OPTICS FOR THE BEAM SWITCHYARD AT THE EUROPEAN XFEL

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Abstract

The European XFEL will be a multi-user facility with the possibility to distribute electron bunches of one beam pulse to different beamlines each serving its own set of undulators. The initial stage foresees two electron beamlines, a third beamline can be added in the future. In addition, the integration of the transport line to the beam abortion dump allows a flexible selection of the bunch repetition pattern for each beamline. The beam extractions are realized with a kicker and Lambertson septum layout. In this paper we discuss the optics solutions for the beam switchyard.

INTRODUCTION

The European X-Ray Free-Electron Laser (XFEL) Facility [1] has been planed as a multi-user facility, and from the beginning there will be the possibility to distribute the electron bunches between the two electron beamlines each serving its own set of undulators. In the future the facility can be extended by adding a third electron beamline. Because the users may have different requirements, the bunch repetition pattern can be adjusted individually for each electron beamline. This operational flexibility is reached by a beam distribution system, which uses fast single bunch kickers to kick individual bunches into the dump line before the distribution and the flat-top kickers to distribute the bunches into undulator beamlines (once during one bunch train). Both the beam deflection into the dump line and the extraction into the undulator beamline are realized with a kicker-septum scheme [1, 2].

In the first design of the switchyard [2] the Lambertson septum was proposed for the deflection into the dump line, and the horizontal deflecting DC septum for the beam extraction into the undulator beamline, that allowed in the latter case to make the kick and deflection in the same plane and design the flat deflection arc.

In this paper we present the magnet lattice and the optics solutions for the deflection arcs using the Lambertson type septum for all extractions. The disadvantage of the kicker-Lambertson-septum layout is that the different bending planes by the kickers and the septum make the dispersion suppression (horizontal and vertical) more difficult. In addition, these is a shift of the beam in the kicker bending plane, which has to be taken into account in the geometrical layout of the downstream beamline. Among all the other constraints on the design of the extraction arcs one may point out the following: The deflection elements of the distribution system will be placed in a straight section with a FODO focusing structure that imposes the constraints on the possible location of kickers and septa. In addition, the Twiss functions at the entrance of extraction arcs are fixed and defined by the behaviour of betatron functions in the FODO lattice. The optics of the beam deflection to the undulator beamlines must meet a very tight set of performance specifications. It should be able to accept bunches with different energies (up to $\pm 1.5\%$ from nominal energy) and transport them without any noticeable deterioration not only of the transverse but also the longitudinal beam parameters, i.e. it must be sufficiently achromatic and sufficiently isochronous. Though the beam quality in the dump line is not so important, we design the optics with good chromatic properties. It is obviously necessary to avoid collisions of magnets from different beamlines.

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LAYOUT OF BEAM SWITCHYARD

The beam distribution section is located downstream of the collimation section which follows the main linac. The layout of the switchyard is described in the paper [2].

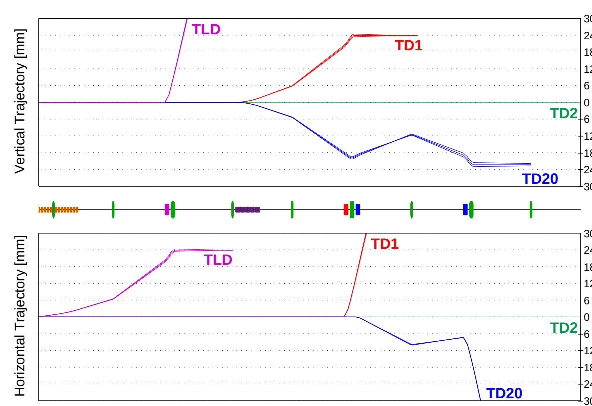

Figure 1: Trajectories of kicked particles (with the relative energy deviations of -1.5%, 0% and $+1.5\%$) in the separation area. Magenta, red and blue colors mark the extractions into the dump line TLD, the undulator beamline TD1, and the future line TD20, respectively. Green color marks the straight line TD2.

