AC loss calculation of two-layer REBCO superconducting cable by 3D electromagnetic field analysis

Ryo Okadome and Hideki Noji

National Institute of Technology, Miyakonojo College
Advanced Course of Mechanical and Electrical Engineering

Outline

1. Background and objective

2. Calculation method of AC loss

3. Calculation results and discussion

4. Summary

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1. Background and objective

What is superconductivity

Phenomenon in which electric resistance becomes zero at a certain temperature when cooling certain metals and semiconductors to absolute zero

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Superconductivity applied to the field of power transmission.

Problem of conventional cable

Due to the electrical resistance, 5% of the power generation amount is a loss.

Benefits of Superconducting Cable

・The power loss at the time of power transmission and the cost of the entire power transmission infrastructure can be reduced.

・The superconducting cable is large capacity and compact, they are easy to under the ground in urban areas.

Fig.1 AC superconducting cable

Source : http://www.sei.co.jp/ir/individual/step04.html

1. Background and objective

Problems of superconducting cable

Loss occurs when passing alternating current through the superconducting cable.

through the superconducting cable

Direct current → Loss is zero

Alternating current → Loss occurs

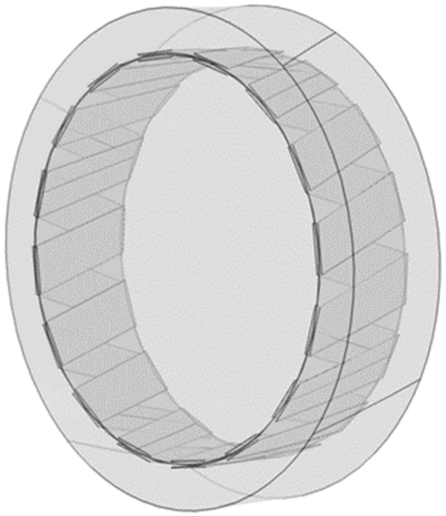
We research aiming at realizing superconducting cable to reduce such AC loss.

1. Background and objective

- **Quasi-3D electromagnetic field analysis(Calculation method so far)**

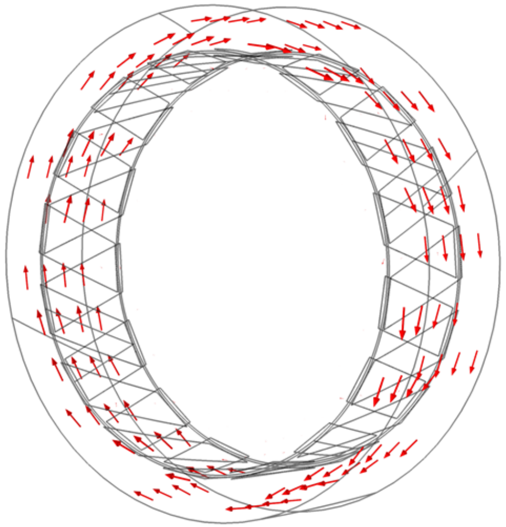
  “two-dimensional electromagnetic field analysis” + “electric circuit model”

- **3D electromagnetic field analysis(We introduced it newly)**
  - Analyzes the electromagnetic field of superconducting cable three-dimensionally
  - <u>Results not obtained by Quasi-3D electromagnetic field analysis are obtained.</u>



Pass an alternating current

Analyzes the electromagnetic field



1. Background and objective

In this study

- AC losses of “two-layer REBCO superconducting cable” is calculated by 3D electromagnetic field analysis using COMSOL.

- We try to design a low-loss cable.

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2. Calculation method of AC loss

Electromagnetic field of the cable is analyzed by COMSOL.

COMSOL : Software that analyzes models using the finite element method(FEM).

