Magnets Working Group Meeting Notes

Magnet Working Group

30 March 2023

Indico Link: https://indico.cern.ch/event/1240043/

News

- Kick off meeting for MuC on 28/03/23 -> Please check the slides from the indico link MuCol kick-off: https://indico.cern.ch/event/1219912/
- For an upcoming meeting, we could report on the cooling solenoids
- Upcoming annual meeting
- Topics for upcoming meetings
  - Topic: conductors
    - Draft HTS procurement spec (link from 2 meetings ago)
  - Topic: performance limits of collider magnets
  - Topic: radiation protection, discussing what areas are going to be active
  - Topic: moving magnets by roughly 15cm up/down in machine

Annual Meeting Agenda

- Give a presentation in the annual meeting - for the accelerator, collider, cooling etc. what technology options do we have available (mini-report)? And what do we want to do for those options → **Send Luca ideas for preparation.**

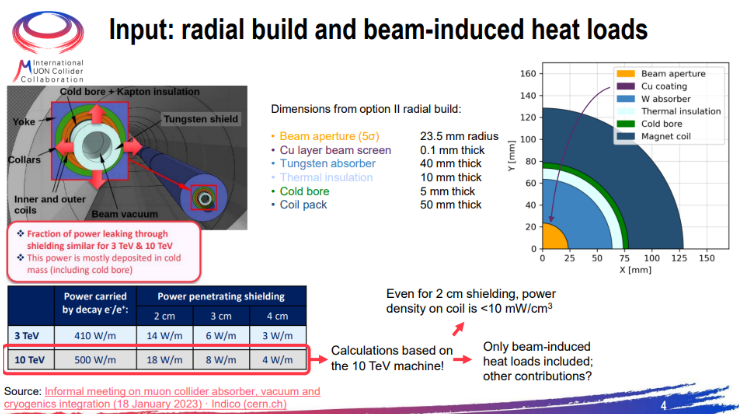
Presentations

I. Cryogenics options for future accelerators
II. Solenoids for 6D Cooling

I. **Cryogenics options for future accelerators (focused on the collider) –** Dr Patricia Tavares Coutinho Borges De Sousa

Some key notes

a) Radial build for Dipole (and quadrupole) magnets in arc are taking shape
b) Input radial build diagram (see slide pasted below)
   a. Absorber can be 2 to 4 cm based on previous meetings



c) Heat loads (steady-state)
   a. Heat inleaks: thermal radiations, conduction via supports
   b. Beam induced: beam decay, image charge, synchrotron radiation, etc.
      i. Decay (500 W/m)
   c. Resistive heating (magnet splices, current leads) – yet to be defined!
d) Final heat load to consider on absorber essentially just from beam decay: 500 W/m
e) **Heat load estimation – assumptions made:**
   a. Cold mass temperatures: 2, 4.5, 10, 20 K
   b. Heat load to cold mass (dependent on absorber thickness and cold mass temperature)
      i. See slides for detailed specs how each heat load defined in c) is calculated
   c. Absorber temperature: 80 to 300 K
   d. Heat load to absorber (independent of absorber geometry): 500 W/m
   e. External thermal shield around cold mass temperature: 80 K
f) See slides 8 and 9 (9 includes a heat intercept option) for detailed plots of the heat loads to the cold mass as a function of the varied cold mass temperature and absorber temperature from the various sources. Some key takeaways
   a. Heat load to coil/cold mass largely independent of coil/cold mass temperature, however, the effort to extract the heat will heavily depend on this temperature!
   b. Lower absorber temperature is better, reaching down to a minimum of roughly 5 W/m (at absorber temperature 80 K)
   c. With a heat intercept, the minimum 5 W/m roughly unchanged, but at higher absorber temperatures heat load much less (~half).
g) How does heat load transfer to operating electric power (assume that 25 MW gets allocated to the collider ring)
   a. 25 MW for the collider translates to 2.5kW/m -> we aim to stay at or below this!
h) Increasing the Coil temperature and the absorber temperature helps go toward the target of < 2.5kW/m
i) Adding a heat intercept between coil and absorber improves things
j) Fluid Options (**see slides** for advantages/disadvantages for each):
   a. absorber cooling - for given absorber temps:
      i. ~300K – single-phase water
      ii. 250K – two phase CO2
      iii. 100K – two phase N2
      iv. 80K   – two phase N2
   b. Cold mass cooling – for given cold mass temps:
      i. 20K – two phase H2
      ii. 10K – supercritical He
      iii. 4.5-5.5K – supercritical He
      iv. 2K   – He II
k) Distribution losses – see slides for rough estimation of these losses

