1LP3-03

AC loss calculation of a cosine-theta dipole magnet wound with coated conductors considering iron yoke influence

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1. Background and objective

Magnets wound with coated conductors for rotating gantry

○ High thermal stability and cooling by cryocooler

× Ac losses generated by time-dependent magnetic field

To evaluate...

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

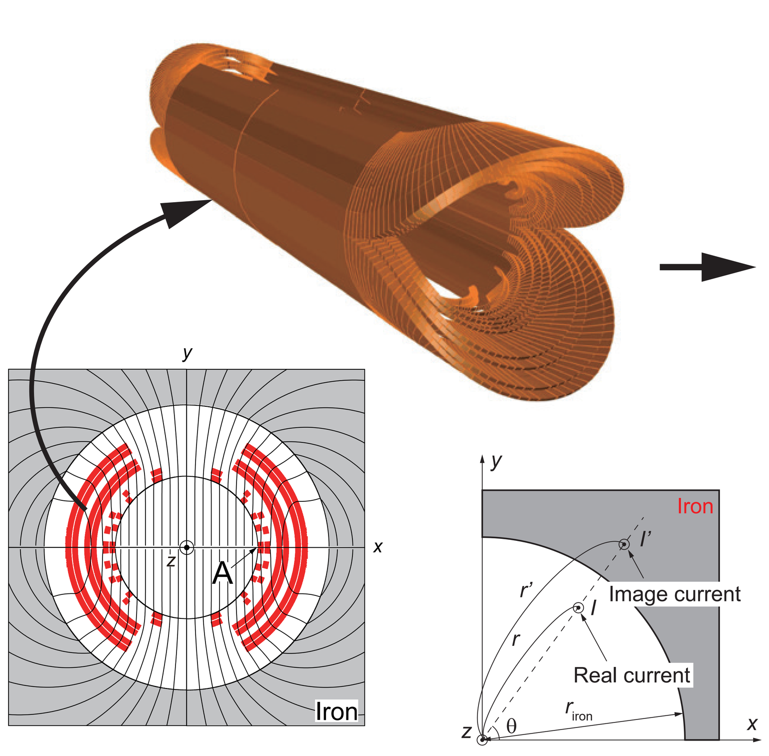
Equation to be solved in analysis model

$$\nabla \times \left(\frac{1}{\sigma} \nabla \times \boldsymbol{T} \right) + \frac{\partial}{\partial t} \frac{\mu_0}{4\pi} \int_V \frac{(\nabla \times \boldsymbol{T}') \times \boldsymbol{r}}{r^3} \mathrm{d}V + \frac{\partial \boldsymbol{B}_{\mathrm{ext}}}{\partial t} = \boldsymbol{0}.$$

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

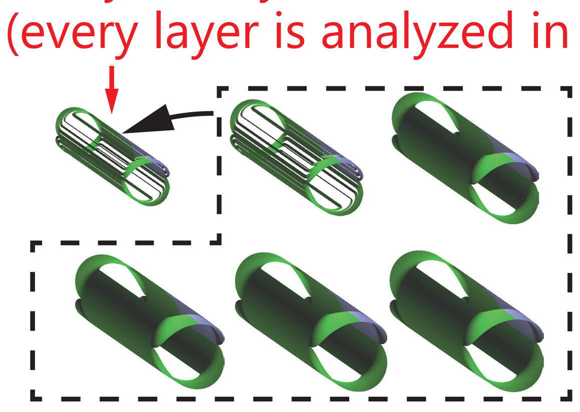
Y. Sogabe, et al.: IEEE Trans. Appl. Supercond. vol. 25, no. 3 (2015) Art. No. 4900205.