FEM : Method that regards a model as an aggregate of elements, divides it into elements, and analyzes each element to approximate the overall analysis result

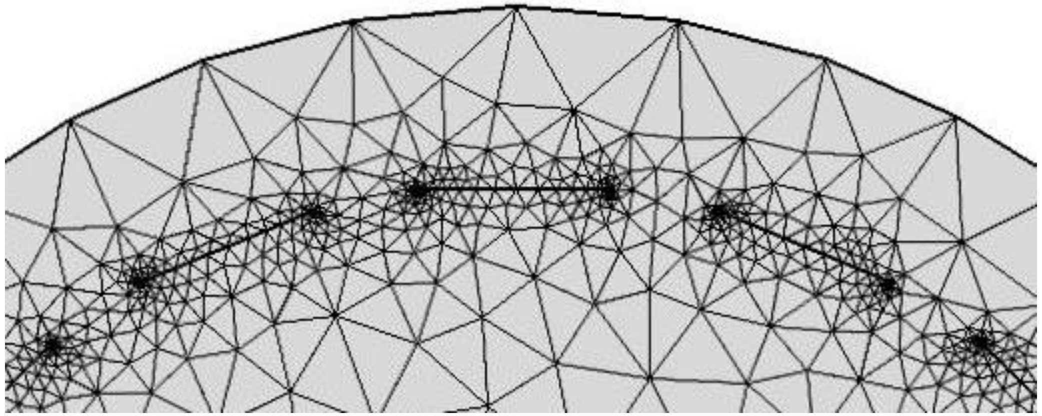

Fig. 2 Mesh of model

2. Calculation method of AC loss

- **Faraday's law(The basic formula)**

$$\mu_0\mu_r\left[\frac{\partial H_x}{\partial t},\frac{\partial H_y}{\partial t},\frac{\partial H_z}{\partial t}\right]^T+\left[\frac{\partial E_z}{\partial y}-\frac{\partial E_y}{\partial z},\frac{\partial E_x}{\partial z}-\frac{\partial E_z}{\partial x},\frac{\partial E_y}{\partial x}-\frac{\partial E_x}{\partial y}\right]^T=0$$

- **Ampere's law(The boundary condition)**

$$[J_x,J_y,J_z]^T=\left[\frac{\partial H_z}{\partial y}-\frac{\partial H_y}{\partial z},\frac{\partial H_x}{\partial z}-\frac{\partial H_z}{\partial x},\frac{\partial H_y}{\partial x}-\frac{\partial H_x}{\partial y}\right]^T$$

- **Equation of resistivity**

$$[\rho_{scx},\rho_{scy},\rho_{scz}]^T=\left[\frac{E_c}{J_c}\left(\frac{J_x}{J_c}\right)^{n-1},\frac{E_c}{J_c}\left(\frac{J_y}{J_c}\right)^{n-1},\frac{E_c}{J_c}\left(\frac{J_z}{J_c}\right)^{n-1}\right]^T$$

- **Ohm's law**

$$[E_x,E_y,E_z]^T=[\rho_{scx}\cdot J_x,\rho_{scy}\cdot J_y,\rho_{scz}\cdot J_z]^T$$

