specific Twiss functions in order to mitigate emittance growth due to CSR [2, 3]. The FLASH2 undulator beamline is equipped with variable gab undulators [4] for SASE and reserves space for future seeding options. The extraction to a proposed third beamline hosting a plasma wake field experiment is considered in the beamline layout at the end of the FLASH2 arc.

DISPERSION MEASUREMENT AND MATCHING

The linear dispersion describes the derivative of the transverse beam position w.r.t. the relative momentum offset:

$$\eta_{x,y} = \frac{\Delta(x, y)}{\Delta p/p_0} \tag{1}$$

where $\eta_{x,y}$ describes the dispersion in horizontal or vertical plane, $\Delta(x, y)$ is the horizontal respectively the vertical beam offset caused by the dispersion and $\Delta p/p_0$ is the relative momentum offset.

In the extraction arc leading to the FLASH2 undulator beamline the beam is deflected in horizontal plane. However, due to the use of a Lambertson septum that requires a vertical offset – realized with two vertical kickers and additional kicks applied by quadrupole magnets – the vertical dispersion in the FLASH2 extraction arc is not zero. The extraction was designed such that the dispersion in each plane is closed after the last bending magnet deflecting in that plane. The FLASH2 design dispersion functions are shown in the lower plot in Fig. 1.

Two methods for closing the dispersion were quickly identified: First, one can adjust the strength of the dipoles in the extraction arc or, secondly, one can change the focusing strength of the quadrupole magnets in the dispersive section. However, both methods come along with a large number of possible optimization variables. It would be preferable to have a solution with a small number of parameters that can then be scanned until the (horizontal) dispersion is closed.

The results from different beam energy models in FLASH (the vector sum of the accelerating modules and two different models employing dispersive measurements) are not fully consistent. Thus a potential energy scaling error is an obvious candidate for causing the major part of the residual dispersion leaking out of the extraction arc. A wrong scaling of the main magnets plus steerer corrections to hit the reference trajectory can lead to spurious dispersion from the arc.

The approach is to correct the energy scaling of the extraction arc which will automatically close the dispersion of the arc. The only optimization parameter in this procedure is the design beam energy. We setup the arc for different beam energies within a range of ± 10 MeV and measured the horizontal dispersion (which is large than the vertical). This was repeated until the dispersion was closed. Since this method is convenient and since it worked, it is now the default procedure to close the horizontal dispersion in the FLASH2 extraction arc.

The plots in Fig. 2 show the results of the dispersion measurement after the optimization procedure was completed. As one can see the vertical dispersion is not perfectly closed but the remaining dispersion is small. It is planned to correct this in future measurements with the two vertical dipoles installed downstream the last horizontal bends or with quads located at positions were the horizontal dispersion is already closed.

BEAM OPTICS MEASUREMENT AND MATCHING

The design beta functions of the FLASH2 beamline including the injector, the linac, the extraction arc, the matching section as well as the undulator section are shown in the upper plot in Fig. 1.

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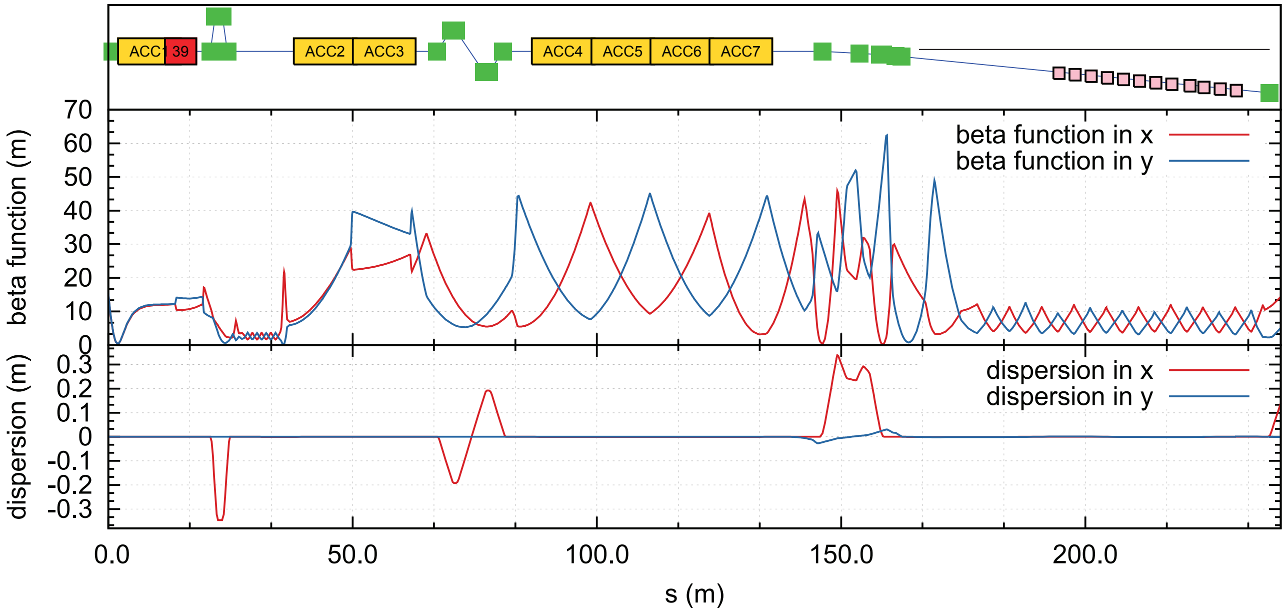