At first, bunches can be extracted into the dump line (TLD line) (see Fig. 1). A set of fast kickers kicks the beam horizontally, and the Lambertson septum deflects it in the vertical plane. Second, flat-top kickers can offset the beam vertically in the septum which makes the deflection in the horizontal plane into the beamline (TD1 line) that transports the bunches to the undulator SASE2. Unkicked bunches go straight into the beamline (TD2 line) which serves the undulators SASE1 and SASE3.

The layout of the initial parts of the deflection arcs are very similar (there are slight differences described in the next section), only the bending planes of the kicker-septum combinations in the two lines are perpendicular. The arcs start from the kickers. A set of four septa is used for the extraction. The first septum magnet is placed just in the front of a large aperture quadrupole and tilted in such a way that it deflects the beam not only in the septum bending plane but also slightly in the other plane. It is done to compensate the deflection produced by the downstream large aperture quadrupole and in order to have the beam going in parallel to the septum bending midplane at the entrance of the three untilted septa which are located behind the quadrupole. The remaining parts of deflection arcs are different and constructed from normal dipoles and quadrupoles.

The later addition of one more beamline (TD20 line), leading to a third set of undulators, is already taken in consideration in the design of the switchyard. The beamline is foreseen to be directed to the other side of the straight line TD2. To satisfy the site boundary conditions, it is currently proposed to use the kickers, which deflect the beam into the beamline TD1, to kick the beam also into the line TD20. In the layout of the distribution section free spaces are reserved for future addition of deflecting elements.

OPTICS FOR BEAM LINES

In this section the optics solutions for the deflection arcs into the undulator beamline TD1 and the dump line TLD are discussed in details. For the future beamline TD20 only a conceptual solution will be presented.

Beam Line TD1

The flat-top kickers (5 kickers each $1\,m$ long) to the beamline TD1 are placed close behind the quadrupole of the FODO-lattice transport line. After the enhancement of its deflection by the following quadrupole, the beam comes to the entrance of the first (tilted by approximately 12°) septum with $20\,mm$ vertical separation from the horizontal midplane $y = 0$ (see Fig. 1). The total kick angle required in this layout is $0.523\,mrad$. Three remaining (untilted) septa are placed behind the quadrupole (which follows the first septum) and moved downstream from this quadrupole to provide free space for the first septum to the future beamline. All four septa (Lambertson type) have $1\,m$ length and the maximum value of the magnetic field of $0.4\,T$. The total horizontal deflection by the arc is about 2.286°. The arc ends by a dogleg consisting of two vertical dipoles which is used for closing the linear vertical dispersion (initially generated by kickers) and to bring the beam back to the horizontal plane $y = 0$. The total deflection arc (from the entrance of the first kicker up to the exit of the last vertical dipole) is a first-order isochronous beamline: r_{56} coefficient of the arc transfer matrix is equal to zero. This is achieved by the usage of two reverse bend horizontal dipoles placed close to the arc center (see Fig. 2).

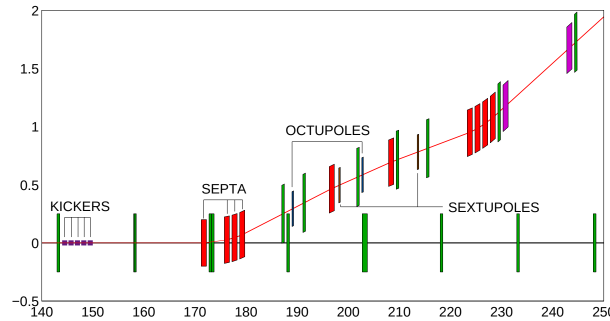

Figure 2: Top view of the separation area between the straight line and the beamline TD1. Green and red/magenta colors mark quadrupoles and horizontal/vertical dipoles. Horizontal and vertical distances are measured in meters.

