OPTICS MEASUREMENTS AT FLASH2

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Abstract

FLASH2 is a newly build second beam line at FLASH, the soft X-ray FEL at DESY, Hamburg. Unlike the existing beam line FLASH1, it is equipped with variable gap undulators. This beam line is currently being commissioned. Both undulator beam lines 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 optic in the extraction arc with horizontal beam waists in the bending magnets is mandatory in order to mitigate CSR effects. Here we will show first results of measurements and compare to simulations.

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 45 nm. The photons generated in the fixed gap SASE undulators can be delivered to five experimental stations one at a time. A second undulator beam line was attached to the linac during the last three years and is now under commissioning [2]. The FEL will continue to be referred as FLASH and the two beam lines are named FLASH1 and FLASH2. Fast kickers and a DC Lambertson-Septum are 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 coherent synchrotron radiation (CSR) [2, 3]. The FLASH2 undulator beam line is equipped with variable gab undulators [4] for SASE and reserves space for future seeding options. The extraction to a proposed third beam line hosting a plasma wake field experiment is considered in the beam line layout at the end of the FLASH2 arc.

In this paper, we will describe the first optics and dispersion measurements and the matching of the these functions to the design values in a diagnostic section upstream of the FLASH2 undulators.

DISPERSION MEASUREMENT AND MATCHING

The dispersion describes the dependence of the transverse position on the relative momentum offset.

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

With the dispersions $\eta_{x,y}$, the positions x, y and the relative momentum offset p/p_0. The design dispersion functions of FLASH2 can be found in Fig. 2. In order to minimize the distortion of the centroid trajectory through non-linear dispersion, the measurement should be performed using bunches with minimized energy spread. Since the RF systems are capable of splitting their 800 μs long flat tops between FLASH1 and FLASH2, this can be achieved to a large extent for FLASH2 while FLASH1 is in SASE operation [5]. We measured the horizontal beam offset at four different BPMs [6–10] downstream the extraction while changing the beam energy with the accelerating Module ACC45 of the linac. A MATLAB [11] script was used to control the measurement, to change the gradients of the accelerating module and to read the beam positions from the BPMs. The beam energy was changed during the procedure in 10 steps from 551.7 MeV to 554.7 MeV. The dispersion matching was carried out with a linac version of MAD8 [12, 13]. First, a setting of η_x and η'_x upstream the second last quadrupole in the extraction arc was searched fitting the measured dispersions at the four BPMs using the current machine settings. These values where then be used to close the dispersion in an optimization run using the last two quads in the extraction arc. After five iterations the procedure had converged. The data from the last measurement is presented in Fig. 1.

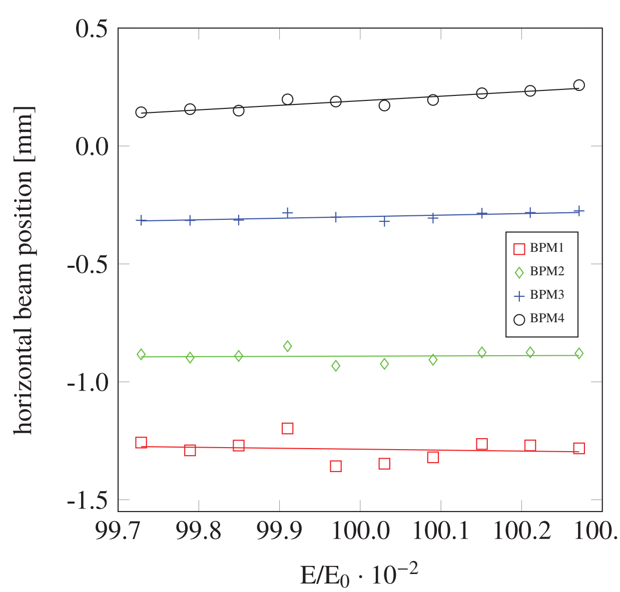

Figure 1: Results of the last dispersion measurement. This plot shows the horizontal beam positions at four different BPMs for different relative beam energies. The energy is normalized to E_0 = 552 MeV.

The final dispersion at the four positions was $\eta_{x,i}$ = [-4, 1, 7, 20] mm and the dispersion prime at the first BPM was calculated as $\eta'_{x,1} = 3.8 \cdot 10^{-4}$.

