Design of the FCC-ee Positron Damping Ring and Transfer Line

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Background

The John Adams Institute for Accelerator Science (JAI) is a UK-based accelerator physics consortium comprised of researchers from the University of Oxford, Imperial College London, and Royal Holloway, University of London. As part of the JAI postgraduate training course, a preliminary design study of various components of the FCC-ee Positron Damping Ring and corresponding Transfer Line was conducted. Components were modelled using commercially-available software: MADX, FEMM, Poisson Superfish, and CST Studio. Models were then optimised to meet FCC-ee beam requirements while taking consideration of cost and environmental impact. Designs largely achieved target parameters (bunch compression, good field region, quality factor, etc). Further research with more specialist tools and a wider range of considerations (such as material) is required.

Transfer Line Bunch-Compressor Lattice

Performance criterion:
- Bunch compressors typically consist of an RF cavity followed by optics.
- The RMS bunch length is minimized by setting the R65 and R56 parameters of the cavity such that:

\[ p_{\text{optics}}(s) = \frac{1}{s} \frac{1}{R65} \]

Dog-Leg Bunch Compressor:
- Achieves compression through oppositely-bending dipole magnets. Quadrupoles are used to ensure beam achromaticity by performing a 2π dispersive phase shift.
- Successful bunch compression from 2 mm to 1 mm is achieved; future work would be to introduce sextupoles for higher-order chromatic corrections

C-Bend Achromat Compressor:
- R56 parameter tuned by varying magnetic field gradient of two additional focusing quadrupoles
- RMS bunch length also reduced from 2 mm to 1 mm
- Large size (3 cells ~80 m)
- Requires dedicated RF cavity at 3 GHz and 10 MV, and additional matching section to guide compressed bunches back into the Common Linac

Positron Damping Ring Magnets

Performance criterion:
- Good Field Region (GFR) \( \Rightarrow 2/3 \) beampipe diameter
- Dipole:
  - B-field of 0.059ST
  - GFR of 30 mm \( \Rightarrow \) beampipe radius of 25 mm
- Quadrupoles:
  - Magnetic gradient of 3.717 T/m
  - GFR of 16.97 mm above target of 16.67 mm
- Sextupoles:
  - Focusing: 523.81 T/m², 104.7 A
  - Defocusing: -743.74 T/m², 148.7 A
  - GFR of 16.05 mm (1D), 18.01 mm (2D) above target
- Kicker:
  - Average B-field = 1.55 ± 0.003 \( \times \) 10^{-5} T
  - 20 turns at 0.025A, field outside negligible (10^{-9} T)
- Lambertson Septum:
  - Average B-field = 1.18 ± 0.05 \( \times \) 10^{-5} T
  - 4 turns at 0.025A, beam pipe field negligible (10^{-9} T)
- Wiggler:
  - Designed a ferrite wiggler using two opposing Halbach arrays; an example is shown in Fig. 3.
  - B-field of 0.161 T
  - There were issues with modelling the wiggler in 2D as edge effects are not considered.
  - Also modelled a wiggler with electromagnets, thereby allowing variable magnetic fields at higher cost.
  - Remained far from saturation but with a "one-dimensional GFR" of roughly 1mm

Positron Damping Ring RF Cavities

Performance criterion:
- 5 MV RF voltage in a maximum length of 1.5 m
- Chose a compact RF cavity design with good efficiency
- Geometry of each design was optimized in Superfish (SF)
- A benchmark of SF against CST Microwave was performed

Normal conducting (NC)
- 400 MHz NC cavity did not meet the space requirement
- No cryogenics required, but worse efficiency than SC

Superconducting (SC)
- 800 MHz SC design has a low transit time factor and is compact
- 400 MHz SC has a high efficiency and is in use at the LHC

Cavities were then modelled using CST Microwave to determine the electromagnet fields on axis across the SC 400 MHz cavity, computed in CST Superfish.

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The 400 MHz SC design was chosen for the pDR.