LARGE ENERGY ACCEPTANCE DOGLEG FOR THE XFEL INJECTOR

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Abstract

The option to install two injectors is foreseen at the European XFEL Facility [1]. The injectors will be located on top of each other in the same building, both with an offset of 2.75 m with respect to the main linac axis. The translation system (dogleg) from the injector axis to the main linac axis has to fulfill very tight requirements of the chromatic properties, because the energy chirp required for the downstream bunch length compression in magnetic chicanes will be created upstream in the injector linac. In this paper we present such a large energy acceptance dogleg and discuss the optical principles which form the basis of its design.

DESIGN RECIPES FOR LARGE ENERGY ACCEPTANCE DOGLEG

We will consider a parallel beam translation system (dogleg) where the bend magnet block (arc) which is symmetric about the horizontal midplane $y = 0$ is followed by the same block but rotated by 180° about the longitudinal axis.

In order to design a dogleg which does not give rise to unacceptable emittance dilution due to chromatic effects one has to control both, dogleg nonlinear dispersions and dogleg chromatic focusing properties. That can be done using the following design rules:

Let us assume that the arc transport matrix is free from linear dispersions and its horizontal focusing part is equal to the two by two identity matrix. Then in the dogleg transfer map the second order dispersions are automatically canceled. If we will add to these assumptions the requirement that the arc map is a second order achromat, we will obtain a dogleg which is a second order achromat by itself and in which the first nonzero dispersions are at least of fifth order.

These properties were used during the design of a beam transport system for the TESLA X-ray Facility and allowed to work out a dogleg with an energy acceptance bigger than $\pm 10\%$ [2, 3]. The sextupoles used in that dogleg are essential for achieving such large energy acceptance and play a twofold role. They are responsible for both, control of chromatic focusing aberrations by making the arc to be a second order achromat and for the absence of nonlinear dispersions up to fifth order.

Nevertheless, as concerning suppression of nonlinear dispersions alone, the tuning of the arc to be a complete second order achromat is not necessary. It is sufficient to make it a second order achromat only with respect to the bending plane (horizontal) motion (i.e. to make the horizontal components of the arc map free from the second order chromatic and geometric aberrations on the manifold $y = p_y = 0$) and thus to reduce the number of sextupoles required for cancellation of third and fourth order dispersions by a factor of two. Additional possibilities for dispersion cancellation are obtained if we will assume that the arc is constructed by a repetition of n identical cells ($n > 1$) with the arc horizontal focusing matrix equal to the two by two identity matrix and with the cell horizontal focusing matrix not equal to the two by two identity matrix (which guarantees that the arc transport matrix is automatically free from the linear dispersions). In this case let us summarize the rules for the dispersion suppression as follows:

- Without any additional assumptions the second order dogleg dispersions are equal to zero.
- If the arc cell is free from the linear dispersions, then the second and the third order dogleg dispersions are equal to zero.
- If the arc map is a second order achromat with respect to the horizontal motion, then the second, the third and the fourth order dogleg dispersions are equal to zero.
- If the arc map is a second order achromat with respect to the horizontal motion and the arc cell is free from the linear dispersions, then the second, the third, the fourth and the fifth order dogleg dispersions are equal to zero.

One sees from the above list that it is not a big problem to construct a dogleg without sextupoles which, nevertheless, is free from first, second and third order dispersions. But what can be done in this case (or in the case when the arc map is a second order achromat only with respect to the horizontal motion) to control chromatic focusing aberrations? One possible way is to employ the concept of apochromatic focusing which, though having been developed mostly for straight drift-quadrupole systems [4, 5], can be generalized on systems with bending and sextupole magnets included.[1]

SOLUTIONS FOR THE XFEL INJECTOR DOGLEG

In this section we will present three solutions for the XFEL injector dogleg designed according to the discussed optical principles.

[1] The theory of apochromatic focusing states that for every drift-quadrupole system there exists an unique set of Twiss parameters, which will be transported through that system without first order chromatic distortions. Most interesting for us in this paper is the statement of this theory concerning apochromatic Twiss parameters of periodic systems [5], which is based on averaging and can be extended to include bend magnet systems with sextupoles.

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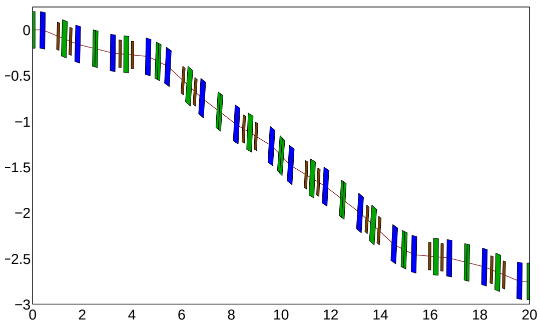

Figure 1: Overall layout of the dogleg variant one. Blue, green and brown colors mark dipole, quadrupole and sextupole magnets, respectively.