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ISBN 978-3-95450-133-5

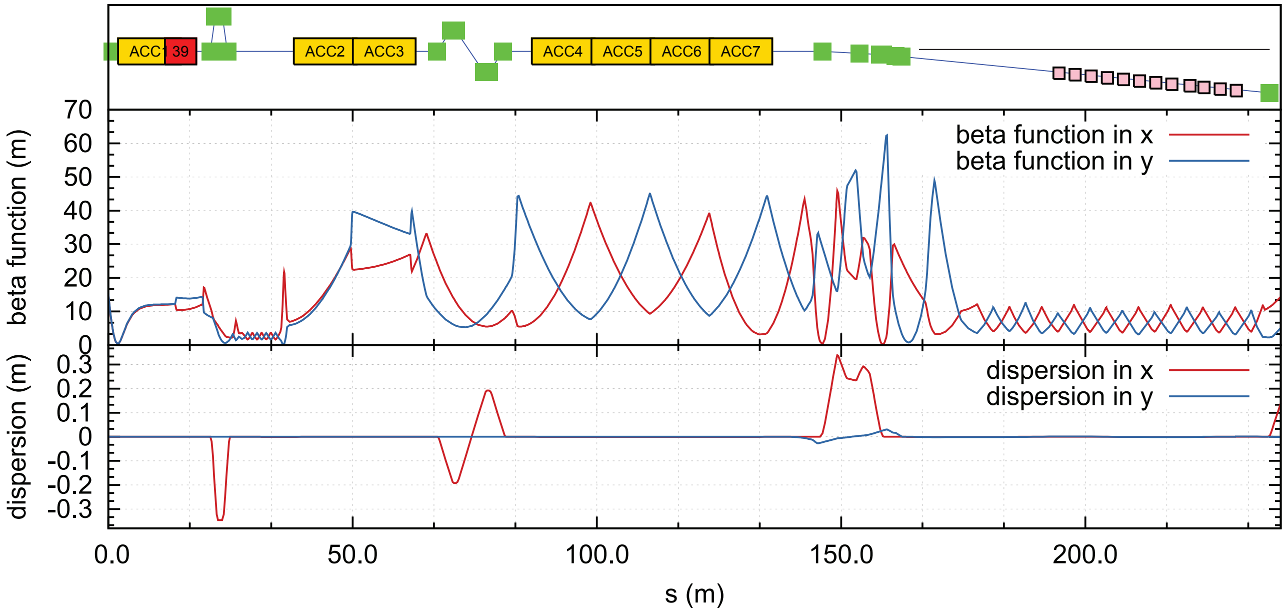

Figure 2: The upper plot shows the design optics of the FLASH2 beam line including the linac, the extraction arc and the undulator section. In the lower plot one can find the horizontal and vertical design dispersions in the two bunch compressors and in the FLASH2 extraction arc.

OPTICS MEASUREMENT AND MATCHING

We used fours OTR screens in a periodic FODO structure between extraction and the SASE undulators with about 30° phase advance in between to measure the Twiss functions and the transverse emittances of the beam [14]. The upper plot in Fig. 2 shows the design optics of the new beam line including the linac and the arc. The beam was on-crest for this measurement and the dispersion was closed as good as described above. The optics measurements were carried out using a suite of shell scripts for the communication with the control system of the FEL. The fits of the measurement data were made with gnuplot [15] and the matching of the Twiss parameters was again carried out with a linac version of MAD8. The match between the design optics and the measured beam optics can be described by the mismatch amplitude [2]:

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

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

with the mismatch parameter m_{par}, the design Twiss parameters α, β and γ and $\tilde{\alpha}$, $\tilde{\beta}$ and $\tilde{\gamma}$, the Twiss parameters of the measured beam. The mismatch amplitude describes the amplitude of the oscillation of an unmatched beta function around the design beta function. The range of the oscillation is $1/m_{\text{amp}}\,\beta \le \tilde{\beta} \le m_{\text{amp}}\,\beta$. After five iterations, the beam optics measurement procedure had converged. The start and end values for the mismatch amplitude can be found in Table 1. The beta functions in the matching section before and after the optimization as well as the design beta functions are shown in Fig. 3. The measured normalized transverse emittances were $\epsilon_{nx} = 6.9\,\mu$m rad and $\epsilon_{ny} = 3.0\,\mu$m rad and thus larger than expected. The first idea was to explain this with the remaining dispersion in the FLASH2 seed section but the following estimation shows that this effect is smaller. The effective emittance ϵ_{eff} including $\epsilon_\beta = \sigma^2/\beta$ as well as the contribution of the dispersion η can be calculated as follows [16]:

Table 1: Mismatch Amplitude of the Horizontal and Vertical Plane at Start and End of Matching Procedure