l) Summary and combination of all requirements
    a. To stay below 2.5 kW/m, absorber temperature must be above 230 K
m) **Combining requirements** from both energy consumption and what is feasible at absorber and coil levels:
    a. Absorber temperature ≥ 250 K
    b. Coil temperature ≥ 4.5 K
    c. Power consumption ≤ 2.5 kW/m

Some questions and comments

- Reducing absorber thickness from 4 cm to 3 cm, heat load doubles, but heat conduction from support reduced only by 30 %
- [LB] – power allotted for collider ring (25 MW) needs to be re-looked at (based on an initial power estimation for MuC of 300 MW). [DS] – ''in the initial estimations, got 35 MW for the cooling of the collider ring"
    - 'You have to compute in the power calculation, must include distribution loss multiplied by copper temperature'' – LB ...*
- Coil and cold mass distinction – assumed these temperatures are temperature levels in the cooling pipe... but if cooling tube is far away in yoke maybe need to consider coil temp could be a bit higher.
- Absorber material is Tungsten. consider other materials with better heat conduction ex. with water.

II. **Initial Evaluations of the Cooling Solenoids for the Rectilinear 6D Cooling Channel –**

Jonathan Pavan, Dr Siara Fabbri

Some key notes

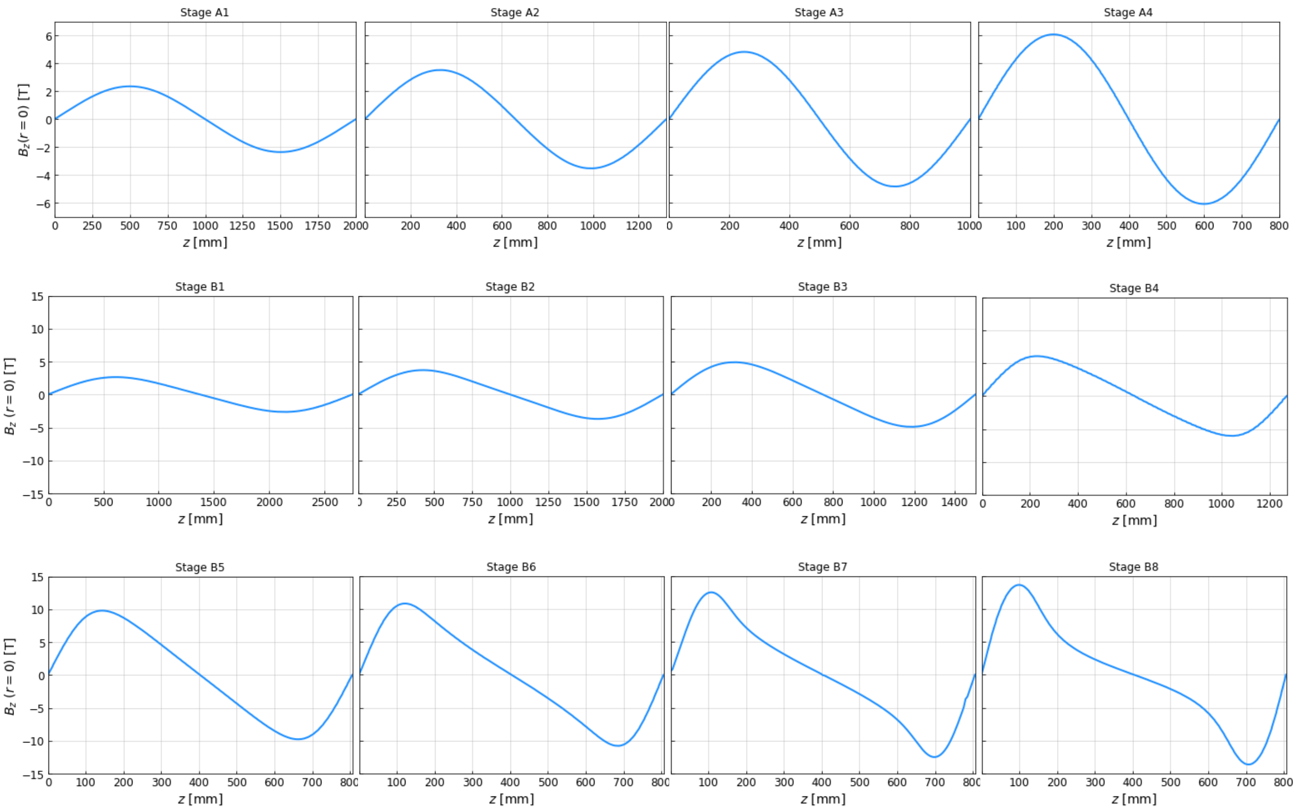
a) Goal of study presented: Simulate and characterize the cooling solenoid magnets based on geometries and parameters from US MAP study
b) Simulation Study:
- Methods: COMSOL, validated against analytic equations and supplied G4beamline fieldmaps
- Parameters computed: magnetic fields, stray fields, inductance and stored energy, stresses, forces, mechanical props (mass of coils)
- Computation types: single coil types, single cells, cell in a lattice
- See slides for more details on mesh and computation...

