A simplified electromagnetic modelling of accelerator magnets wound with Conductor on Round Core wires for ac loss calculations

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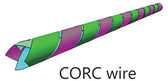
1. Background and objective

Conductor on Round Core (CORC) wires

are attractive for accelerator magnets.
3D geomatry of them is challeging for simulations.



Accelerator magnets using HTS coils

required *time-dependent* magnetic field generation.

↓

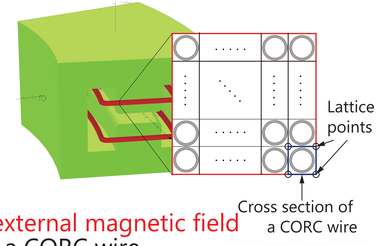
AC loss reduction in HTS coils is one of the key issue.

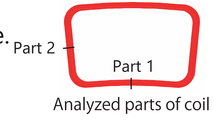
- Development of 3D electromagnetic field analysis model for accelerator magnets wound with CORC wires.

2. 2D field calculation in coil cross-section

Calculate magnetic field seen by a cross section of a CORC wire

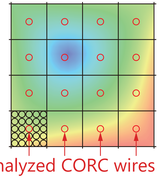
- Assuming uniform current distribution in cross sections of the CORC wires in the magnets
- Calculate magnetic field of lattice points of a cross section and calculate magnetic field of each element of the CORC wire using data of lattice points
  →Use data of each element as external magnetic field in the calculation of ac loss in a CORC wire
- Full size analysis of coil will take too much time.
  →Analyze typical part only
  Estimate full size loss from those results



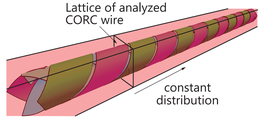


3. 3D field distribution in a single CORC wire

- Considering distribution of magnetic flux density, we divide cross section of coil into 16 parts, and analyze CORC wires which is at the center of each parts of cross section
- Assuming 2D external magnetic field distribution in cross-section is uniform in longitudinal distribution of CORC wire



Ignored to obtain external magnetic field
Exact current distribution in coil
3D geometry of Coil
Shielding current in coated conductors



4. Governing equation of analyses and consideration of iron yoke

Governing equation of simulations

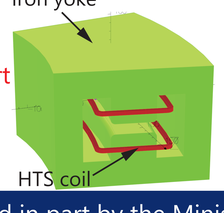
$$\nabla\times\left(\frac{1}{\sigma}\nabla\times\boldsymbol{n}T\right)\cdot\boldsymbol{n}+\frac{\partial}{\partial t}\frac{\mu_0 t_s}{4\pi}\left(\int_{S'}\frac{(\nabla\times\boldsymbol{n}'T')\times\boldsymbol{r}\cdot\boldsymbol{n}}{r^3}\mathrm{d}S'+\boldsymbol{B}_{\mathrm{ext}}\cdot\boldsymbol{n}\right)=\boldsymbol{0}.$$

Using thin strip approximation
Applied Hierarchical matrices

[1] M. Nii et al., SUST, vol. 25, Art. no. 095011.
[2] N. Tominaga et al., IEEE-TAS, vol. 28, Art. no. 4900305.
[3] Y. Sogabe et al., IEEE-TAS, vol. 29, Art. no. 5900505.

Calculation of external magnetic field in magnets having iron yokes

Magnetic flux density generated by the HTS coil current without the current in analyzed part
+
Externally-applied magnetic flux density to the HTS coils generated by the magnetized iron yoke

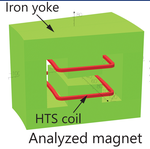


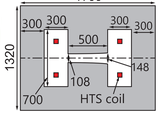
5. Specifications of analyzed magnet and coil

Magnet parameters	
Maximum magnetic flux density	1.40 T
Bending radius	5.00 m
Bending angle	11.25 degree
Length of dipole magnet	1.053 m

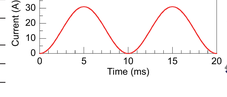
Coil and current parameters	
Current	31.0 A/turn 186 A/wire
Frequency	100 Hz
Number of CORC wires	400 wires (20 × 20)

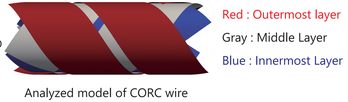
CORC wire parameters	
Number of layers	3
Number of tapes in each layer	2
Diameter of core	2.5 mm
Width of tape	2.0 mm
Thick of superconducting layer	1.0 μm
Distance between bottom of tape and superconducting layer	7.5 μm
Distance between tapes	45.0 μm
Pitch length	5.6 mm
Distance between wires	0.03 mm



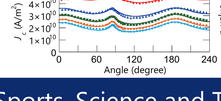


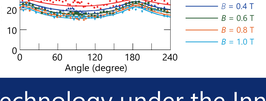
Analyzed magnet



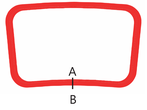


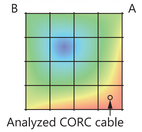
Analyzed model of CORC wire
view from inside of coil



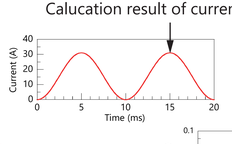


6. Example of analysis result of a CORC wire

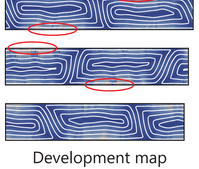




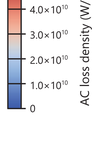
Analyzed CORC cable



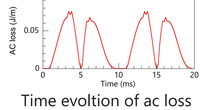
3D distribution



Development map



Loss density distribution of a CORC wire



Time evolution of ac loss

Total ac loss of 2nd cycle
9.91 J/m/cycle

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