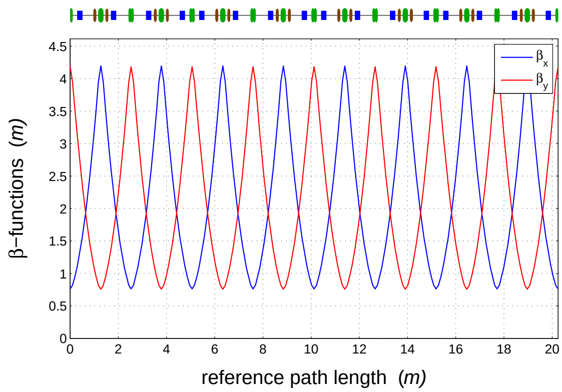

Figure 2: Betatron functions along dogleg variant one.

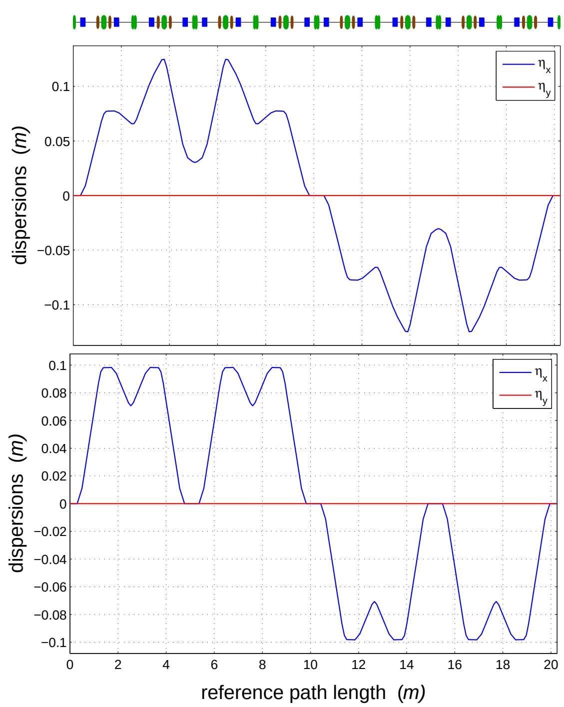

Figure 3: Dispersions along doglegs variant one (top) and variant two (bottom).

The first solution (dogleg variant one) is the dogleg which originally was designed for the XFEL injector [6]. The second solution (dogleg variant two) is the slight modification of the first and has better chromatic properties with sextupoles switched off. The third solution (dogleg variant three) utilizes much smaller number of magnets than the first two, does not uses sextupoles at all, but still has an energy acceptance of the order of $\pm 3\%$. It is a perspective solution and, if the practical operations with the first XFEL injector will show that its energy acceptance is sufficient, then this dogleg can be realized for the usage with the second XFEL injector.

The doglegs variant one and variant two use the same number of magnets and have very similar layouts and betatron functions (Fig.1 and Fig.2). Arcs of both doglegs are first order achromats, i.e. their transport matrices are equal to the identity matrix except for the r_{56} element for the dogleg variant two. They can be tuned to become second order achromats with respect to the bending plane (in this paper horizontal) motion using two sextupole families and are constructed as two cell systems, where each cell is mirror symmetric with respect to its center and has the same arrangement of dipole and quadrupole magnets as the cell of the arc of the XFEL post-linac collimation section [7].

What makes these two doglegs different is the behavior of their linear dispersions. For the dogleg variant two it is closed already after one arc cell (Fig.3). As the result of that even with sextupoles switched off the dogleg variant two has an energy acceptance of the order of $\pm 3\%$, while the dogleg variant one appears to be nonoperational (Fig.4). The price paid for this dispersion adjustment is that while the dogleg variant one is first order isochronous beamline with $r_{56} = 0$, the dogleg variant two has $r_{56} \approx 3\,cm$ (with the same sign as for the usual four-bend magnetic chicane) and will make slight beam compression during its transport, but currently it is considered even as an advantage in comparison with the dogleg variant one.

Note that with the sextupoles switched on both doglegs show excellent beam transfer properties (Fig.5).

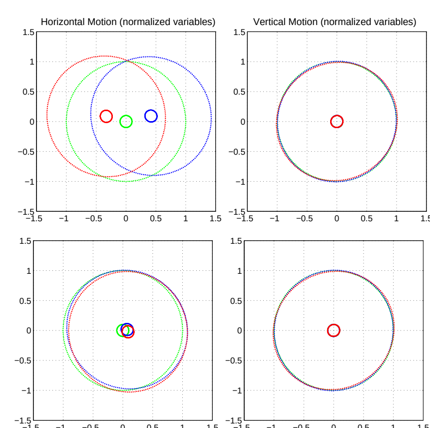

Figure 4: Phase space portraits of monochromatic $0.1\sigma_{x,y}$ and $1\sigma_{x,y}$ ellipses (matched at the entrance) after tracking through the dogleg variant one (top) and the dogleg variant two (bottom). The relative energy deviations are equal to $\pm 3\%$. Sextupoles are switched off.