3D shape of the magnet



Layer-by-layer model

Analyzed layer (every layer is analyzed in turn)



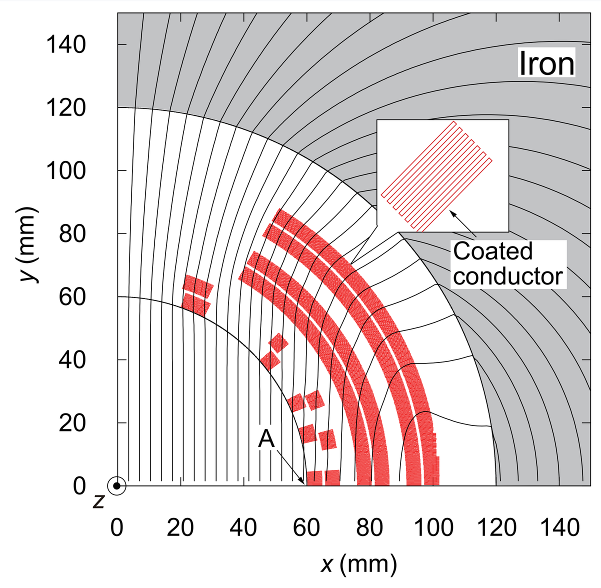
Non-analyzed layers

Generating $\boldsymbol{B}_{\mathrm{ext}}$ 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 iro yoke	3000



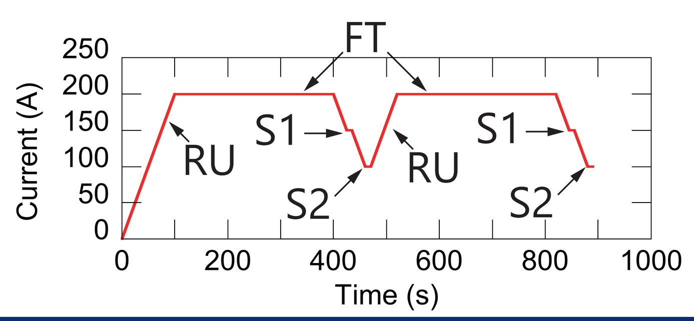
Cross-section

Parameters of coated conductor	
Width	5 mm
Thickness	0.2 mm
Superconductor layer thickness	2 µm
E_0	10^{-4} V/m
n	40
J_{c0}	1.6×10^{11} A/m² at 20 K 1.3×10^{11} A/m² at 30 K
B_0	1.0 T