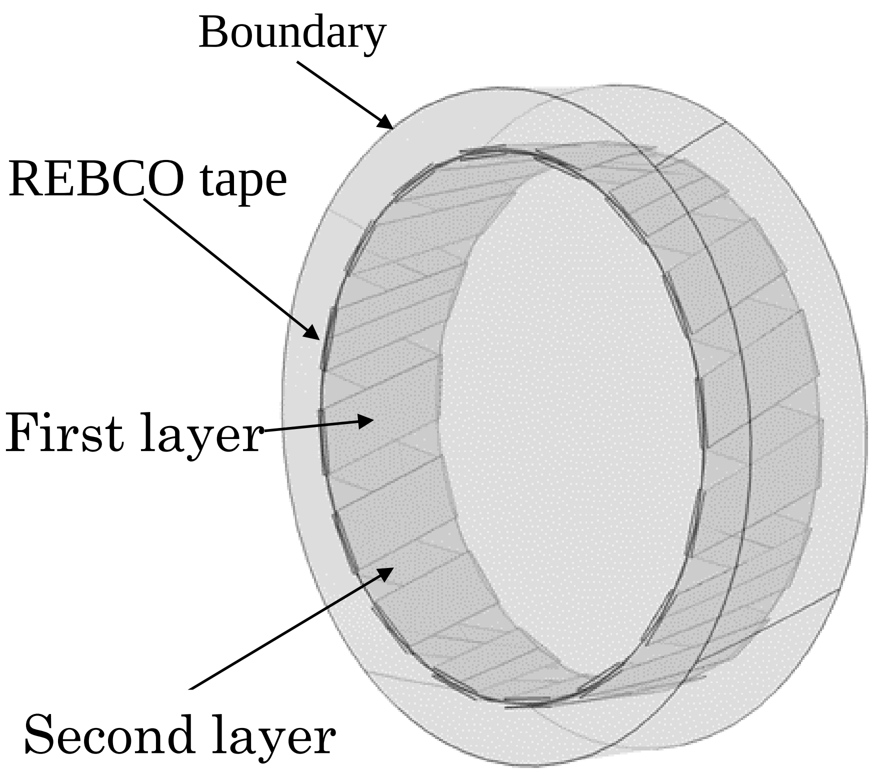

Fig. 3 3D model of two-layer REBCO superconducting cable

2. Calculation method of AC loss

We introduce these equations into the model.

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analyze the electromagnetic field
three- dimensionally

- AC loss is calculated by

$$Q = f \cdot \int_{\frac{1}{f}} dt \int_{S} E(J) \cdot J ds \quad [\mathrm{W/m}]$$

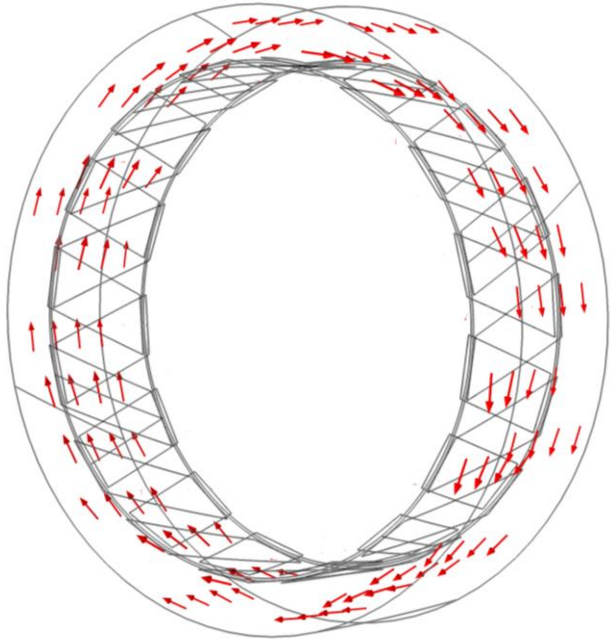

Fig. 4 Electromagnetic field profiles

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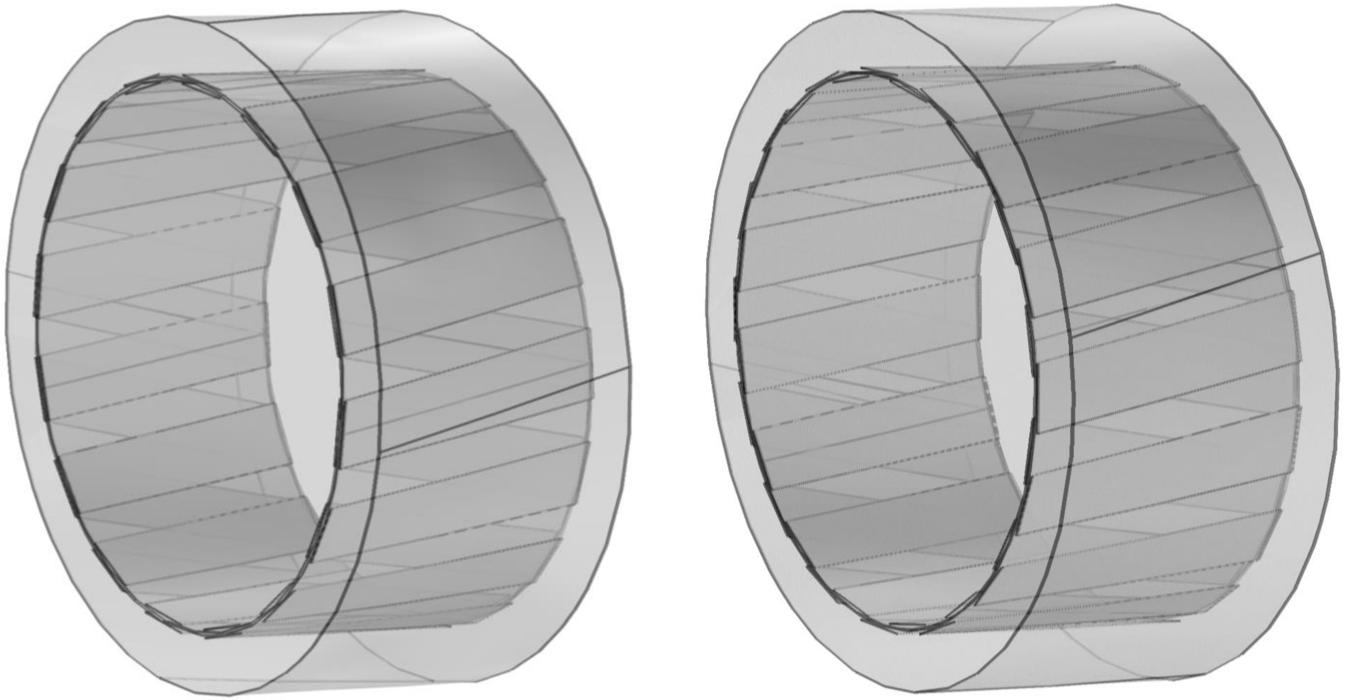
- **AC loss of SZ winding two-layer REBCO cable**

