Design Studies of a Superconducting Super Proton Synchrotron Upgrade

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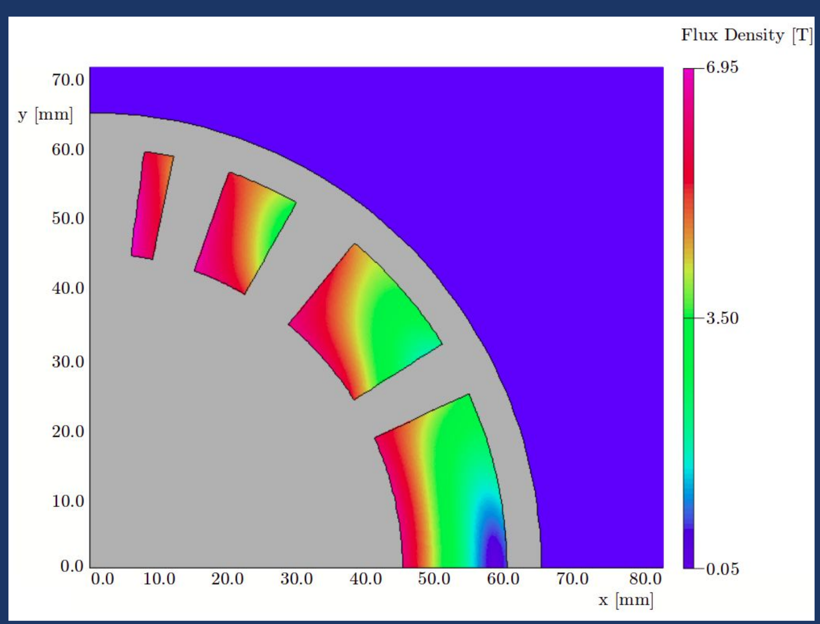
Introduction

- Superconducting SPS (scSPS) upgrade could be a cheap injector for FCC-*hh*[1].
- The upgrade would increase energy from 26 GeV - 1.3 TeV (SPS 450 GeV).
- Design requires:
  - Further lattice studies, including dispersion suppression and chromaticity correction.
  - Fast ramping 6 T dipoles and 146.25 T/m quadrupoles.
  - New high bandwidth RF system.
- First year JAI students completed a design study on the lattice, magnets and RF cavities.

Magnets

- Superconducting dipole and quadrupole magnets designed with cable based on fast ramping SIS300 magnets[3].
- Single layer design with 15 mm thick NbTi cables able to run @ T = 1.9 K.

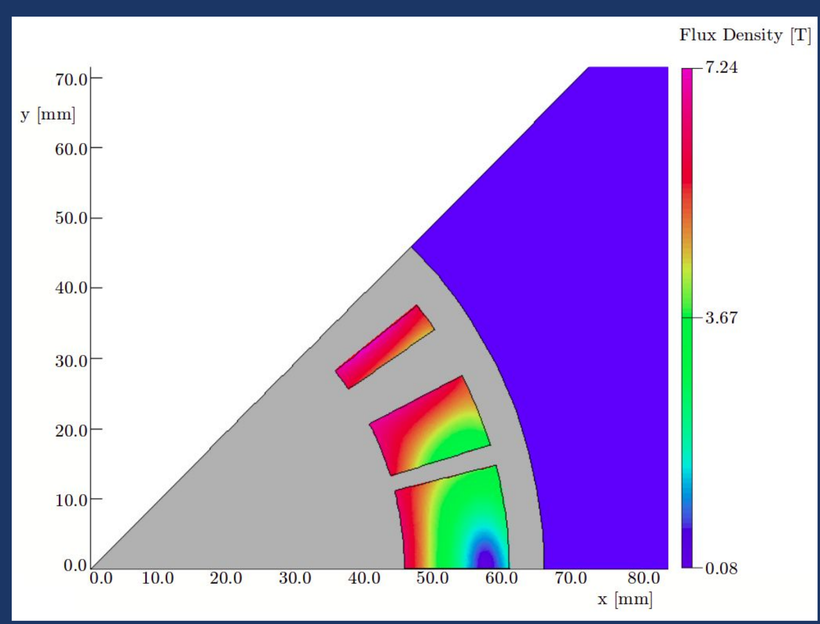
Dipole



Load margin 74 %

		I = 224 A	I = 12,500 A
b1	[1e-4]	10,000	10,000
b3	[1e-4]	-138.50	-34.04
b5	[1e-4]	70.64	77.23
b7	[1e-4]	3.75	4.56
b9	[1e-4]	4.88	5.33