Figure 1: The FLASH2 design beta functions and the corresponding dispersion in both planes. Both plots show all sections of the electron beamline including the injector, the linac, the extraction arc, a matching section as well as the undulator.

The beam sizes in FASH2 can be measured with four screens located upstream the undulator [5]. With the results from these measurements we calculate the Twiss functions at the position of the first screen and compare them with the design values. Typically, the mismatch between the measured and the design functions is described with the mismatch amplitude:

$$m_{\text{amp}} = m_{\text{par}} + \sqrt{m_{\text{par}}^2 - 1} \tag{2}$$

with the mismatch parameter

$$m_{\text{par}} = \frac{1}{2}\left(\tilde{\beta}\gamma - 2\alpha\tilde{\alpha} + \beta\tilde{\gamma}\right), \tag{3}$$

and the design Twiss parameters α, β and γ as well as with the Twiss parameters calculated from the measurements $\tilde{\alpha}$, $\tilde{\beta}$ and $\tilde{\gamma}$. Starting with mismatch amplitudes better than 2, we manage to match the Twiss parameters to mismatch amplitudes below 1.1 in both planes typically within five iteration steps. We use usually five quadrupole magnets to match the beam optics, which are all installed downstream the extraction arc. The plots in Fig. 3 show the beta functions at the start and at the end of a matching progress as well as the design beta functions. The plots are separated in the horizontal (upper plot) and the vertical plane (lower plot). The plots include the extraction arc, the matching section as well as a part of the periodic FODO which continuous through the undulator.

It is also planned to apply optical response measurements (ORM) in the FLASH2 beamline as they are successfully established in the FLASH linac as well as in the first beamline [5,6].

CONCLUSIONS

The two beam optics measurements which were described in this paper are important tools to ensure optimum beam quality for the FEL operation in FLASH2. Especially during the currently ongoing commissioning of the new beamline.

We found a solution how we can close the horizontal dispersion at the end of the extraction arc that needs only one optimization parameter. The final optimization of the vertical dispersion will be done in the future with two dedicated vertical bending magnets and quadrupole magnets installed downstream the last horizontal dipole magnets of the extraction arc where the horizontal dispersion is closed.

The established beam size measurement procedure in the FLASH2 beamline works as planned and we are able to match the beam optics with the four screens down to a mismatch amplitude smaller than 1.1 in both planes.

With the achieved good electron beam quality we managed to get first lasing in FLASH2 in August 2014 [7].

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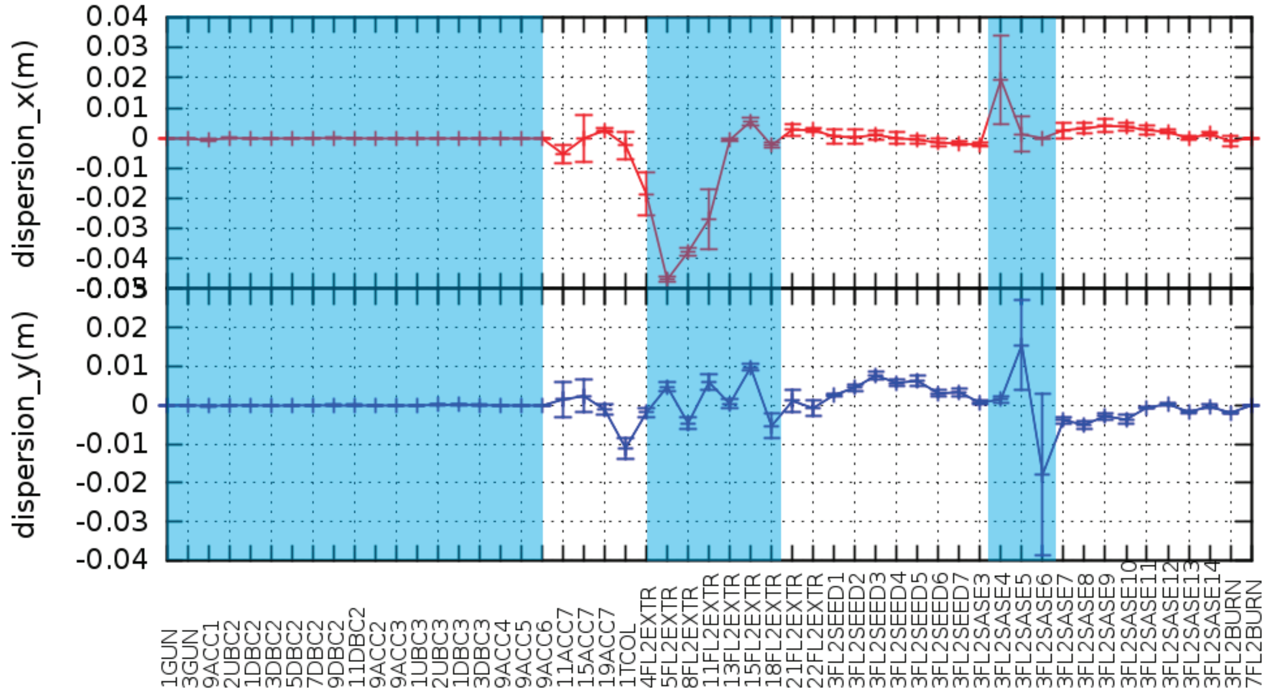