Mismatch Amplitude	Start	End
Horizontal	1.86	1.07
Vertical	1.99	1.07

$$\epsilon_{\text{eff}} = \epsilon_\beta + \frac{1}{2}\left(\gamma\eta^2 + 2\alpha\eta\eta' + \beta\eta'^2\right)\delta^2 \tag{3}$$

with the Twiss functions α, β and γ, the dispersion and dispersion prime η and η' as well as with the relative momentum deviation $\delta = \Delta p/p_0$. Using the matched Twiss parameters and the dispersion measured at the OTR, $\epsilon_\beta = 2\,\mu$m rad and $\delta = 5 \cdot 10^{-3}$ one obtains the expected normalized horizontal effective emittance which is $\epsilon_{\text{nx,eff}} \approx 3\,\mu$m rad. This apparent inconsistency suggests that either the energy spread of the beam or the initial emittance of the beam is larger than estimated.

CONCLUSIONS

We presented the results of the first dispersion and optics measurements in the new undulator beam line FLASH2

ISBN 978-3-95450-133-5

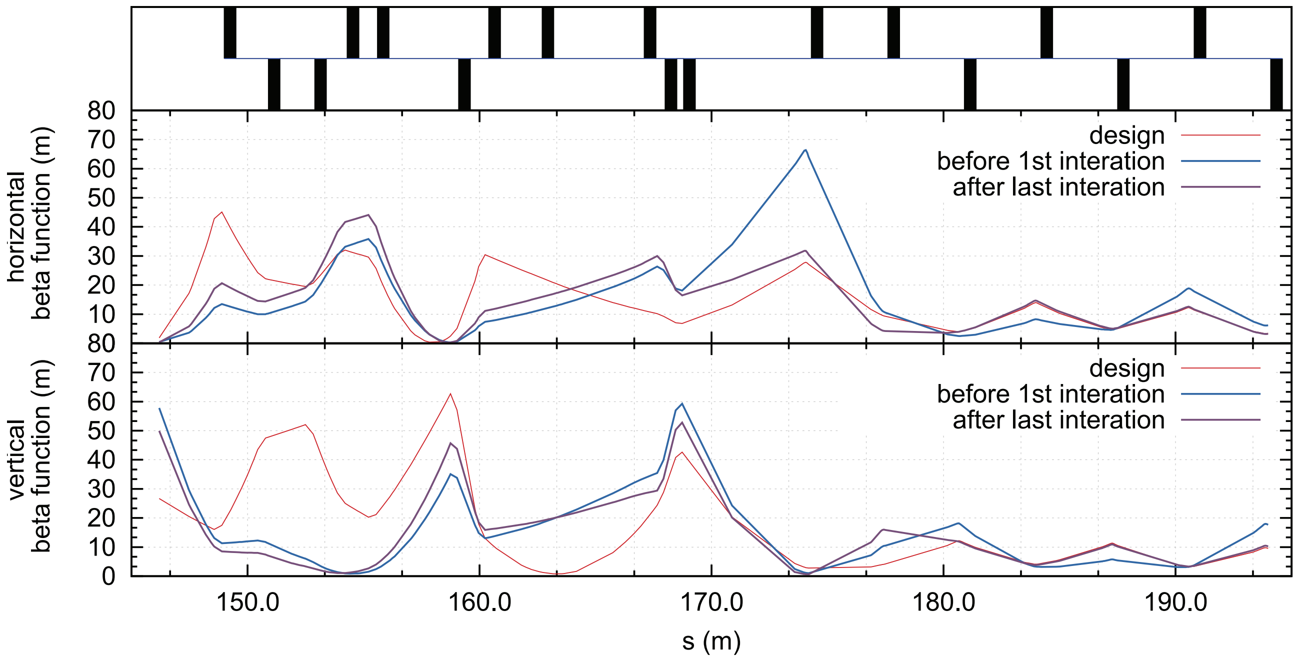

Figure 3: These plots show the design beta functions, the beta functions at the start of the matching and those at the end of this procedure. The latter match the design beta functions at the end of the seed section. The upper plot shows the horizontal plane and the lower plot the vertical plane.

and we showed that the used measurement and optimization tools work. The results were obtained while FLASH1 was in SASE operation. At the time of the measurement we did not have the diagnostic tools to verify during SASE operation in FLASH that the energy spread was completely minimized. This might had a certain degrading effects on the dispersion measurement. The closed dispersion and the matched beam in the FLASH2 beam line lead also to very small losses in the undulator section. With this beam we will start first lasing tests in the following weeks.

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