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LAYOUT AND OPTICS OF THE DUMP LINE AT THE EUROPEAN XFEL

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Abstract

The purpose of the optical system, which we call the dump line, is not simply the transport of the beam to the beam dump. It is an essential part of the beam switchyard which provides the possibility to distribute electron bunches of one beam pulse to different FEL beam lines, allowing a flexible selection of the bunch pattern at each FEL experiment. In this paper we describe the final layout of this optical system as it is now under construction.

INTRODUCTION

The European X-Ray Free-Electron Laser (XFEL) facility [1] is currently under construction in the Hamburg area. From the beginning it is planed as a multi-user facility with the possibility to distribute the bunches from one RF pulse between different electron beamlines (two lines at present) serving their own set of undulators. A combination of slow and fast switching devices allows generation of different bunch patterns for different experiments. Between undulator beamlines the beam is switched using the (slow) flat-top kicker, and before this a fast single bunch kicker can kick the unwanted bunches out of the train (during the ramp time of the slow kicker and to adjust the bunch pattern) into the dump line which provides the beam transport to an additional beam dump. This dump line can also be used during the commissioning and operation of the accelerator while maintenance work is going in the undulator tunnel.

The beam distribution system is a part of the conventional beamline transporting the beam from the main linac to FEL undulators and it is located after the beam collimation and trajectory feedback systems. During the design the magnet lattice and the beam optics of the distribution beamlines have gone through a few changes [2, 3]. Both extractions into the dump line and the undulator beamline are realized using a kicker and a Lambertson septum [3] that brought in the design the task of the dispersion suppression in both horizontal and vertical planes. The desire to use standard magnetic elements results in the necessity of an accurate fitting of the geometry and the beam optics simultaneously for both extraction beamlines.

In this paper we present the final layout and the optics solution for the dump line, which provides the extraction of individual bunches out of the train and their further transport to the beam dump. The design of such beamlines might be interesting for other FEL facilities with the option of beam distribution between different experiments.

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DUMP LINE LAUOUT

The layout of the dump line TLD is defined, firstly, by the fact that the extraction elements (for both extraction beamlines) are integrated in the FODO lattice, which is a main part of the straight transport beamline TD2 serving the SASE1 undulator, and secondly, by the the overall layout of transport lines and undulators. The start position of the FODO lattice and the length ($30\,m$) of the FODO cell with 90° phase advance have been optimized to provide more optimum positions for kicker-septum for both extraction beamlines. The extraction into the dump line is made just before the beam distribution between undulator beamlines, and by reason of limited free space this dump line has to be elevated upwards, directed horizontally in between two undulator beamlines and matched geometrically to the final bend to the beam dump. Fig. 1 shows the top view of the separation area.

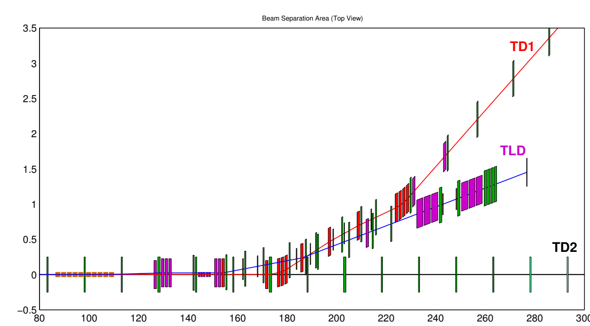

Figure 1: Layout of the separation area (top view). The dump line TLD is in between two undulator beamlines TD2 and TD1. Horizontal and vertical axes are in meters.

Fast horizontal kickers (10 pieces of $2\,m$ long, $0.6\,mrad$ total kick angle) and four vertical septa are grouped around two nearest horizontally focusing quadrupoles of the FODO lattice (see Fig.2). One defocusing quadrupole between kickers and the first septum creates an additional horizontal deflection for the kicked beam (Fig.3) (negative deflection produced by focusing quadrupole between two sets of kickers is small) that allows to decrease the required kicker strength. The first septum is placed just in the front of the large aperture focusing quadrupole and tilted in such a way (12.6°) that it deflects the beam not only vertically but also slightly horizontally. This is needed to compensate an additional deflection produced by downstream quarupole and to bring the kicked beam in parallel to the vertical midplane at the entrance of three remaining (untilted) septa placed behind the quadrupole. The offset of the kicked beam trajectory at the entrance of the first septum is $20\,mm$ and adjusted by kickers (Fig.3). The Lambertson septum magnet

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has a length of $1\,m$ and a field of $0.41\,T$. The aperture of the vacuum chamber in the front of the first septum is larger (96 mm diameter) than the vacuum chamber of the FODO channel (40.5 mm) to accommodate both unkicked and kicked bunches.

