SLAC FACET-II POSITRON DAMPING RING MAGNET DESIGN

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Abstract

The FACET-II facility, currently being designed at SLAC, will contain a small ¨20 m circumference, 335 MeV, positron damping ring. The ring has to fit in the existing linac tunnel, meaning that a compact lattice with short distances between magnets is required. The detailed magnet design is done in Opera-3d, with a finite element model of a full damping ring arc being simulated. This article presents this magnet design in a relatively early stage, with iteration between magnet and lattice design currently in progress.

INTRODUCTION

FACET-II at SLAC will be a user facility for wakefield acceleration research with electron and positron beams, replacing the previous FACET [1] that is currently being decommissioned to make way for LCLS-II. Like the previous facility, FACET-II will use part of the existing SLAC linac to provide electrons and positrons up to 10 GeV at the experiment station. A principle sketch of the facility is shown in Fig. 1 below.

Shooting an electron beam into a production target creates a spray of positrons. After passing through collimators, the positron beam emittance is still so large that a damping ring is necessary to bring it down to useable levels. The basic performance requirement of the FACET-II positron damping ring is to be able to damp the incoming positron beam from normalized emittance $\gamma\varepsilon = 2.5/2.2$ mm-rad to $\gamma\varepsilon = 7.28$ µm-rad in less than 200 ms to allow damped beam extraction at 5 Hz.

The chosen lattice concept for the positron damping ring is two 180° arcs with injection/extraction straights between (as indicated schematically in Fig. 1), where each arc is a 5-bend achromat. The arc width is limited to ca 2.8 m to allow installation in the existing linac tunnel, leading to short distances between consecutive magnet elements (31 mm distances in initial lattice vs 44 mm pole gaps), as well as relatively high magnet field strengths. The pole gaps can not be reduced further due to the beam stay clear needed for the large emittance incoming positron beam. From a magnet design perspective, this means these 180° arcs are the most challenging in the facility.

INITIAL LATTICE EVOLUTION

In the positron damping ring, each 180° arc consists of three central cells flanked by two dispersion suppressor cells facing the long straights, symmetric around the arc center. An early version of this lattice was presented in the FACET-II Conceptual Design Report (CDR) [2] together with a preliminary magnet design. The magnet elements of this version are listed in Table 1, and the Figure 2 sketch of these magnets shows the arc lattice layout.

Table 1: Version 1.3.1 Arc Lattice Elements, with Field Strengths at 335 MeV

magnet	No [pcs]	l [mm]	r_{pole} [mm]	B [T]	B' [T/m]	B''/2 [T/m^2]
BME	4	189.2	22	-1.44		
BMH	4	283.7	22	-1.44	10.18	
BE	12	124.5	22	-1.44		
BC	6	248.9	22	-1.44	10.18	
QDDS	4	30	22		28.94	
QF2H	4	90	22		-51.24	
QFCH	4	70	22		-45.77	
SD	16	15	22			1579
SF	16	15	22			-1338