Quadrupole



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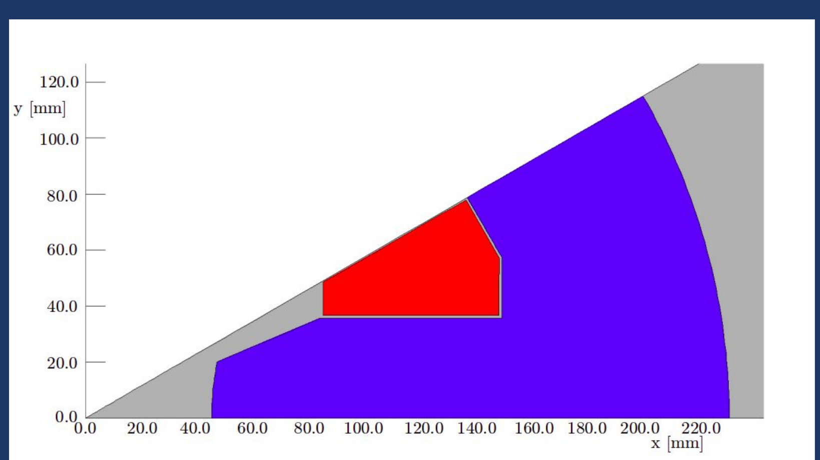
		I = 305 A	I = 17,500 A
b2	[1e-4]	10,000	10,000
b6	[1e-4]	-9.08	2.08
b10	[1e-4]	1.55	1.86
b14	[1e-4]	0.01	0.02
b18	[1e-4]	0.07	0.08

- Design would be significantly easier with 50 GeV injection from PS2.

Sextupole

- Normal conducting sextupoles designed with water cooled copper cables.

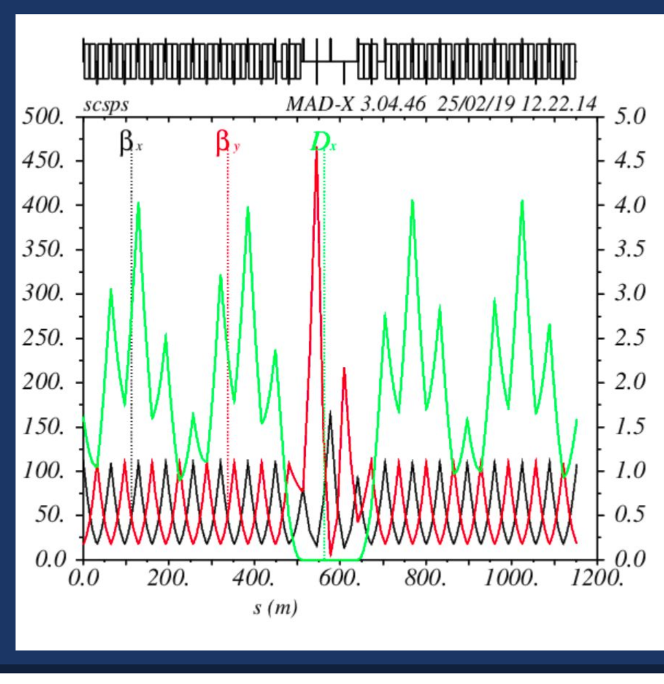


		j = 3.2 Amm^{-2}
b3	[1e-4]	10,000
b9	[1e-4]	7.92
b15	[1e-4]	5.72
b21	[1e-4]	2.03
b27	[1e-4]	1.54

- Peak magnetic flux density in core B_{max} = 1.85 T.
- A superconducting design could reduce the number of sextupoles.

Lattice

- The current SPS cell length, 64 m^2, was compared to 57.6 m and 72 m.
- All three cell lengths fit tunnel dimensions, but 64 m is the optimum.
- Three methods of dispersion suppression were investigated, reduced field, singularly powered quadrupole and trimmer quadrupole suppression.
- Each method reduced the dispersion in the long straight sections (LSS) to 0.
- The reduced field method and singularly powered quadrupoles increased $\beta_{x,y}$ in arcs.
- Trimmer quadrupoles increased $\beta_{x,y}$ in LSS.
- The current SPS missing dipole scheme remains the optimum method.

