AC loss calculation of REBCO cables by the combination of electric circuit model and 2D finite element method

Department of Electrical and Computer Engineering, National Institute of Technology,
Miyakonojo College, Miyakonojo 885-8567, Japan
H. Noji

Abstract

This study investigates the losses in a two-layer REBCO cable fabricated by researchers at Furukawa Electric Co. Ltd. The losses were calculated using a combination of our electric circuit (EC) model with a two-dimensional finite element method (2D FEM). The helical pitches of the tapes in each layer, P_1 and P_2, were adjusted to equalize the current in both cable layers, although the loss calculation assumed infinite helical pitches and the same current in each layer. The results showed that the losses depended on the relative tape-position angle between the layers (ϑ/ϑ'), because the vertical field between adjacent tapes in the same layer varied with ϑ/ϑ'. In the cable developed by Furukawa Electric Co., the tape numbers in each layer, N_1 and N_2, were $N_1 = N_2 = 16$, and the gaps between adjacent tapes, g_1 and g_2, were comparatively wide. Increasing the tape numbers to $N_1 = N_2 = 25$ decreased the gaps and almost canceled the vertical field to the tape face, reducing the dependency of the losses on ϑ/ϑ'. When simulating the real cable, the helical pitches were adjusted and the layer currents were calculated by the EC model. These currents were input to the 2D FEM to compute the losses. The losses changed along the cable length because the difference between P_1 and P_2 altered the ϑ/ϑ' along this direction. The average angle-dependent and position-dependent losses were equal and closely approximated the measured losses. To reduce the loss, the angle and the helical pitches were fixed at $\vartheta/\vartheta' = 0.5$ and $P_1 = P_2 = 100$ mm (S-direction). The calculation with these conditions indicated that the loss is about one order of magnitude lower than the measurement.

