Preserving Bright Electron Beams: Distorted CSR Kicks and CSR Cancellation

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Introduction

- Short pulse, low emittance beams are necessary to drive bright Free-Electron Laser (FEL) X-rays.
- Bunch compressors (BCs) are used to achieve short pulsed beams.
- Coherent synchrotron radiation is emitted in dipoles, which results in CSR kicks and CSR-induced emittance growth.
- CSR cancellation techniques are commonly used in bunch compressors, but they may be less effective when CSR kicks are distorted.

Summary

- CSR kicks can become distorted in shape and size, this could mean that CSR cancellation techniques are less effective and projected emittance will grow.
- The distortion arises from non-uniform slice Twiss parameters and slice phase advance, which is due to passing a chirped beam through multipole magnets in dispersive sections of a beamline, such as a bunch compressor.
- Further work is needed to determine if distorted CSR kicks will effect the CSR cancellation methods.

Coherent Synchrotron Radiation

- CSR is a collective effect that takes place in dipoles.
- It causes slices of the beam to become offset in the horizontal coordinates, which leads to projected emittance growth (as in Fig. 1).
- CSR-induced emittance growth can be minimised using cancellation techniques such as optical balance [1] and CSR kick matching [2].
- These methods may be less effective when the kicks are distorted.

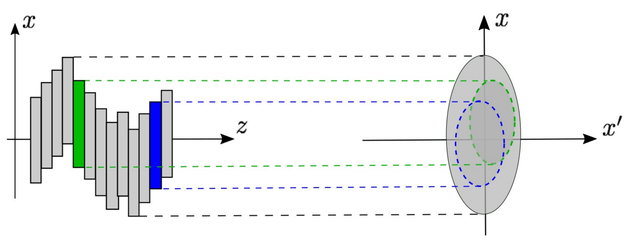

Figure 1. Horizontal slice offsets causing projected emittance growth.

Distorted CSR Kicks

- The point-kick model of CSR is an analytical model, which approximates CSR kicks by a single kick at the centre of a dipole [3].
- The overall CSR kick is found by calculating the point-kick in each dipole and transporting to the end of the bunch compressor (BC) with the 2D horizontal transfer matrix [4].
- When the kicks are calculated with the whole beam parameters, we refer to them as ‘typical’ CSR kicks.
- When the kicks are calculated with the slice beam parameters, we refer to them as ‘atypical’ or ‘distorted’ CSR kicks.

Short Pulse Facility (SPF)

The SPF linac uses a 100 pC electron bunch to be used for FemtoMAX. At the entrance of SPF bunch compressor 2, the electron bunch has an energy of 3 GeV. Bunch compressor 2 has longitudinal dispersion properties: R_{56}= 26 mm, T_{566}= 42 mm and U_{5666}= 49 mm.

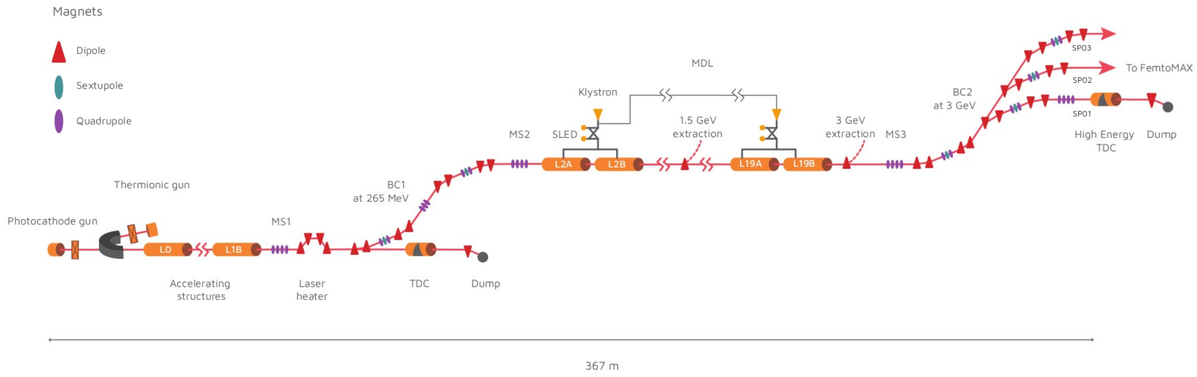

Figure 2. Layout of the MAX-IV facility in Lund, Sweden. Includes layout of SPF and SXL lines and bunch compressors.