Figure 2: The plots show the dispersion functions in the FLASH linac, the FLASH2 extraction arc and in the FLASH2 beamline. The beam position monitors marked with a blue background could not be used for the pictured measurement. Either because of the fact that those are upstream the accelerating modules, which were used for the energy modulation or due to problems with diagnostic electronics (which are now solved). One can see that there is some spurious dispersion at the end of the linac but the horizontal dispersion of the extraction arc is closed. The vertical arc dispersion is slightly larger than the horizontal and has to be corrected further in future approaches.

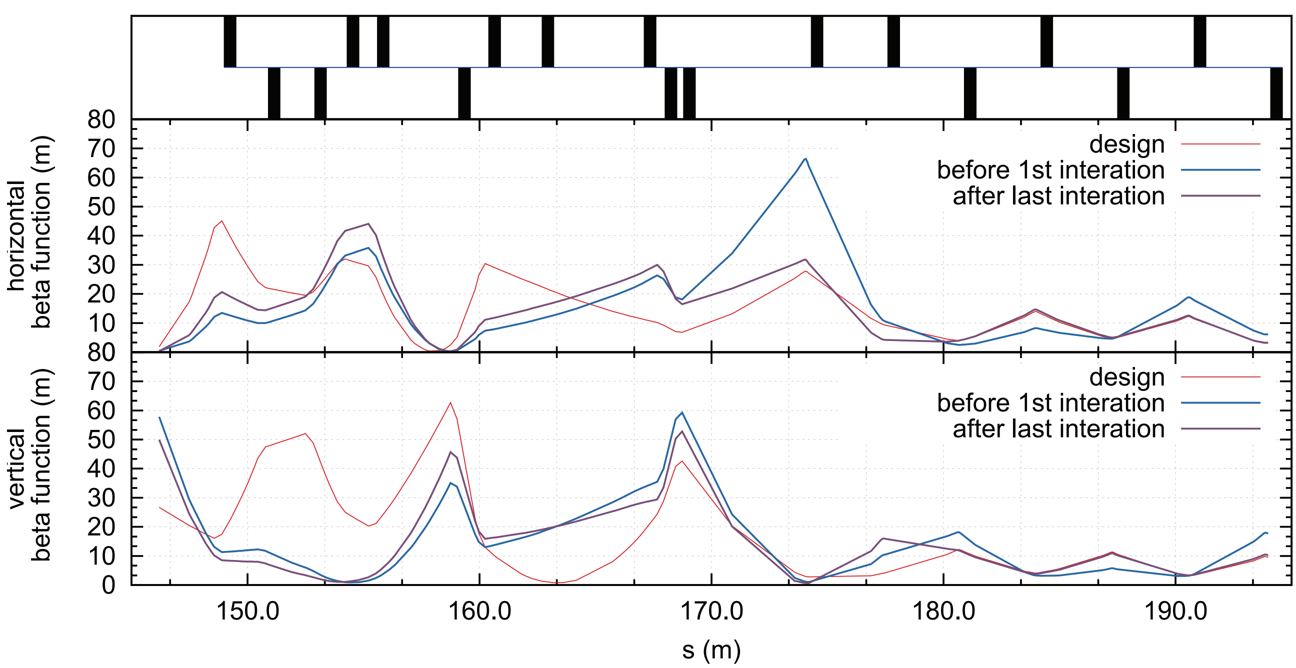

Figure 3: The horizontal and vertical beta function in the FLASH2 extraction arc and in the following matching section. The upper plot shows the horizontal plane and the lower plot the vertical. The red lines describe the design beta functions, the blue lines the reconstructed beta functions after the first optimization iteration and the purple lines represent the functions after the optimization was completed.