For the fixed initial Twiss parameters the exit Twiss functions are designed to be easily matched to the downstream transport line leading to the undulator SASE2 (Fig. 3). For correction of chromatic aberrations in the TD1 arc (with simultaneous nonzero horizontal and vertical dispersions) we use tilted multipoles (two tilted sextupoles and two tilted octupoles), details are discussed in the paper [3].

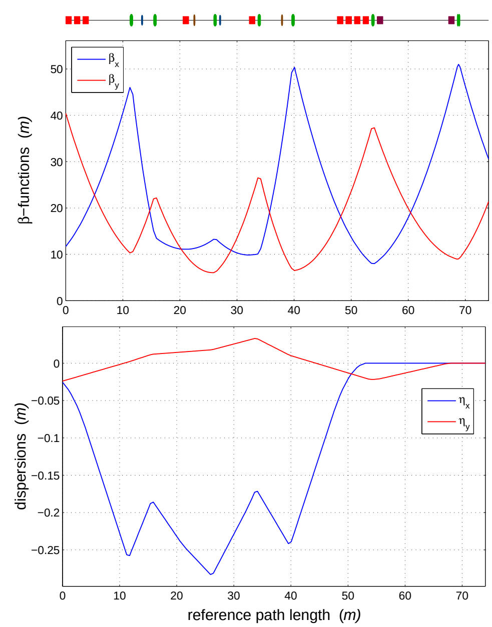

Figure 3: Betatron and dispersion functions along the deflection arc TD1 shown starting from the entrance of the first untilted septum.

Dump Line TLD

The fast single bunch kickers (16 kickers each $0.5\,m$ long), grouped around the quadrupole, provide $20\,mm$ horizontal separation at the entrance of the first Lambertson septum. The required kick angle is about $0.506\,mrad$. The first septum (tilted by around 12.6°) and three untilted septa are placed immediately around the large aperture quadrupole, as it is shown in Fig. 4. The deflection arc has rather complicated geometry: The dump line TLD has to be directed in between the two beamlines leading to the undulators, and has to be matched geometrically to the final vertical bend (by $14°$) to the beam abortion dump.

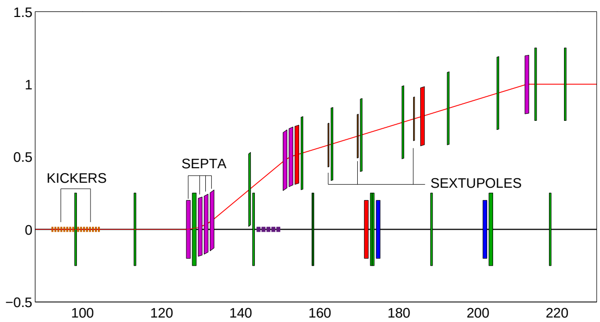

Figure 4: Side view of the separation area between the straight line and the dump line TLD. Green and red/magenta colors mark quadrupoles and horizontal/vertical dipoles.

The search for the beam optics solution is constraint by many aspects: Suppression of both dispersions (horizontal and vertical), suitable betatron functions at the arc end (to be prepared for the matching to the final arc to the beam dump), good chromatic properties, and at the same time avoiding magnet collisions. To satisfy these requirements interleaved vertical and horizontal dipoles and 7 quadrupoles are used, as it is shown in Fig. 4 and 5. To provide acceptable chromatic properties (see Fig. 6), three tilted sextupoles are placed in the arc.