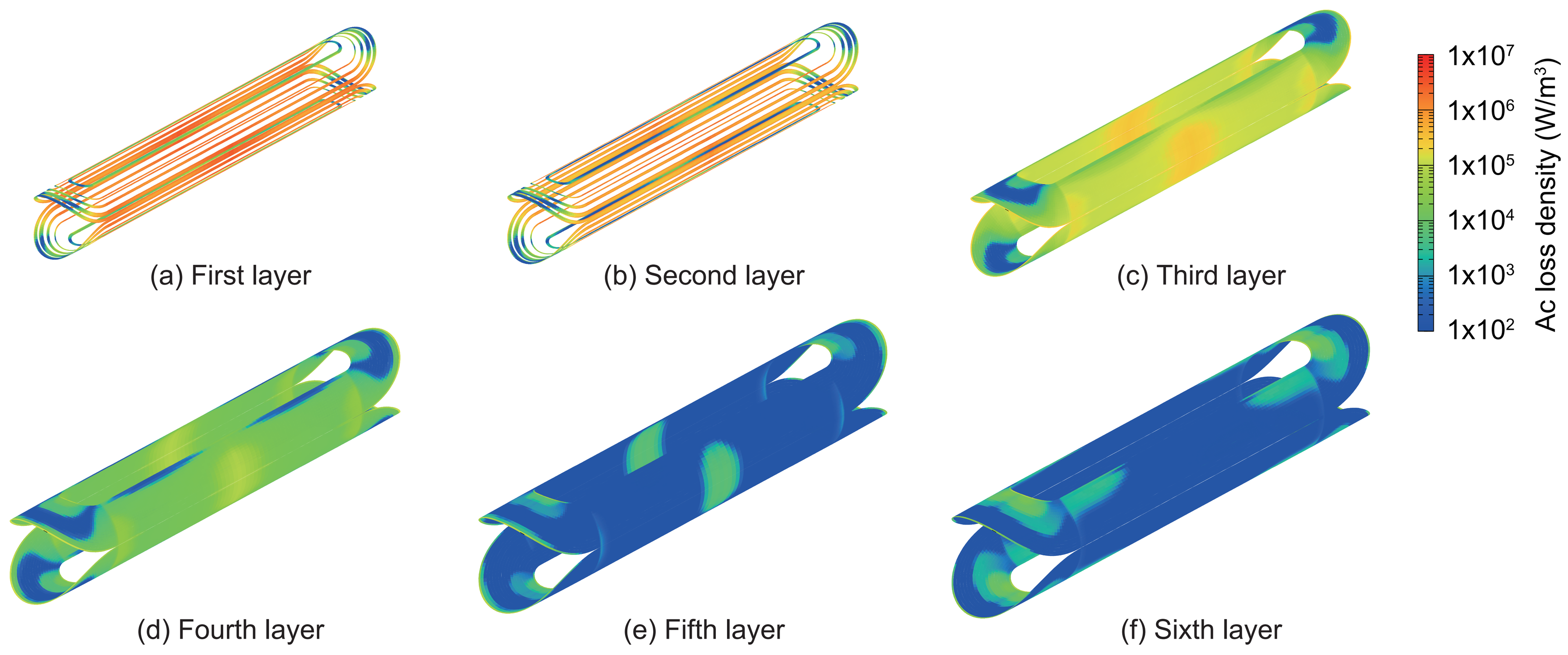
Power-law model $E = E_0 \left(\dfrac{J}{J_c} \right)^n$

Kim model $J_c = J_{c0} \dfrac{B_0}{B_0 + |B_n|}$

Specifications of current profile	
FT	200 A, 300 s
S1	150 A, 10 s
S2	100 A, 10 s
Ramp up/down rate	2 A/s



