ELECTRON OPTICS AND MAGNETIC CHICANE FOR MATCHING AN XFEL-OSCILLATOR CAVITY INTO A BEAMLINE AT THE EUROPEAN XFEL LABORATORY

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Abstract

At DESY the European XFEL (X-Ray Free-Electron Laser) laboratory is currently under construction. Due to the time structure of its electron bunch trains it is in principle possible to run a FELO (Free-Electron Laser Oscillator) at the European XFEL. The major elements of a FELO are the cavity and the undulator. To couple the electron beam with the required beta functions into the cavity, a magnetic chicane and an appropriate focusing structure are considered. In this paper we discuss the lattice design of the magnetic chicane and the focusing section. We also present the results of the beam dynamics simulations performed.

INTRODUCTION

The XFELO concepts as described in [1] and [2] is predicted to offer performance complementary to a SASE (self-amplified spontaneous emission) based FEL. The described XFELO is based on an ERL (energy-recovery linac) and uses a crystal cavity to provide narrow band feedback of the undulator-radiation. The cavity consists of Bragg crystal mirrors which reflect only a narrow bandwidth of the x-rays in the desired direction and grazing incidence mirrors or compound refractive lenses (CRL) to control the modes inside the cavity. Since the European XFEL will be able to generate long bunch trains with a high repetition rate of the bunches it might be possible to adopt this concept for the European XFEL [3]. Compared to a SASE FEL the spectral bandwidth of the radiation of a XFELO is narrower by two to four orders of magnitudes and the longitudinal coherence of the radiation along the photon pulse is significantly larger. In order to bypass the mirrors with the electron beam and match it with the x-ray beam a magnetic chicane or the like and a focusing section are required. Since at DESY a XFELO concept is under consideration there is a need for a corresponding chicane and focusing section.

LAYOUT

The layout of the chicane and the focusing section is mainly determined by the required offset of the electron beam and by the desired twiss parameters inside the undulator. The offset has to be sufficient for the electrons to pass by the mirrors of the FELO cavity. Due to the relatively small diameters of the x-ray and electron beam, both in the range of tens of µm and the arrangement of the x-ray optics, an offset of 10 mm is sufficient. That allowed to design a chicane of 21 m length with a deflection angle of 0.1° without any focusing elements in between. Because of the symmetry of the chicane the dispersion is compensated automatically. In order to overlap the Gaussian x-ray and the electron beam inside the undulator properly a round electron beam with the waist in the middle of the undulator is required. In addition it is desired to keep the beta functions small to reduce beam distortions due to field errors of the magnets. It was investigated if these requirements are met by the scheme shown in Fig. 1. The focusing into the undulator is performed by quadrupoles before and after the chicane. With the deflection angle of 0.1° compression effects of the bunches are negligible.

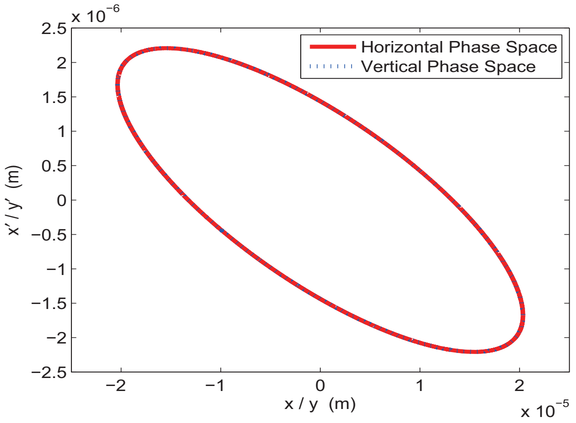

Figure 2: One-σ phase space ellipses in the transversal phase space at the entrance of the undulator. The two ellipses overlap.

Table 1: Beam Parameters

Parameter	Value
Electron energy	17.5 GeV
Bunch charge	1 nC
Bunch length (FWHM)	178 fs
Slice emittance (normalized)	1 µm
Slice energy spread	0.45 MeV

SIMULATIONS

The calculation of the electron optics were performed by using the code elegant [4]. The underlying beam parameters are shown in table 1. The initial α- and β-values

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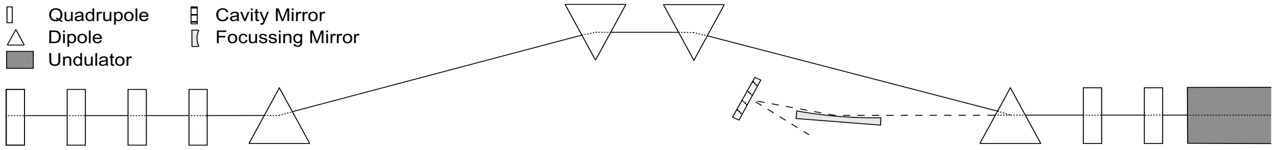

Figure 1: The scheme of the beamline. The black line represents the electron beam and the dotted line represents the x-ray beam. The shown mirrors are a part of the cavity.