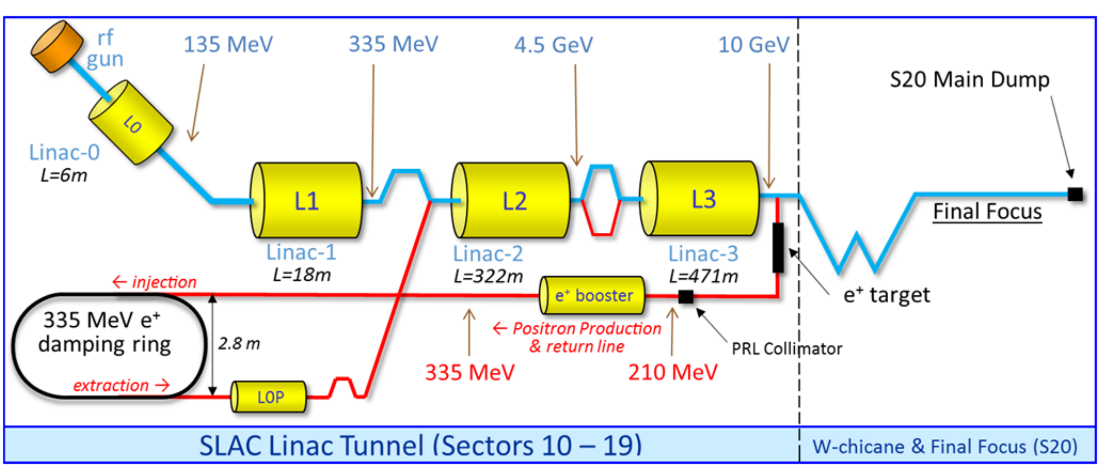

Figure 1: FACET-II schematic layout, with the positron damping ring indicated. Blue line is electron beam path and red line is positron beam path. The whole installation is located in the SLAC linac tunnel, sectors 10-20, with L0 to L3 in this sketch denoting sections of the existing SLAC main linac. (Illustration courtesy of G. White & N. Lipkowitz, SLAC.)

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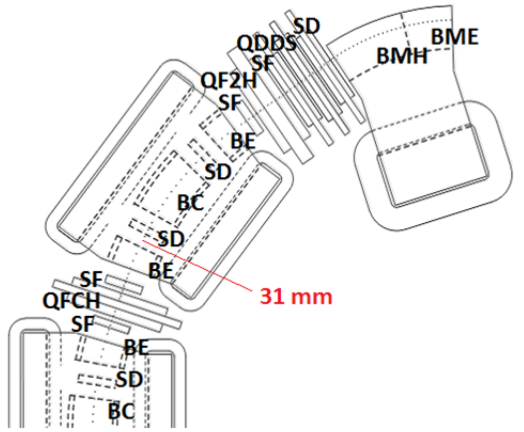

Figure 2: 90° of positron damping ring arc CDR version magnets, viewed from above. Beam direction is counter-clockwise, entering at BME (cf Fig. 1). The smaller SD and SF were assumed to be permanent magnets.

Updated Lattice

To get more space between consecutive elements, a lattice update (v1.3.3) was done combining the quadrupoles and adjacent sextupoles together. The BE-BC-BE layout was unchanged, keeping SD as separate elements. This lattice was used as starting point for detailed magnet design.

First Detailed Magnet Design Attempt

Starting with basic coil design, it is immediately clear that the dipole coils are the most space-consuming, meaning that it is the dipole design that must be solved first. We started with the the BE-BC-BE block, and the Opera-3d [3] model of this magnet, which fits in the lattice v 1.3.3 available length, is shown in Fig. 3.

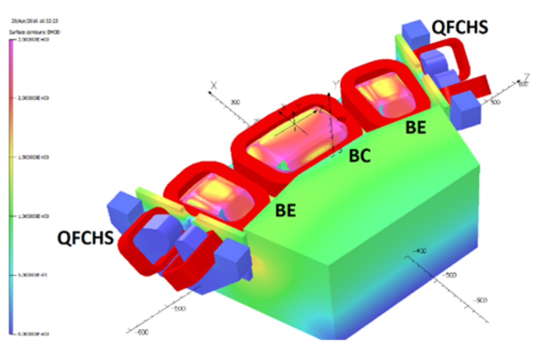

Figure 3: Results from 3d simulation file "BC-BE, MJ160218-06.op3" field distribution in yoke surface for BE and BC coils = 26016 A, QFCHS coils = 0 A. The color scale goes from 0 to 2.5 T.

Major changes compared to the CDR version (Fig.2) were that the return yoke is C-shaped open towards outside, that the coils are located around the poles, and the addition of field clamps to keep the fringe field from extending into the neighbouring quads. It was necessary to use vanadium permendur for both BE and BC, since these short poles pick up stray flux through all sides, causing large parts of the poles to be above 2 T (as seen in Fig. 3).

Introducing Sextupole Content in BC Pole Shape

During the design process, it was realized that the sextupole fields provided by the SD could just as well be distributed over the BC, in the pole shape. Since the sextupole field is of opposite sign to the dipole field, this pole shape adjustment decreases the saturation level in the pole face. A FEMM [4] 2d-model of this design is shown in fig 4. The field in the high side of the pole face is ca 1.7 T, which can be compared to ca 2 T in the 2d model of the Fig. 3 design.

