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1. Background and objective
Magnets wound with coated conductors for a rotating gantry
- High thermal stability and cooling by cryocooler
- Ac losses generated by time-dependent magnetic field

Electromagnetic field analysis
Precise ac loss estimation is essential!! Practical accelerator magnets have three-dimensional geometry

Evaluation of feasibility of a conduction-cooled cosine-theta dipole magnet wound with coated conductors for a rotating gantry for carbon cancer therapy

2. Analysis model
Equation to be solved in analysis model
\[ \nabla \times \left( \frac{1}{\sigma} \nabla \times T \right) + \frac{\partial}{\partial t} \mu_0 \int \frac{(\nabla \times T') \times r}{r^3} dV + \frac{\partial B_{ext}}{\partial t} = 0. \]

Thin strip, nested-loops, and block approximations are used in this model

3D shape of the magnet
Layer-by-layer model
Analyzed layer (every layer is analyzed in turn)

Non-analyzed layers
Generating \( B_{ext} \) to analyzed layer

The influence of iron yoke is considered as the image currents in the iron yoke.

3. Details of analysis conditions
Specifications of analyzed magnet
- Number of turn (conductor length): 2744 (5.48 km)
- Length of straight section: 700 mm
- Length of entire magnet: 1082 mm
- Inner radius of magnet: 60 mm
- Separation of turns: 0.1 mm
- Dipole component: 2.64 Tm
- Higher multipole components: \(< 10^{-4}\)
- Relative permeability of iron yoke: 3000

Parameters of coated conductor
- Width: 5 mm
- Thickness: 0.2 mm
- Superconductor layer thickness: 2 \( \mu m \)
- \( E_c \): 10^4 V/m
- \( I_c \): 1.6 \times 10^7 A/m^2 at 20 K
- \( B_{c} \): 1.3 \times 10^7 A/m^2 at 30 K
- \( B_i \): 1.0 T

Specifications of current profile
- FF: 200 A, 100 s
- S1: 150 A, 10 s
- S2: 100 A, 10 s
- Ramp up/down rate: 2 A/s

4. 3D loss density distribution
3D loss distribution at the end of 2nd RU at 20 K (\( I/I_c = 55\% \))

- Higher loss densities in 1st and 2nd layers
- Loss concentration in the straight section
  - higher normal magnetic field seen by coated conductors

5. Temporal evolutions of ac losses
- Loss at 30 K > loss at 20 K
  - Higher \( I/I_c \) at 30 K
- Much larger ac losses in first RU
  - Large fluxoid movement in coated conductor

6. Feasibility of the conduction-cooled magnet
- Recent cryocooler having the cooling capability in the tens of watts at around 20 K or 30 K

- The conduction-cooled magnet for the rotating gantry is feasible from the viewpoint of the heat load by ac loss except first RU.
  - Slow ramp for the first RU is one method to reduce ac loss, and it is acceptable for rotating gantry magnet.

Poor cooling in the straight section of inner layers will cause thermal runaway and burnout!!