■Configurations of cables

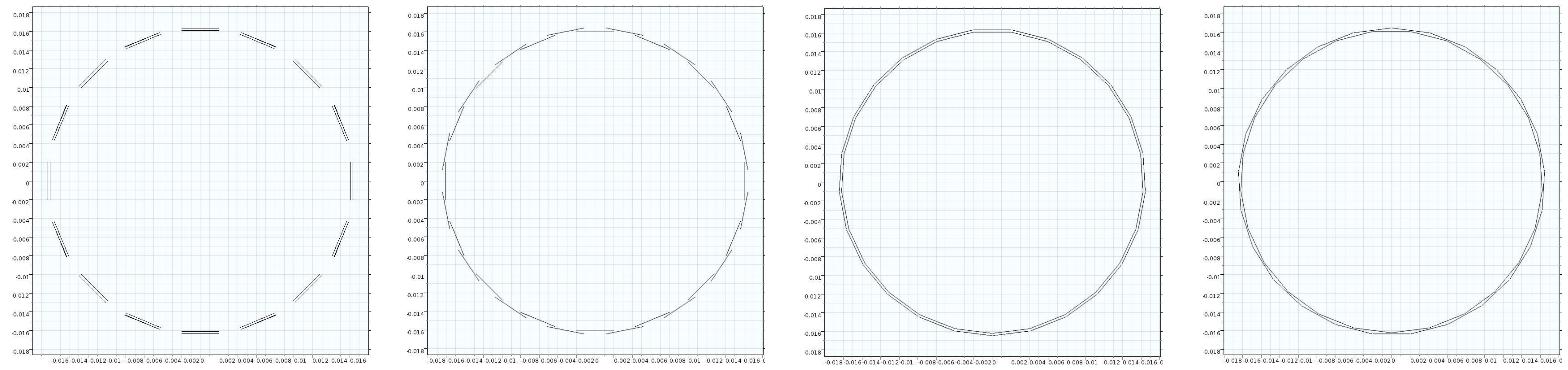
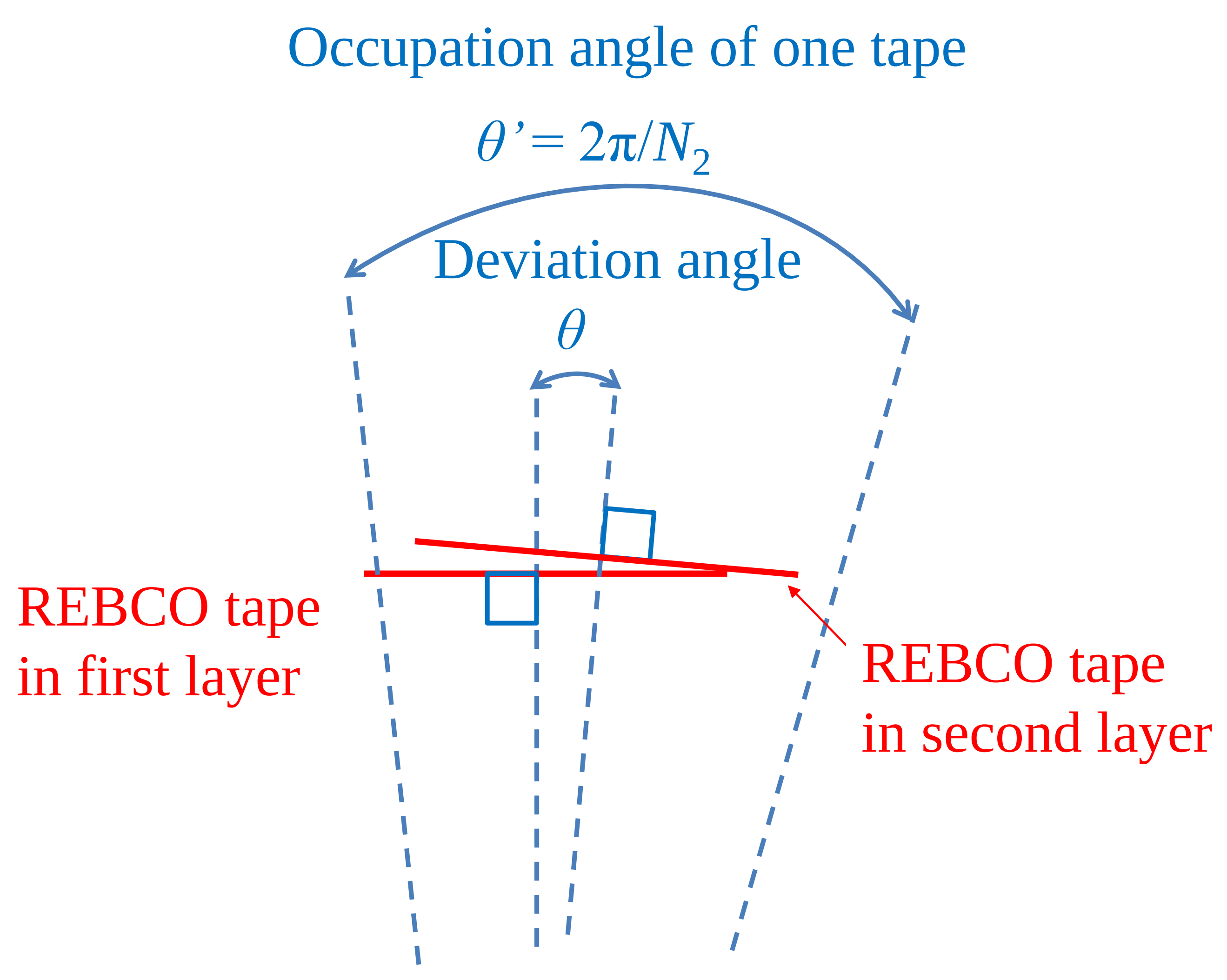


Fig. 1 (a) Fig. 1 (b) Fig. 1 (c) Fig. 1 (d)

Fig. 1. Cross-sections of two-layer cables; (a) $\vartheta/\vartheta' = 0$ and $N_1 = N_2 = 16$, (b) $\vartheta/\vartheta' = 0.5$ and $N_1 = N_2 = 16$, (c) $\vartheta/\vartheta' = 0$ and $N_1 = N_2 = 25$, and (d) $\vartheta/\vartheta' = 0.5$ and $N_1 = N_2 = 25$.