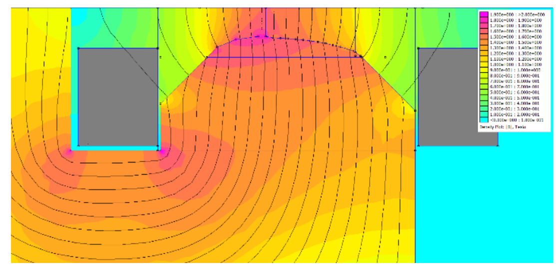

Figure 4: Results from 2d model "BC, MJ160428-16.FEM", field distribution in magnet cross section at NI = 25980 A. The color scale goes from 0-2 T. B_y field in the midplane, by quadratic fit over x = ±20 mm, is B = -1.435, B' = 9.300 and B''/2 = 111.5 T/m^2, with residual <±1 G.

PRESENT LATTICE

The present damping ring lattice (v 1.3.3.1) has adopted the concept of sextupole content in the BC dipoles, removing the permanent magnet sextupoles and the space between BC and BE, releasing more space between the dipole blocks.[1] The quadrupole/sextupoles are also combined. The different magnet elements are listed below.

Table 2: Version 1.3.3.1 Arc Lattice Elements, with Field Strengths at 335 MeV

Magnet	No [pcs]	l [mm]	r_{pole} [mm]	B [T]	B' [T/m]	B''/2 [T/m^2]
BME	4	189.2	22	-1.44		
BMH	4	283.7	22	-1.44	9.34	
BE	12	124.5	22	-1.44		
BC	6	248.9	22	-1.44	9.34	112.1
QDDSS	4	60	22		-7.10	358.4
QF2HS	4	90	22		-39.02	-293.4
QFCHS	4	90	22		-34.47	-293.4

PRESENT MAGNET DESIGN

The present design of the damping ring arc magnets uses the lattice version 1.3.3.1 as basic input. The BE-BC-BE magnet, shown in Fig. 5, has a single long pole with different pole profiles in the central BC part and the flanking BE parts. Compared to the Fig.3 model, this design has lower field in the whole pole[2] allowing it to be made of iron instead of vanadium permendur. The field at the high side of the BC pole face is ca 1.8 T, slightly higher than in the 2D simulation (Fig. 4), but still within what we consider OK.[3]

[1] Note that it is not possible to use this to increase dipole length and decrease the field, since lowering the dipole field increases the damping

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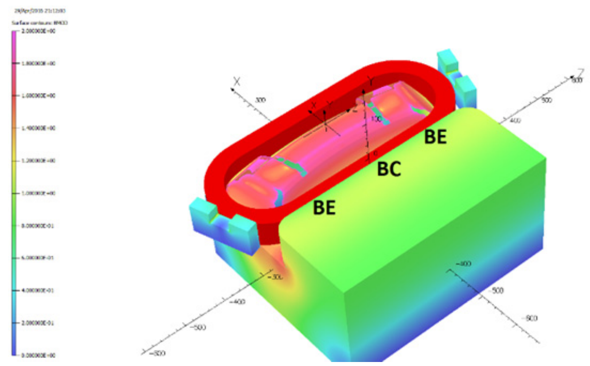

Figure 5: Results from 3d simulation file "BC-BE, MJ160428-24.op3" field distribution in yoke surface for BE/BC coils = 25992 A. The color scale goes from 0 - 2T.

The 3d simulated field in the dipole is analysed by exporting an x,s grid of B_y field values of ca 1x1 mm spacing along the nominal trajectory[4], then subdividing this field map into longitudinal slices and calculating slice average $B_y(x)$ = $\mathrm{int}B_y(x,s)\mathrm{d}s$/slice length, followed by applying a 4th order polynomial fit over x = ±20 mm to each slice. These slice values, as listed in table 3 below, is what is reported back from magnet design to lattice design for evaluation, forming the basis for subsequent design iteration.

Table 3: 3d simulation results from the Fig. 5 model at 2x25992 A, slices in consecutive order from BC center, through BE and straight section out to quad end.

