Advanced design study of superconducting septum magnet for FCC

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FCC-hh extraction

- FCC-hh extraction septum system (from CDR)
  - two stage single-plane extraction
    - superconducting shield septum (Sushi)
      - septum thickness 20 mm, 3 T, 10 m long
  - truncated cosine-theta septa
    - septum thickness 30 mm, 4T, 40 m long

Courtesy of Elisabeth Renner
FCC septum geometry

Injection
1.3 TeV, 3.3 TeV

- superconducting coil
- mechanical support
- cooling
- beam pipe

(25~)30 mm
19 mm
(36.5~)41.5 mm
23 mm

32 mm
25 mm

4 T

34 mm
43 mm
64 mm
49 mm
Why GSI needs high field septa?

- FAIR accelerator complex – *under construction*

**GSI accelerator facility**

**Fair accelerator facility**

**Status**

- **SIS100**
  - dipole magnets
  - produced > 50/108
  - tested > 30/108
  - quadrupole doublet modules
    - First-of-Series under assembly

- **Super-FRS**
  - multiplet
  - First-of-Series under testing
  - dipole
  - First-of-Series Q1 2020

**Future SIS”X”00 (X≥3)**

- Beam rigidity X times higher
- Building is fixed, same as SIS100
- SIS100 with ~ 1.0 Tesla septum
  - ➞ septum magnet $X \ T \geq 3.0 \ T$
## Dipole magnet

- Iron-dominated (Window-frame) Magnet
- Current dominated, cosine-theta Magnet
- More than ~ 2 Tesla

### Septum magnet

- B = 0
- Truncated cosine theta (with iron yoke)
analytical computation

• Useful for "first step" of design
  • necessary ampere*turns
  • define Rc/Ry ratio
  • current density estimation
    • septum < cosine-theta
  • number of cables
    • in cosine-theta aperture
    • between iron yoke and cosine-theta

\[ j = -j_0 \cos \theta \]

\[ B_0 = \frac{\mu_0 j_0}{2} \left( \frac{R_c}{y^2} + \frac{R_c}{R_y^2} \right) \]

\[ B_1 = \frac{\mu_0 j_0}{2} \left( \frac{1}{R_c} + \frac{R_c}{R_y^2} \right) \]

\[ j_i = \frac{j_0}{2} \left( \frac{1}{R_c} + \frac{R_c}{R_y^2} \right) \]
**cross section design**

- **How to design**
  - make full dipole magnet cross section
    - peak field of iron yoke < ~ 2T (no saturation is preferable)
  - keep only one side of full cosine-theta coil, introduce a septum coil
    - in the coil radius, the septum coil cables are constantly arranged
    - out side, the distance increases
  - septum coil must be arranged in the aperture of the yoke
  - no magnetic material (shielding) at the circulating beam side
coil end design

- Complex!
  - two stage coil end
    - symmetric cosine-theta cold end
    - lift-up the cables in positions

Nuclotron cable
(fast ramp, high heat load)

Surface winding
(Medical accelerator)
coil end design

- cosine-theta coil can be simplified
  - lower requirement for the field quality w.r.t. the magnets in the ring
  - saddle shape, block coil near mid-plane
  - racetrack coils, near pole

Preliminary design with flat cable (no keystone angle)

\[ R_{\text{ref}} = 11.5 \text{ mm} \]
\[ b_2, b_3, b_4 = \text{several unit} \left(10^{-4}\right) \]
coil end design

Racetrack coil

Saddle coil

Extracted beam
summary

* achievement
  ✓ truncated cosine-theta concept developed
  ✓ theoretical studies
  ✓ know-how of 2D electromagnetic design
  ✓ 2D optimisation with software (Roxie)
    ● target: 4 T septum, NbTi cable, 30 mm septum thickness
  ✓ preliminary mechanical analysis (2018)
  ✓ various coil end designs are proposed

* further R&D work
  ● mechanical and cryogenic design studies
    ● iteration of electromagnetic design and engineering design
  ● prototyping

* collaborations
  ● general CERN–GSI collaboration meeting (2nd July)
  ● discussion, suggestion, collaboration proposal are very welcome!
Thank you very much!