c) Overview of cooling stages as provided by US MAP study:
- 12 unique stages: 4 before bunch recombination (A1 to A4), 8 after bunch recombination (B1 to B8)
- Each stage has a unique number of a repeating cell type
- Each cell type consists of at least 2 to 6 solenoids, symmetric with opposite polarity.
- **Fields on axis: 2 to 14 T**
- Cell Lengths: 0.8 to 2.7 m
- Total length of all Stages: ~ **1 km**

- 18 unique coil types
    i. 2 to 6 coils per cell
    ii. Inner bore diameter from 90 mm to 1540 mm
    iii. Lengths from 80 mm to 210 mm
    iv. Current densities from 63 to 220 $\mathrm{A/mm^2}$

- Total number of solenoids: 2432

d) On axis fields:



e) Key takeaway points:
- Very high possible self inductance in large coils such as those in B1 (Ex. w/ REBCO 12x0.11mm tape, self inductance in single coil around 6000 H)
- Largest single coil mass: B1 coil – 3567 kg.
- Very high total magnetic energy in some coils (B1 single coil – 27 MJ). For reference, LHC dipoles store 7 MJ.
- Very high peak fields at the conductor (above 17 T, max 18.9T in single cell B6) -> gets difficult for Nb3Sn.
- Large stray fields.
- Hoop stresses up to 336 MPa (above 150 MPa requires reinforcement), radial stresses which are in tension (this is a problem), large longitudinal forces (peak 36.8 MN…).

f) What this study didn't include:
- A more complicated mechanical structure
- Matching sections b/w stages
- Iron, realistic space requirements, …
- Dipole magnets.

Some key questions and comments (from later discussions with Chris Rogers)

- If iterating the magnet design, just need to match on axis field profile (and analyze the harmonics)
- The demonstrator will likely be B2 or B3 (B7 maybe too complicated)
- Next steps – iterate the design process around a radial build (RF design Alexej.grudiev@cern.ch, shielding, insulation) and the magnet parameters -> explore the limits of overlap between optimal/desirable magnet parameters and the desired on axis field profile.