Slice	l [mm]	B [T]	B' [T/m]	B''/2 [T/m^2]	B'''/6 [T/m^3]	B$^{(4)}$/24 [T/m^4]
BC -0	31.1	-1.444	9.420	113.4	-7	-1594
-1	31.1	-1.444	9.392	111.6	63	2221
-2	31.1	-1.444	9.335	110.0	-43	-235
-3	31.1	-1.451	7.655	75.8	-333	570
BE 1	31.1	-1.462	1.371	9.4	-26	1625
0	31.1	-1.456	0.118	1.0	1	594
-0	31.1	-1.294	1.266	5.2	46	11953
-1	31.1	-0.851	1.953	9.6	23	2251
str -2	21.7	-0.528	1.220	17.6	-12	1922
-3	21.7	-0.321	0.608	24.3	-57	13
-4	21.7	-0.137	0.190	23.2	-37	9847
-5	21.7	-0.026	-0.004	14.7	-276	44677
-6	21.7	-0.002	-0.008	3.2	0	-175
-7	21.7	0.000	-0.001	0.1	-1	-20

Comparing Table 3 with the Fig. 4 result, we see that the BC-0 central slice B' and B''/2 agree to ≈1% with the 2d model, indicating that the approach of optimizing a 2d model and then using this pole profile in 3d is valid here.

The B' content that is seen in the BE entrance slices is edge focusing, as specified in the v1.3.3.1 lattice, which has been set by using the BE entrance face angle as a free parameter in the 3d design.

The sextupole and higher order content that is seen in the fringe slices are design imperfections, that in principle could be lowered by more advanced pole shaping in the entrance and BE/BC transition regions. However, preliminary lattice simulations using the Table 3 slices indicate that these do not have any large impact (and that having the distributed sextupole content in the BC pole shape works).

[2] As can be seen in Fig. 5, there is local saturation above 2 T along the sharp edges where the BE profile meets the BC profile, and at the BE outer corners, but this is expected to be easily removed by adding chamfers/smooth transitions, to be done in coming design iterations.

[3] Cf. for example the MAX IV/Solaris 1.5 GeV ring gradient dipoles [5] which have ca 1.7 T in the high side of the pole face.

[4] According to lattice v1.3.3.1, a constant radius arc through the magnet followed by a straight line out from the end.

Interaction Between Neighbouring Magnets

A test has been made by first 3D-simulating with only one magnet at a time present, then repeating with adjacent magnets present (Fig .6), and then repeating again with the other magnets powered. Results are listed in Table 4 below.

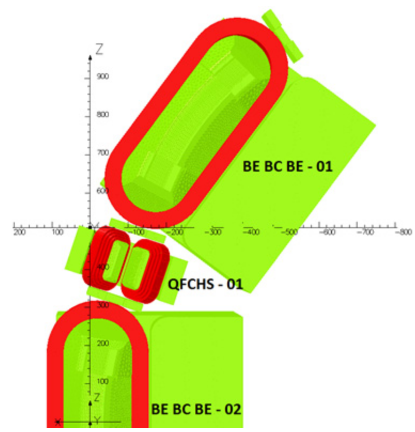

Figure 6: arc Opera-3d model with 3 magnets (cf. Fig 2).

Table 4: Results from 3d simulations, main field component integrated strength per magnet, for repeated simulations with different magnets present/powered.

magnet	alone	with others present	with others powered
QFCHS-01	3.107 T	3.043 T	3.042 T
BEBCBE-02	-0.7185 Tm	-0.7185 Tm	-0.7185 Tm

The quadrupole/sextupole shows some difference between alone and with other magnets present, but a repeat simulation with the dipole field clamps kept in place give int B' = 3.042 T, showing that they are the determining factor.

This coarse check indicate that the different magnets should be possible to field measure independent of each other, meaning that once the task of designing all the magnets to fit in the damping ring 180° arcs has been accomplished, specifying for production should be relatively straight forward.

REFERENCES

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[3] Opera 18R1 (Build 34977) x64 Professional Edition, http://operafea.com

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[5] M. Johansson, MAX-lab Internal Note 20130712, available at http://www.maxlab.lu.se/node/999