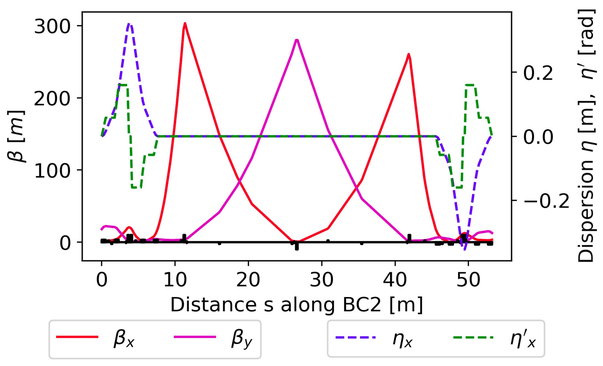

Figure 3. β-functions and horizontal dispersion in BC2 of SPF, taken from elegant simulations.

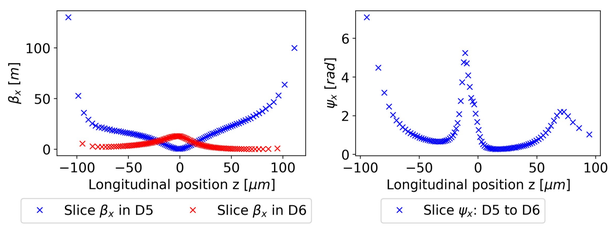

Figure 4. Slice β_x in dipole 5 and 6 (left) and slice ψ_x between dipole 5 and 6 (right), for BC2 of SPF.

- The CSR kick in *x* (Fig. 5) and *x’* (Fig. 6) is distorted in shape and magnitude for BC2 of SPF.
- From the typical CSR kicks the predicted horizontal geometric emittance growth is 0.34%, where as from the distorted kick this predicted emittance growth is 1.8%.

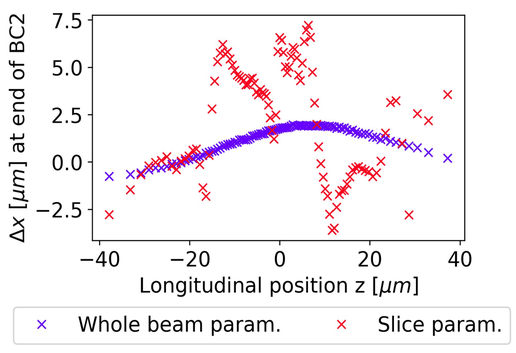

Figure 5. Typical (blue) and distorted (red) CSR kicks in *x* at the end of SPF BC2.

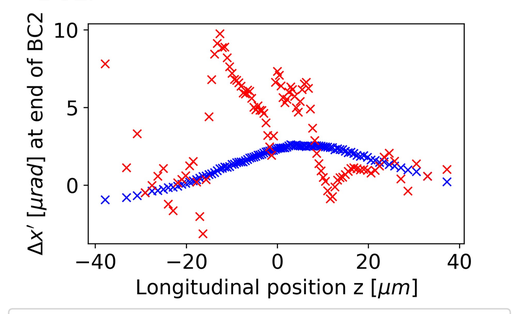

Figure 6. Typical (blue) and distorted (red) CSR kicks in *x’* at the end of SPF BC2.

Soft X-ray Laser (SXL)

The SXL linac uses a 10 pC electron bunch to be used for upcoming FEL. At the entrance of SPF bunch compressor 2, the electron bunch has an energy of 3 GeV. Bunch compressor 2 has longitudinal dispersion properties: R_{56}= 26 mm , T_{566}= -86 mm and U_{5666}= 87 cm.