Occupation angle of one tape

$\theta' = 2\pi/N_2$

Deviation angle

θ

REBCO tape
in first layer

REBCO tape
in second layer

Fig. 2. Explanation of the relative angle ϑ/ϑ'.

Table 1. Specifications of two-layer cable

Tape width *w*	4 mm
Tape thickness	0.1 mm
Thickness of superconductor *d*	1 µm
Outer radius of former r_f	16 mm
Inner radius of first layer's superconductor r_1	16.099 mm
Inner radius of second layer r_s	16.25 mm
Inner radius of second layer's superconductor r_2	16.349 mm
Number of tapes in first layer N_1	16 or 25
Number of tapes in second layer N_2 (= N_1)	16 or 25
Critical current of the tape I_C	45.6 A

Table 2. Specifications of Mukoyama's cable

Layer number *m*	Inner radius R_m [mm]	Tape numbers N_m	Critical current I_{Cm} [A]	Helical pitch P_m [mm] (direction)
1	16.099	16	730	340 (S)
2	16.349	16	730	280 (Z)

AC losses vs relative angle

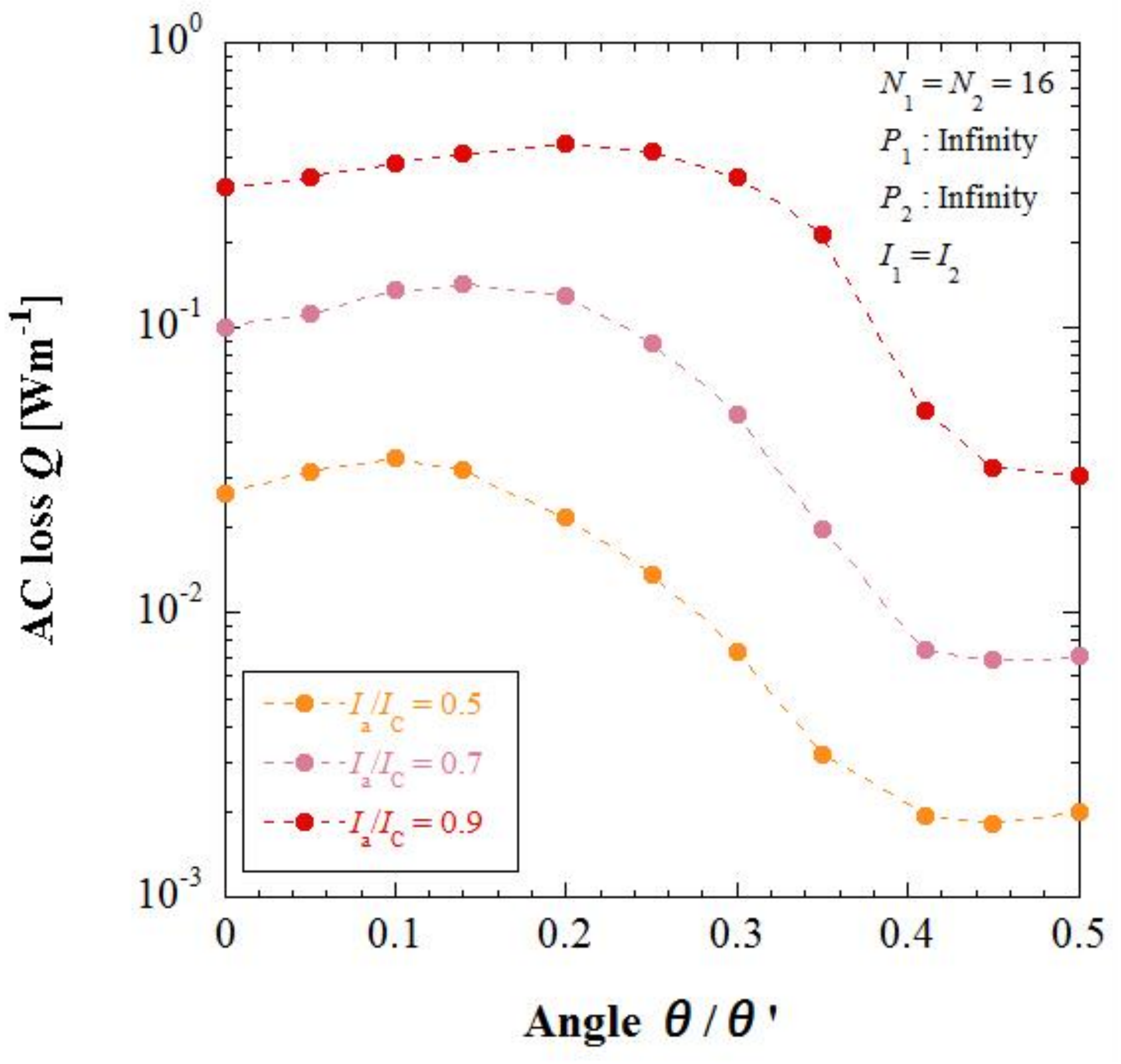


Fig. 2 (a)