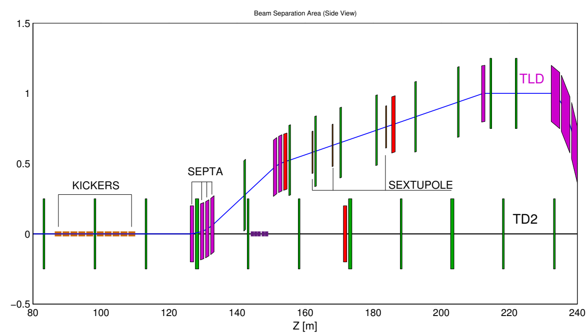

Figure 2: Layout of the separation area (side view) showing the initial part with kickers and septa and the deflection arc of the dump line TLD. Green and red/magenta colors mark quadrupoles and horizontal/vertical dipoles. Horizontal and vertical axes are in meters.

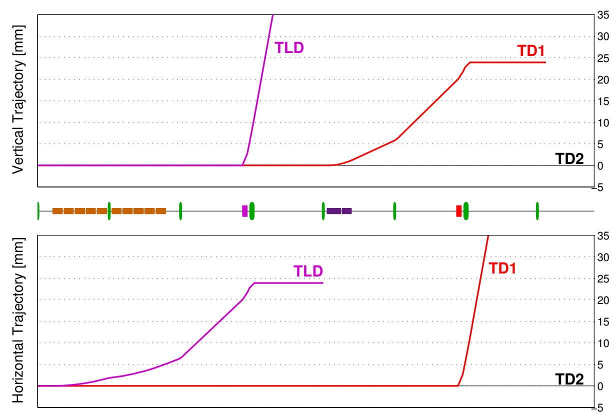

Figure 3: Trajectories of kicked beams in the separation area. Magenta and red colors mark the extraction into the dump line TLD and the undulator beamline TD1.

The remaining part of the dump line is constructed from normal dipoles and quadrupoles. Because the separation area has to accommodate the elements from three beamlines, we used a minimal number of magnets to avoid overcrowding and simplify the installation in this area. To match the dump line geometrically interleaved vertical and horizontal dipoles are used. After the deflection in the vertical plane for 1.26° by means of four septa, three reverse (to septa) vertical dipole magnets are used to provide the beam elevation of about $1\,m$. Between vertical dipoles two horizontal dipole magnets are placed to deflect the beam for the required angle of 0.77°. This allows to fit the deflection arc in the available space and to the final vertical bend (by 14°) to the beam abortion dump. The length of the deflection arc is about 84 m (starting from the entrance of the second septum). The final achromatic arc to the beam dump is composed from two identical dipoles (3 pieces each), two quadrupoles for suppression of the dispersion and two sextupoles (Fig.4).

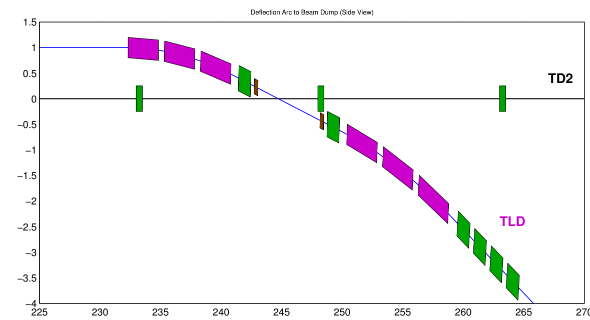

Figure 4: Layout of the final arc to the beam dump (side view). Green, brown and magenta colors mark quadrupoles, sextupoles and vertical dipoles. Horizontal and vertical axes are in meters.

BEAM OPTICS

From the point of view of the beam optic the complete dump line can be considered as consisting of three parts. The initial part is a part of the FODO lattice with kickers and the first septum through which both unkicked and kicked beams are going. In this section the behaviour of betatron functions are defined by the FODO lattice (Fig.5), the dispersions are generated by kickers and the first septum, and the trajectory of the kicked beam is calculated with respect to the reference orbit of the unkicked beam (Fig.3). The second part (which we call the extraction arc) is starting at the entrance of the second (first untilted) septum. And the last part consists of the vertical arc and a short transport section (with 4 quadrupoles) to the beam dump (Fig.4). The beam optics in this last part is mainly defined by the requirements to suppress the dispersion at the arc exit (strengths of two arc quadrupoles are fixed) and to enlarge the beam size at the dump window.