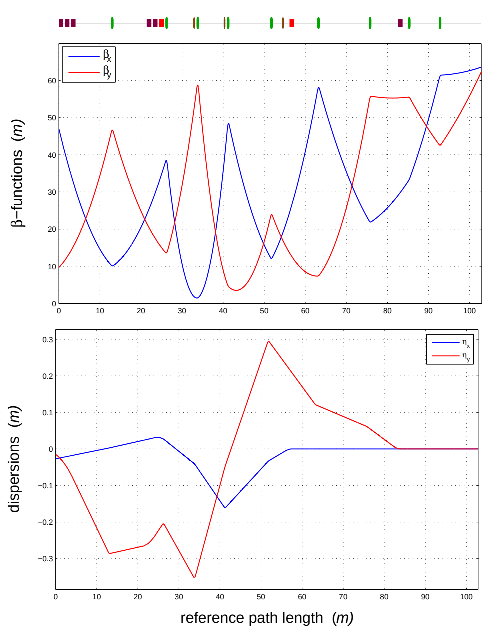

Figure 5: Betatron and dispersion functions along the deflection arc into the dump line TLD shown starting from the entrance of the first untilted septum.

Future Line TD20

The kickers, which kick the beam into the undulator beamline TD1, will be used to produce the reverse vertical kick (downwards) into the beamline TD20 (see Fig. 1).

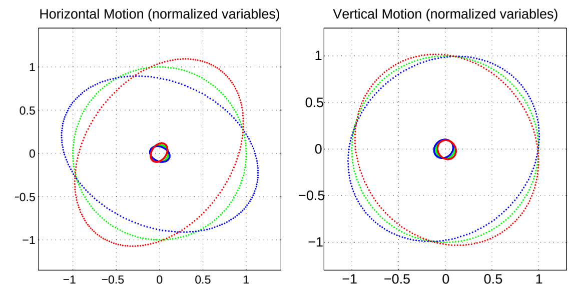

Figure 6: Phase space portraits of monochromatic $0.1\sigma_{x,y}$ and $1\sigma_{x,y}$ ellipses (matched at the entrance) after tracking through the extraction arc into the dump line TLD. The relative energy deviations are equal to -1.5%, 0% and $+1.5\%$ (red, green and blue ellipses, respectively).

To provide the beam extraction in the present layout of the separation area, five septa (two tilted and three untilted) are proposed to use. The layout of the separation area with the possible extraction arc into the additional beamline is shown in Fig. 7, all needed space is already reserved.

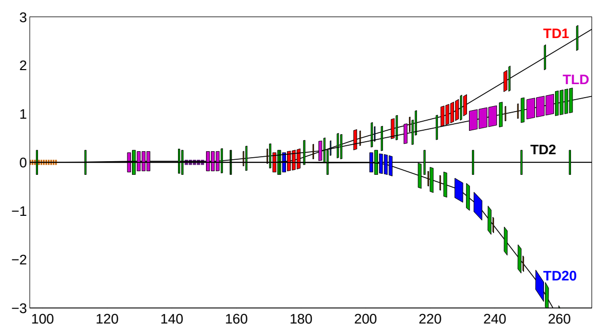

Figure 7: Top view of the separation area. Red, magenta and blue colors mark septa and dipoles of beamlines TD1, TLD and TD20, respectively. Horizontal and vertical distances are measured in meters.

SUMMARY

The beam switchyard at the European XFEL provides fast beam switching between the two undulator beamlines (a later addition of the third line is also taken in consideration) and allows the extraction of individual bunches in the beam dump. The careful optics design presented in this paper meets the main design specifications.

REFERENCES

[1] M.Altarelli, R.Brinkmann et al. (Eds), "XFEL: The European X-Ray Free-Electron Laser. Technical Design Report", DESY 2006-097, DESY, Hamburg, 2006.

[2] W.Decking, F.Obier, "Layout of the Beam Switchyard at the European XFEL", EPAC'08, Genoa, June 2008, WEPC073, p. 2163, `http://www.JACoW.org`.

[3] V.Balandin, W.Decking, N.Golubeva, "Tilted Sextupoles for Correction of Chromatic Aberrations in Beam Lines with Horizontal and Vertical Dispersions", IPAC'10, Kyoto, May 2010, THPE062, p. 4656, `http://www.JACoW.org`.