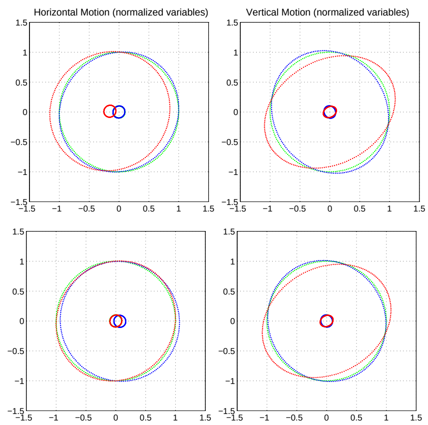

Figure 5: Phase space portraits of monochromatic $0.1\sigma_{x,y}$ and $1\sigma_{x,y}$ ellipses (matched at the entrance) after tracking through the dogleg variant one (top) and the dogleg variant two (bottom). The relative energy deviations are equal to $\pm 15\%$. Sextupoles are switched on.

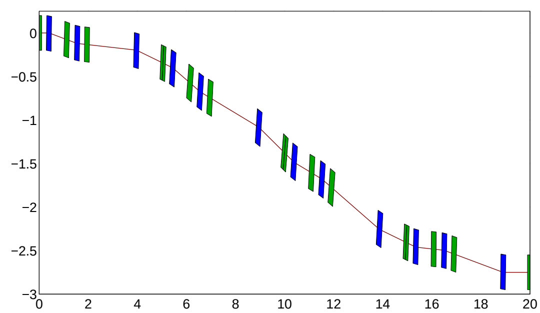

Figure 6: Overall layout of the dogleg variant three. Blue and green colors mark dipole and quadrupole magnets, respectively.

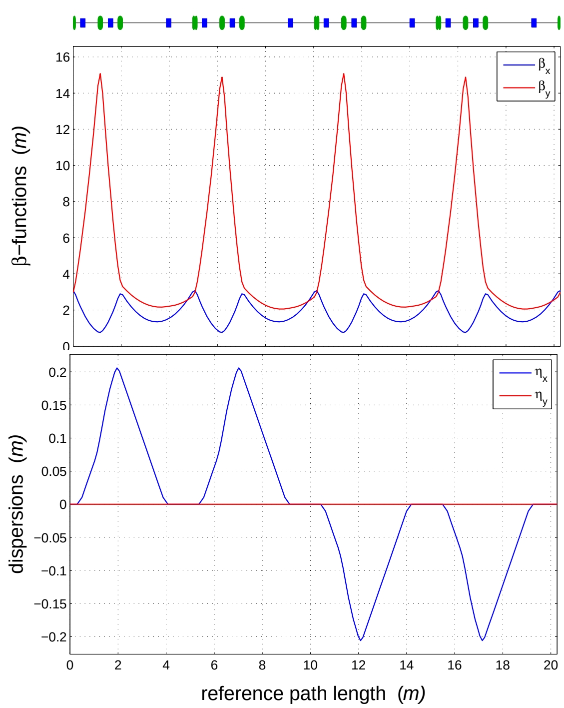

Figure 7: Betatron functions and dispersions along dogleg variant three.

The layout and the Twiss parameters of the dogleg variant three can be seen in Fig.6 and Fig.7. This dogleg uses a smaller number of magnets than the first two doglegs presented in this paper, which is achieved by reduction of the phase advance of the vertical motion by a factor of two in comparison with the horizontal motion. The horizontal focusing part of the arc transfer matrix for this dogleg is equal to the two by two identity matrix, while its vertical focusing part is equal to the two by two minus identity matrix. Similar to the dogleg variant two the dogleg variant three will make slight beam compression during its transport ($r_{56} \approx 4.4\,cm$) and has the linear dispersion closed already after one arc cell. The chromatic beam transfer properties of this dogleg can be seen at Fig.8.

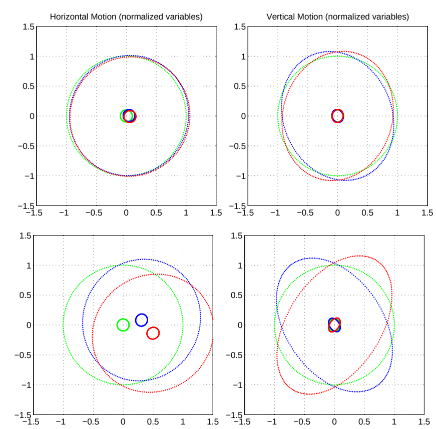

Figure 8: Phase space portraits of monochromatic $0.1\sigma_{x,y}$ and $1\sigma_{x,y}$ ellipses (matched at the entrance) after tracking through the dogleg variant three. The relative energy deviations are equal to $\pm 3\%$ (top) and $\pm 5\%$ (bottom).

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