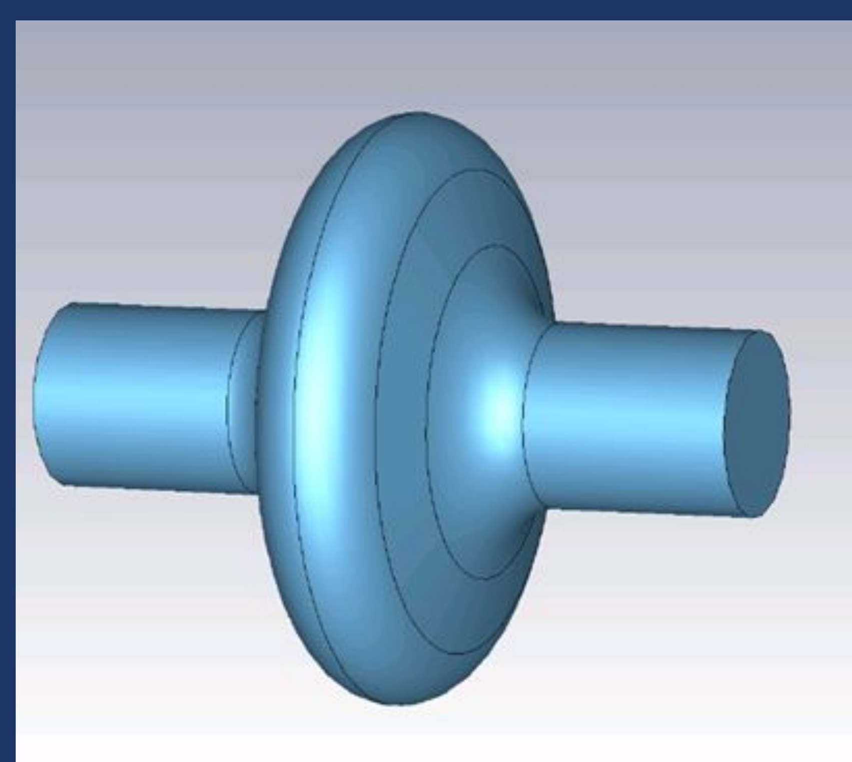


Chromaticity Correction

- A new chromaticity correction scheme must be devised for the scSPS.
- The chromaticity for the scSPS was calculated to be -35.3.
- Using 216 sextupoles, similar to the current SPS, with a maximum pole tip field of 0.33 T, chromaticity can be reduced to ~ 0.02.

RF Cavities

- Superconducting (sc) cavities are desirable due to their reduced power losses for same accelerating gradient compared to normal conducting.
- RF frequency constrained at < 240 MHz due to capture efficiency of 4.2 ns beam from PS - leads to large space requirements of sc cavity (diameter ~ 1.5 m, inside SPS tunnel diameter ~ 4 m).
- Due to energy swing of scSPS, RF cavity must have wide frequency range (130 kHz for 200 MHz cavity) - natural frequency bandwidth of sc cavity is < 1Hz and hence novel tuning methods would be required.
- A sc cavity at 200 MHz was designed and optimised using SUPERFISH to reduce surface fields, maintain transit time factor and suppress higher order modes (HOM). It was found that increasing aperture radius improved HOM suppression.
- Final geometry was tested using CST Microwave studio, and gave results consistent with SUPERFISH.



Conclusions

- The scSPS lattice can be based on the SPS lattice causing minimal problems.
- Single layered superconducting magnets can operate successfully at 1.9 K.
- Operation at higher temperatures would require a 2 layer graded design.
- Chromaticity correction only requires normal conducting sextupoles.
- A superconducting 200 MHz RF cavity was designed for scSPS parameters, with considerations for HOM suppression, peak fields and transit time factor

Future Work

- Investigate using fewer, stronger sextupoles for chromaticity correction.
- Mechanical properties and stresses must be calculated for magnets.
- Evaluation of extra cryogenic costs vs. cost of a second layer of superconductor need for operation at 4.2 K.
- Investigate hybrid RF design, using nc cavity for beam capture followed by sc cavity for acceleration to high energies.
- Study further the benefits of 50 GeV injection from the PS2.

References

[1] F. Burkartet al., "Conceptual design considerations for a1.3-TeV superconducting SPS (scSPS)," inProc. IPAC'17 Copenhagen (2017).
[2] The 300 GeV programme. Geneva: CERN, 1972. url: https : / / cds . cern . ch / record /104068.
[3] H. Mueller et al. "Next Generation of Fast-Cycled Dipoles for SIS300 Synchrotron". In: IEEE Transactions on Applied Superconductivity 24.3 (June 2014), pp. 1–4. issn: 1051-8223. doi: 10.1109/TASC.2013.2287635.

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