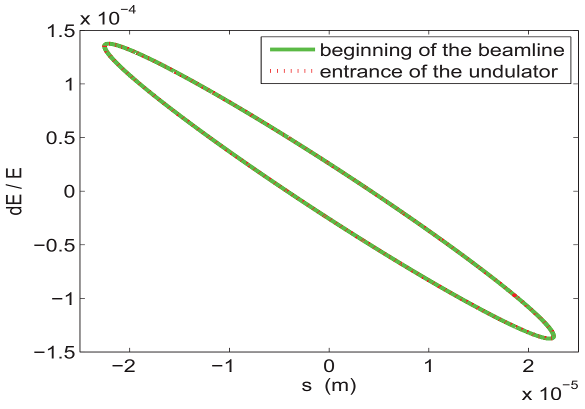

Figure 3: One-σ phase space ellipses in the longitudinal phase space at the beginning of the beamline and at the entrance of the undulator.

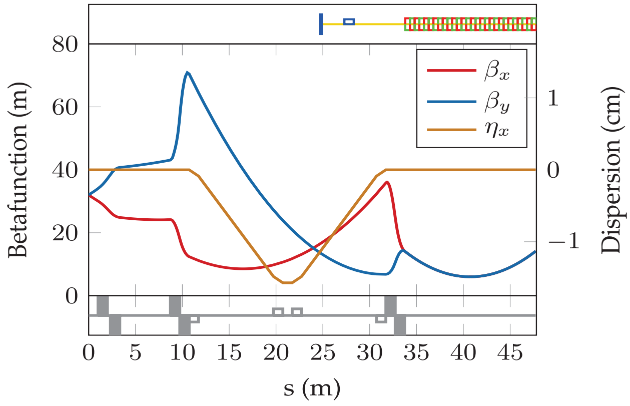

Figure 4: The beta functions and the dispersion of the beamline. In the upper part the undulator and the x-ray mirrors are shown. In the lower part the arrangement of the quadrupole (bold) and dipole magnets (normal) are shown.

where taken from the European XFEL lattice design. In order to get the required beam profile inside the undulator an optimization problem with the quadrupole strengths as the variables had to be solved. The conditions of the optimization were set in the middle of the undulator to: $\alpha_x = \alpha_y = 0$, $\beta_x = \beta_y = 6\text{m}$. Figure 4 shows the result of the optimization. It can be seen that the beam is transformed into a round shape at the entrance of the undulator and has the beam waist in the middle of the undulator. This beam profile meets the requirement defined above to overlap the electron beam with the Gaussian x-ray beam. It can also be seen that the dispersion returns to zero after the chicane. It is important to enter the undulator without dispersion to keep the beam diameter small and hence overlap the electron beam with the x-ray beam properly. Furthermore, Fig. 4 shows in the upper part the dimensions of the undulator and the x-ray optics and in the lower part the arrangement of the magnets along the beamline. After setting up the electron optics, 500000 particles were tracked through the beamline. Figure 2 shows the 1σ ellipses in the transversal phase space for the x- and y-direction at the entrance of the undulator respectively. As shown, the ellipses are identical as it could be anticipated from Fig. 4. Figure 3 shows the 1σ ellipse of the longitudinal phase space distribution for the beginning of the beamline and for the entrance of the undulator. It can be seen that the two ellipses are identical. That shows that the bunch compression effect of the chicane is negligible. In Fig. 2 and 3 the ellipses where shown for the entrance of the undulator because at this point further simulations need to be conducted by specialized software. Simulations showed [3], that the natural focusing of the undulator is negligible. Hence the calculation of the beta functions inside the undulator were performed by assuming the undulator to be a drift space.

CONCLUSION

The considered magnetic chicane and focusing section are suitable to couple the corresponding electron beam into the cavity of the XFELO that is under consideration at DESY. Figure 4 shows that the requirement of a round beam with a beam waist in the middle of the undulator was met. Furthermore it shows, that according to field quality specifications of the European XFEL quadrupole magnets, the maximum beta function is small enough to neglect distortion of the beam due to field errors of the magnets. Figure 4 shows also that due to the symmetry of the chicane the dispersion is compensated. As can be seen in Fig. 3 bunch compression effects are negligible because of the relatively small deflection angle of the bending magnets.

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