Table 1 Parameters of two-layer REBCO cable

Tape width	4 mm
Tape thickness	1 μm
Radius of first layer	16.0 mm
Radius of second layer	16.5 mm
Number of tapes in each layer	16
Critical current of one tape I_C	45.6 A
Helical pitch of first layer P_1	340 mm
Helical pitch of second layer P_2	280 mm

3. Calculation results and discussion

- **AC loss of SZ winding two-layer REBCO cable**



(a) tape-on-tape (b) tape-on-gap

Fig. 5 3D model of two-layers REBCO superconducting cable

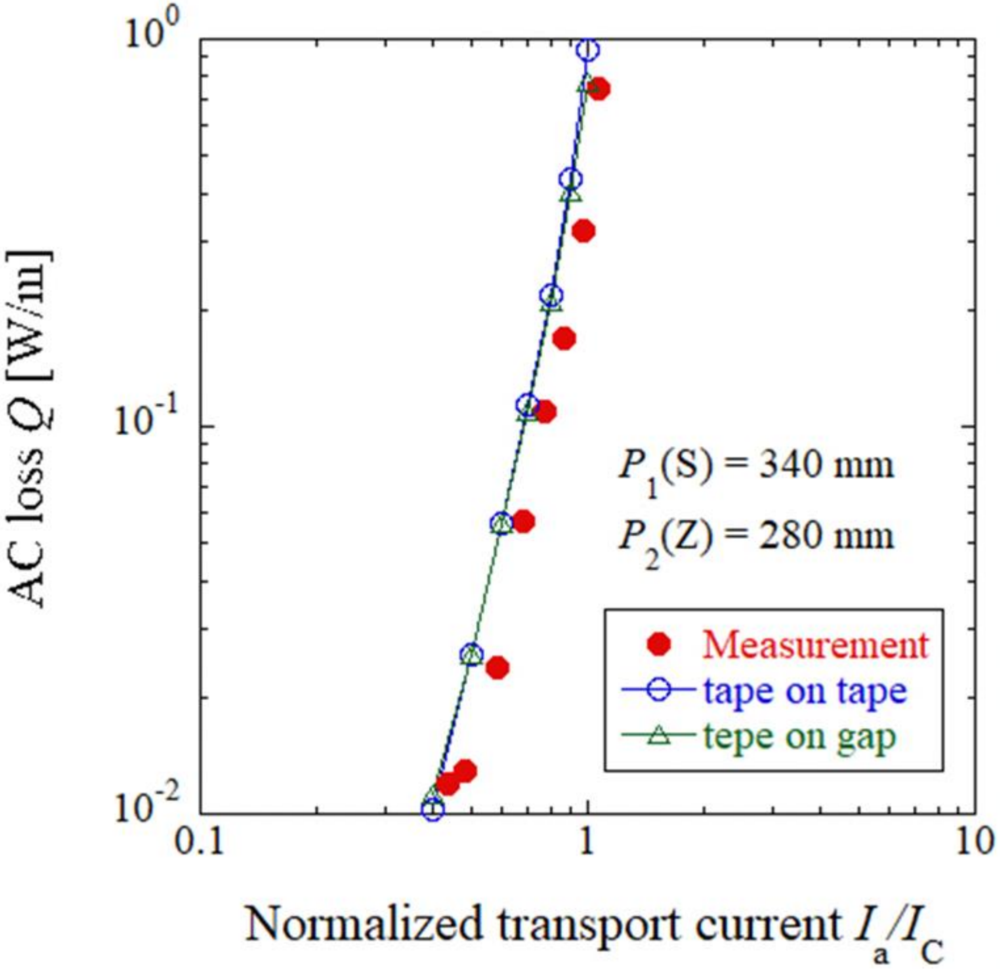
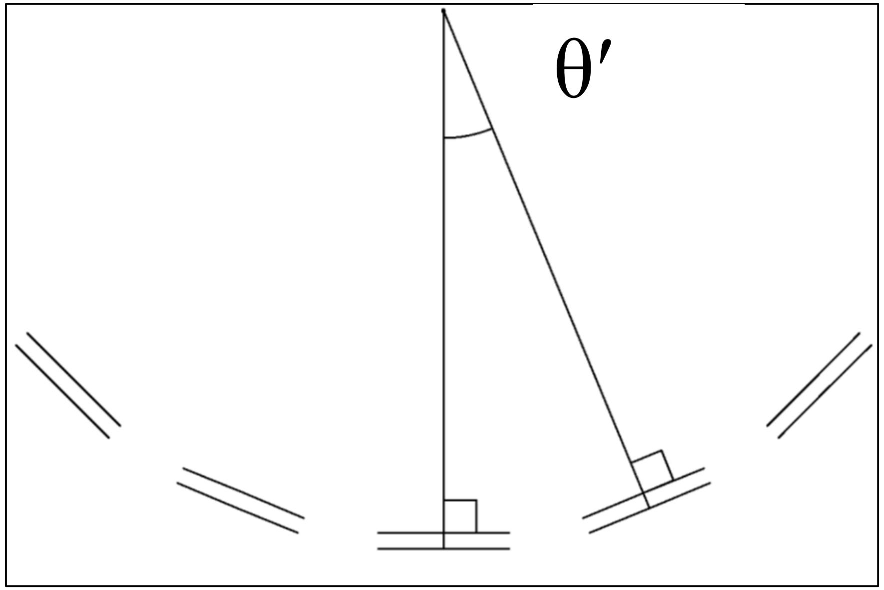


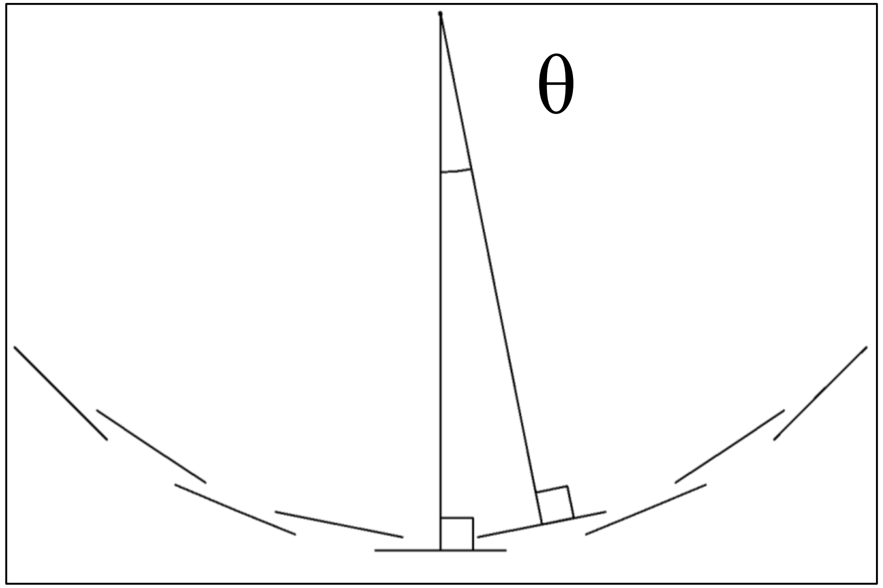
Fig. 6 AC loss characteristic against normalized current.