4. 3D loss density distribution

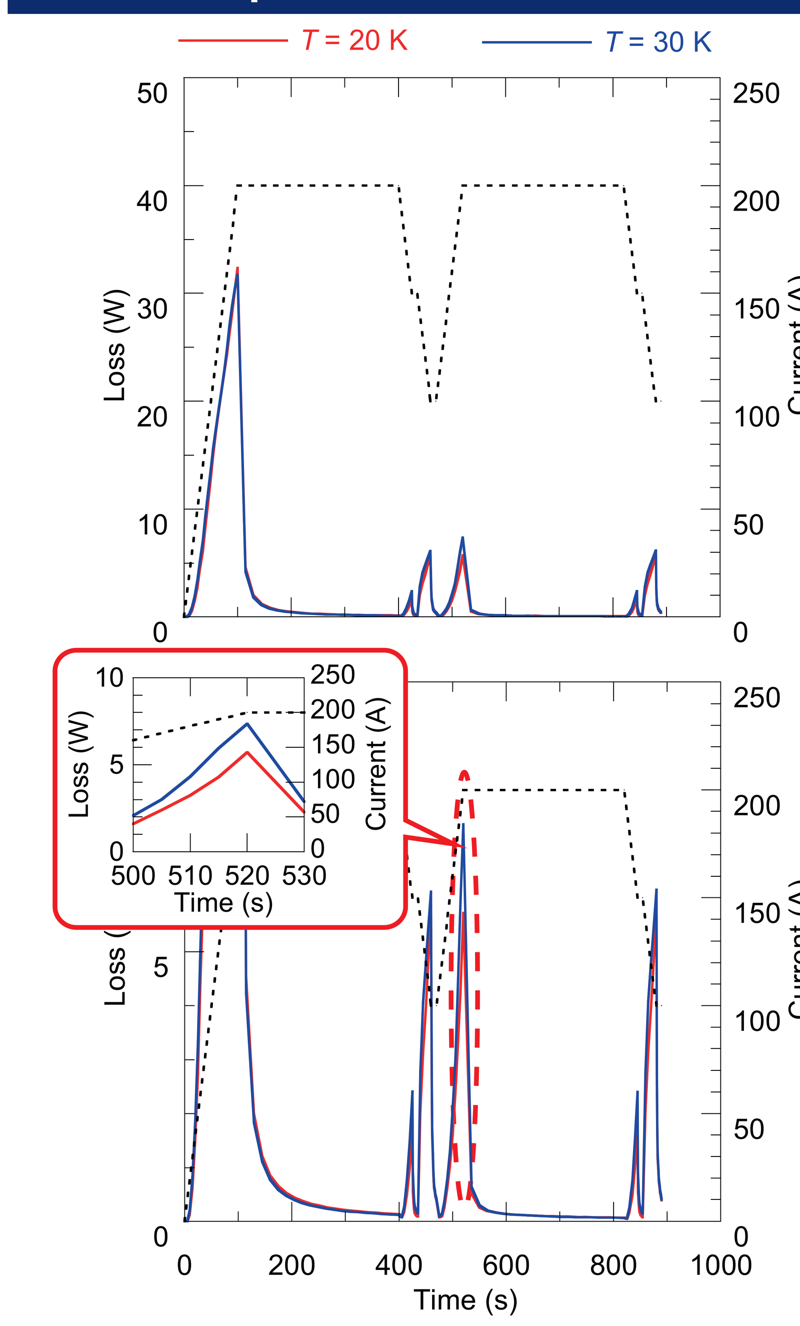


3D loss distribution at the end of 2nd RU at 20 K (I_t / I_c = 55%)

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

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

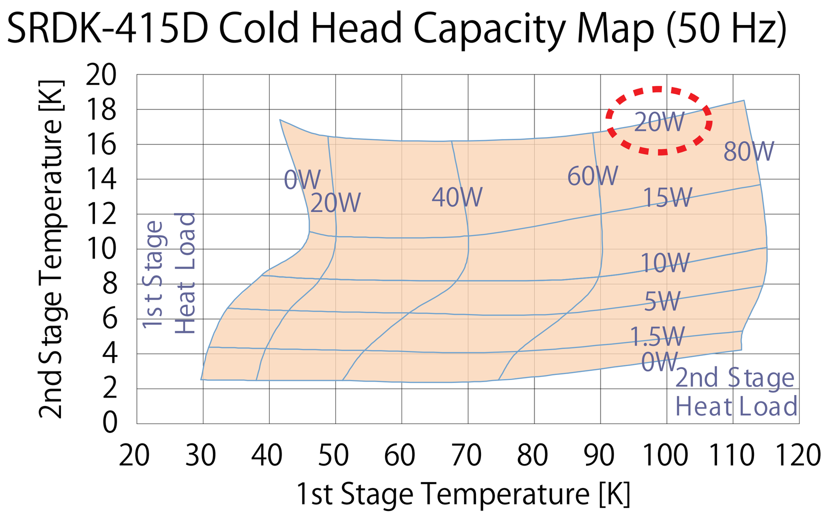
5. Temporal evolutions of ac losses



- Loss at 30 K > loss at 20 K
  ← Higher I_t / I_c (lower I_c) at 30 K
- Much larger ac losses in first RU
  ← Large fluxoid movement in coated conductor
- Peak overall ac losses were *5.7 W* at 20 K, and *7.4 W* at 30 K
  ← Peak losses appeared at the end of the second RU

6. Feasibility of the conduction-cooled magnet

SRDK-415D Cold Head Capacity Map (50 Hz)



Sumitomo Heavy Industries, Ltd., Cryocooler Product Catalogue

- 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.

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