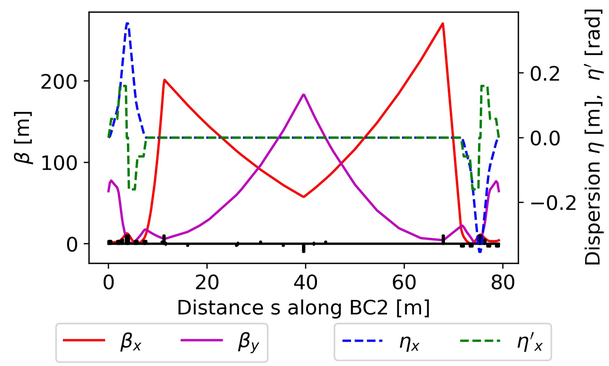

Figure 7. β-functions and horizontal dispersion in BC2 of SXL, taken from elegant simulations.

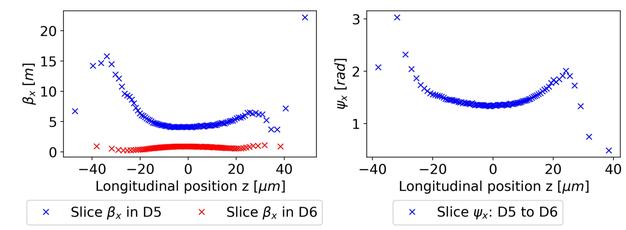

Figure 8. Slice β_x in dipole 5 and 6 (left) and slice ψ_x between dipole 5 and 6 (right), for BC2 of SXL.

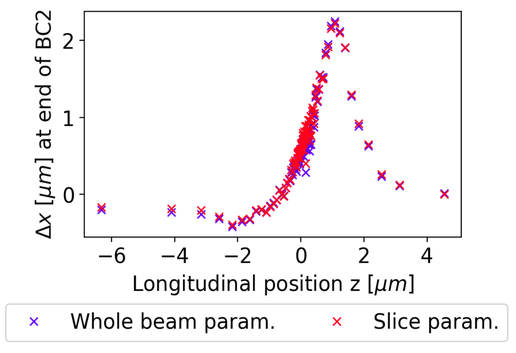

Figure 9. Typical (blue) and distorted (red) CSR kick in *x* at the end of SXL BC2.

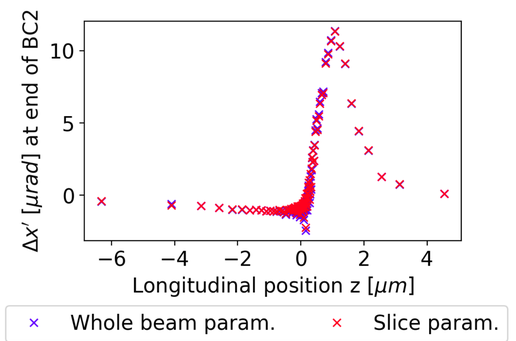

Figure 10. Typical (blue) and distorted (red) CSR kick in *x’* at the end of SXL BC2.

- The CSR kicks in *x* (Fig. 9) and *x’* (Fig. 10) are not distorted when calculated with the slice parameters.
- Both the typical and distorted CSR kicks predict a horizontal geometric emittance growth of 41%, where as the elegant shows a 71% horizontal geometric emittance growth.

References:

1. Di Mitri S, Cornacchia M, Spampinati S. Cancellation of Coherent Synchrotron Radiation Kicks with Optics Balance. Phys Rev Lett. 2013 Jan;110(1):014801.
2. Hajima R. Emittance Compensation in a Return Arc of an Energy Recovery Linac. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment. 2004 Aug;528(1-2):335–339.
3. Jiao Y, Cui X, Huang X, Xu G. Generic Conditions for Suppressing the Coherent Synchrotron Radiation Induced Emittance Growth in a Two-Dipole Achromat. Phys Rev ST Accel Beams. 2014 Jun;17(6):060701.
4. Wolski A. Beam Dynamics in High Energy Particle Accelerators. London : Singapore ; Hackensack, NJ: Imperial College Press ; Distributed by World Scientific; 2014.
5. Charles TK, Boland MJ, Oide K, Zimmerman F. Bunch Compression and Turnaround Loops in the FCC-ee Injector Complex. J Phys: Conf Ser. 2018 Sep;1067:062023.

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MAX IV