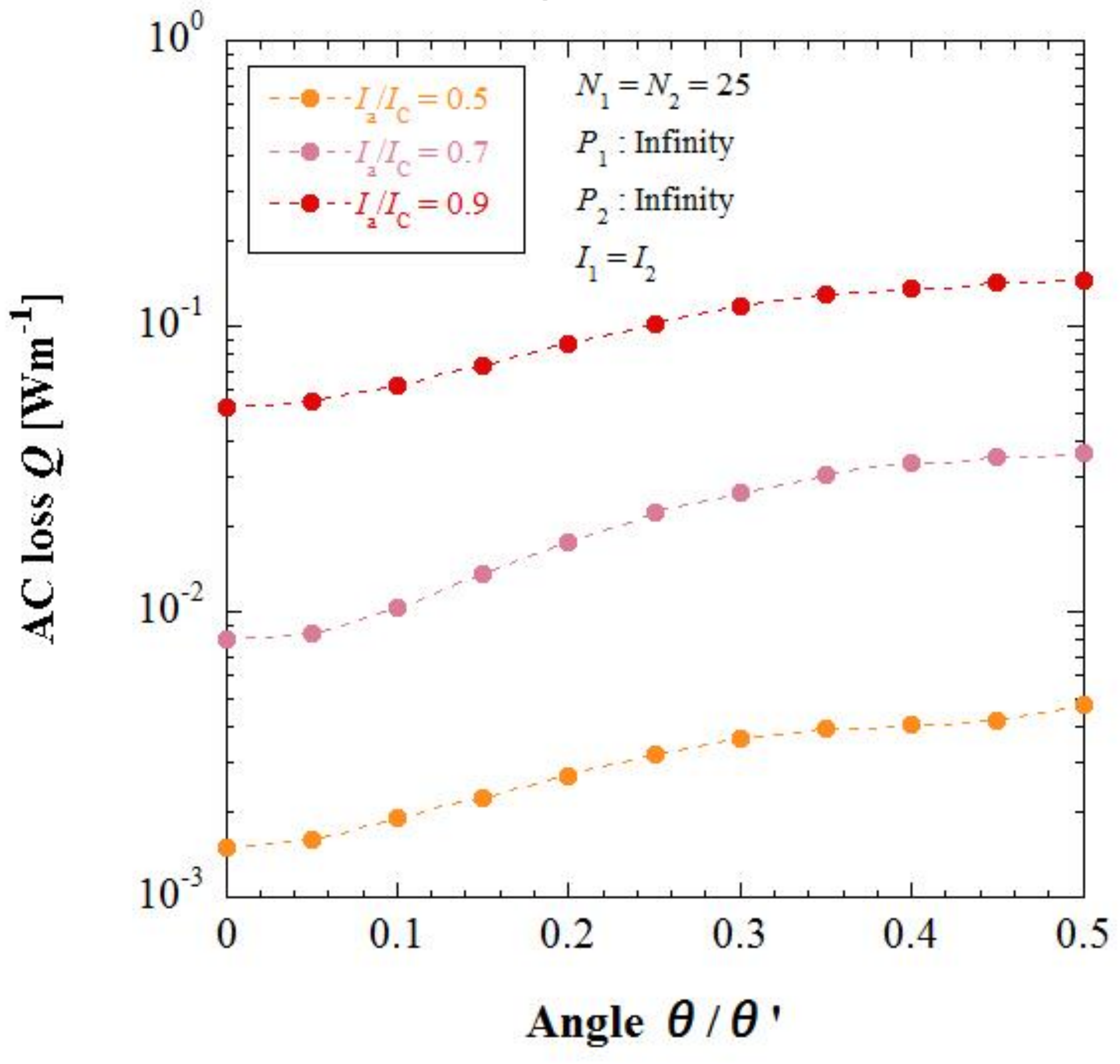


Fig. 2 (b)

Fig. 2 AC losses in a two-layer cable versus the relative angle ϑ/ϑ' between the tape positions of the layers determined at various transport currents (normalized by critical current), fixing $P_1 = P_2$ = infinity, $I_1 = I_2$, (a) $N_1 = N_2 = 16$, and (b) $N_1 = N_2 = 25$.