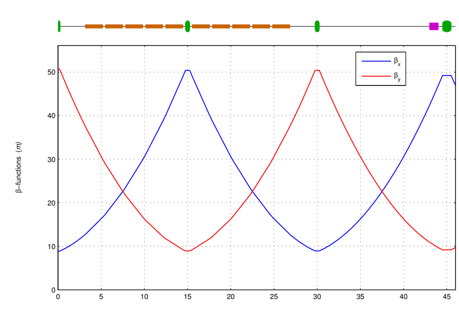

Figure 5: Betatron functions in the initial part of the dump line TLD starting from the quadrupole before kickers up to the entrance of the second (first untilted) septum.

The main efforts have been applied to find an appropriate beam optics for the extraction arc which is in between

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two practically fixed sections. The search for the optics solution is constrained by many aspects. The initial optical functions (betatron functions and dispersions) are fixed, they are coming from the initial part. Both vertical and horizontal dispersions have to be not very large along the beamline and suppressed at the extraction arc exit. The betatron functions at the arc end have to be prepared for the matching to the last part of the beamline. At the same time the magnet collisions from different beamlines have to be avoided. Taking into account the tight space constraints the search of the beam optics for the extraction arc was not a separated task, but was done simultaneously with the design of the geometrical layout. The final solution with 7 quadrupoles between dipoles and 2 quadrupoles behind the last arc dipole allows to satisfy the requirements and keep the betatron functions below 60 m in the arc, and the vertical and horizontal dispersions below 0.35 m and 0.15 m, respectively. The behaviour of the optical functions along the extraction arc is shown in Fig.6.

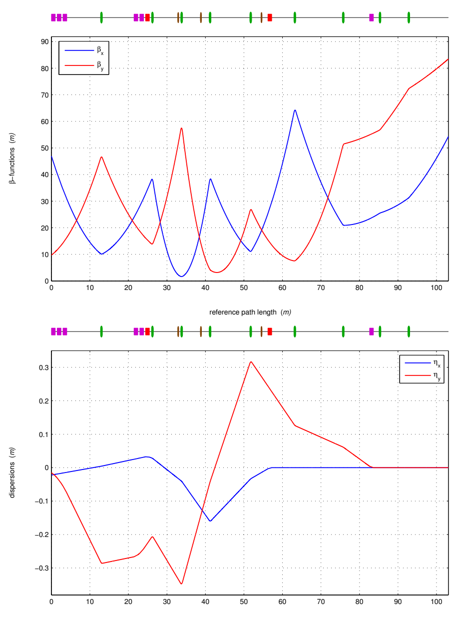

Figure 6: Betatron (top) and dispersion (bottom) functions along the TLD extraction arc shown from the entrance of the second (first untilted) septum up to the vertical bend to the beam dump.

Though the beam quality in the dump line is not so important, we were designing the optics with good chromatic properties, that ensures stable operation of the system. The design specification for undulator beamlines is to provide the transport of bunches with different energies (up to ±1.5% from nominal energy) without any noticeable deterioration. For the extraction arc of the dump line we are keeping the same requirement.

Because the extraction arc with interleaved dipoles has nonzero vertical and horizontal dispersions simultaneously (Fig.6), in addition to the generation of nonlinear dispersions in both transverse planes, the horizontal and vertical oscillations become chromatically coupled due to horizontal dispersion in the vertical bending magnets and vertical one in the horizontal dipoles. In such beamlines the usage of tilted sextupoles [4] allows to keep the total number of multipoles required for correction of chromatic aberrations on the same level as required in the midplane symmetric systems. Three tilted sextupoles placed in the extraction arc allows to have the appropriate chromatic properties, as can be seen in Fig.7.

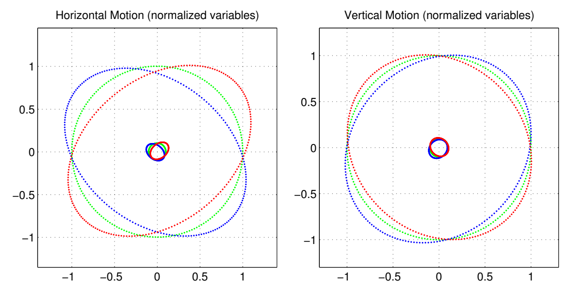

Figure 7: Phase space portraits of monochromatic $0.1\sigma_{x,y}$ and $1\sigma_{x,y}$ ellipses (matched at the entrance) after tracking through the TLD extraction arc. The relative energy deviations are equal to -1.5%, 0% and $+1.5\%$ (red, green and blue ellipses, respectively.

SUMMARY

The beam distribution system at the European XFEL will allow to distribute the bunches of one RF pulse between two undulator beamlines and control individually the bunch pattern for each electron beamline. For providing such flexibility an additional dump line is required into which the unwanted single bunches can be kicked before the beam distribution. The layout and optics design for this dump line presented in this paper satisfies the geometrical constraints and requirements coming from the beam dynamics, and ensures flexible operation of the system.

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