3. Calculation results and discussion

・AC loss of SS winding two-layer REBCO cable



(a) θ/θ’ = 0

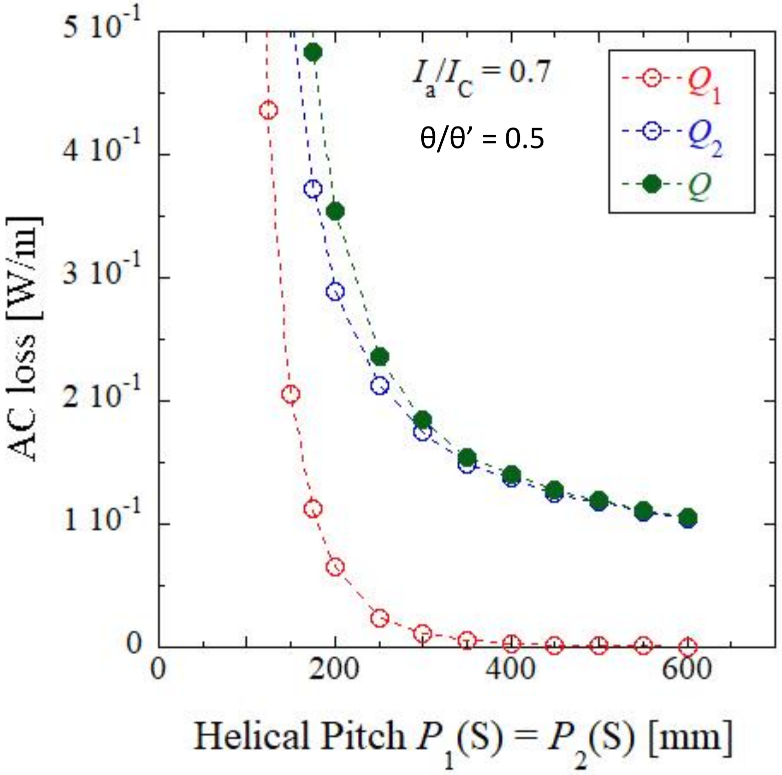


(b) θ/θ’ = 0.5

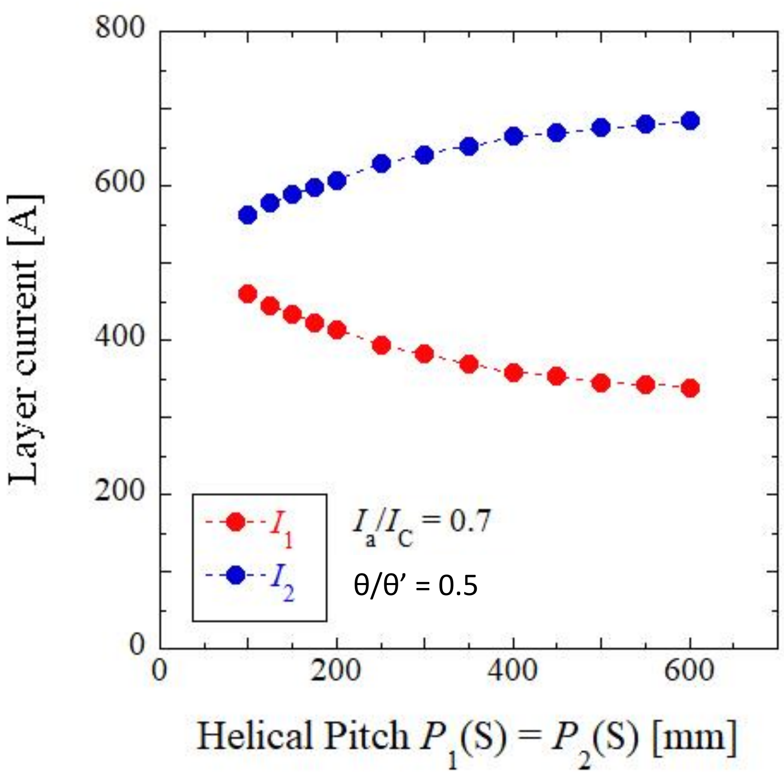
Fig. 7 Explanation of relative position angle

3. Calculation results and discussion

・AC loss of SS winding two-layer REBCO cable



(a) AC loss characteristic



(b) Layer current characteristic

Fig.8 AC loss and layer current characteristics against P_1(S) = P_2(S).

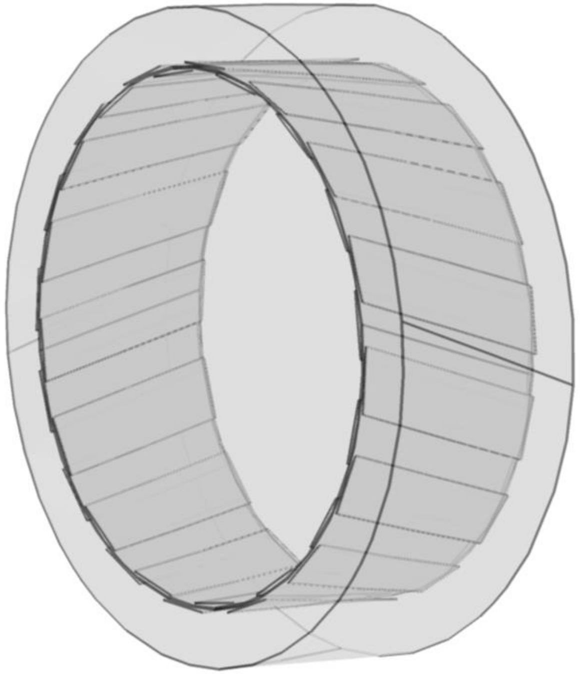


Fig. 9 3D model (P_1(S) = P_2(S))

3. Calculation results and discussion

・**AC loss of SS winding two-layer REBCO cable**

・REBCO tapes are aligned parallel to the cable length direction.
・θ/θ’ = 0.5
・Ia/Ic = 0.7

The minimum loss in this study
Q = 0.07 W/m

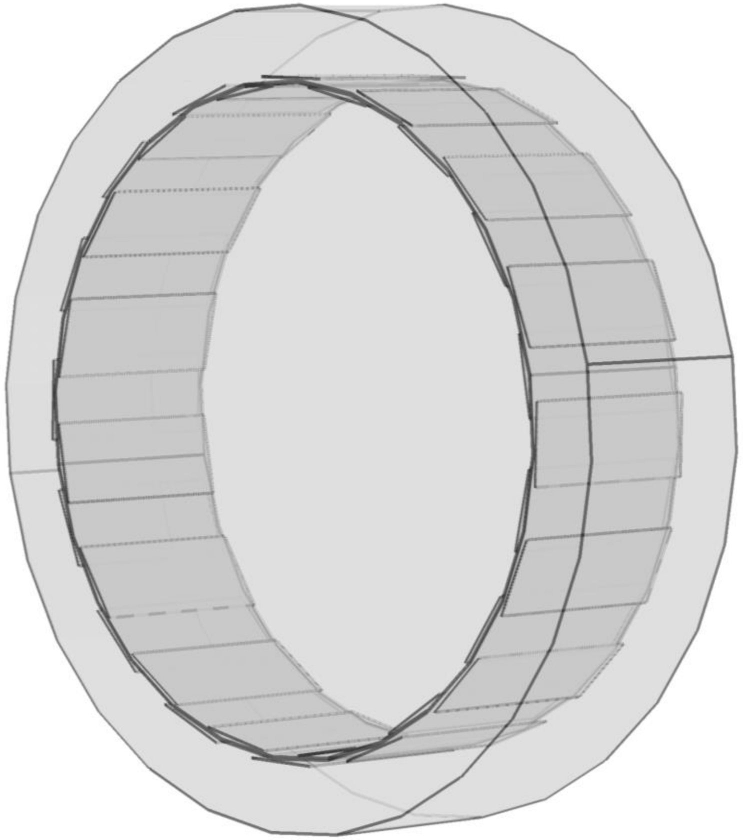


Fig. 10 3D mode with minimum loss

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- Calculated value of AC loss of 2 layer REBCO superconducting cable obtained by 3D electromagnetic field analysis agreed with the experimental value of Furukawa Electric.

- The AC loss of the two-layer REBCO superconducting cable was calculated with the SS winding, placing the superconducting tape on the tape-on-gap and minimizing it when there is no helical pitch.