Magnetic field profiles

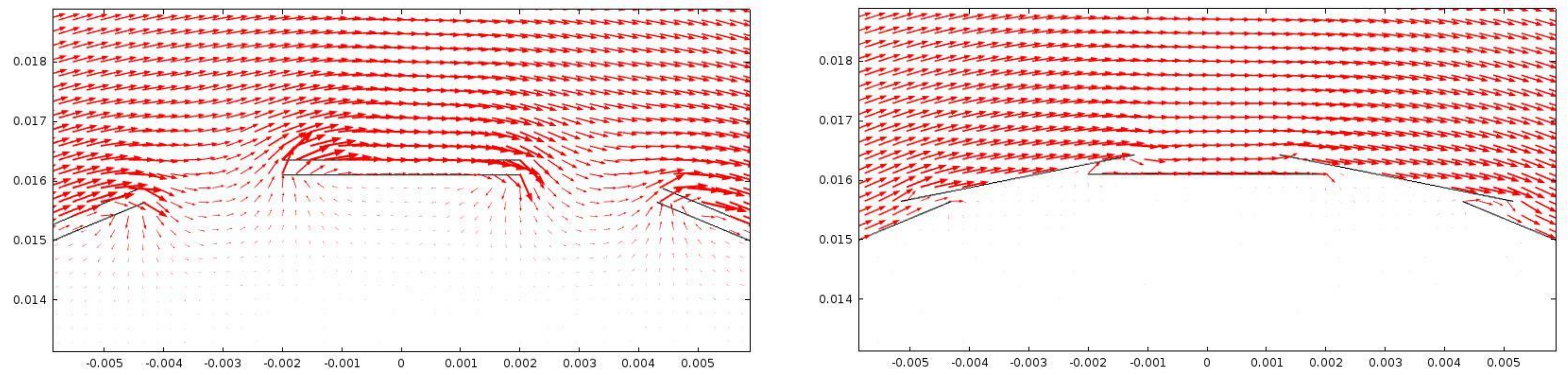


Fig. 3 (a) Fig. 3 (b)

Fig. 3 Magnetic field profiles around the tapes in a two-layer cable with $N_1 = N_2 = 16$; (a) $\vartheta/\vartheta' = 0$ and (b) $\vartheta/\vartheta' = 0.5$.

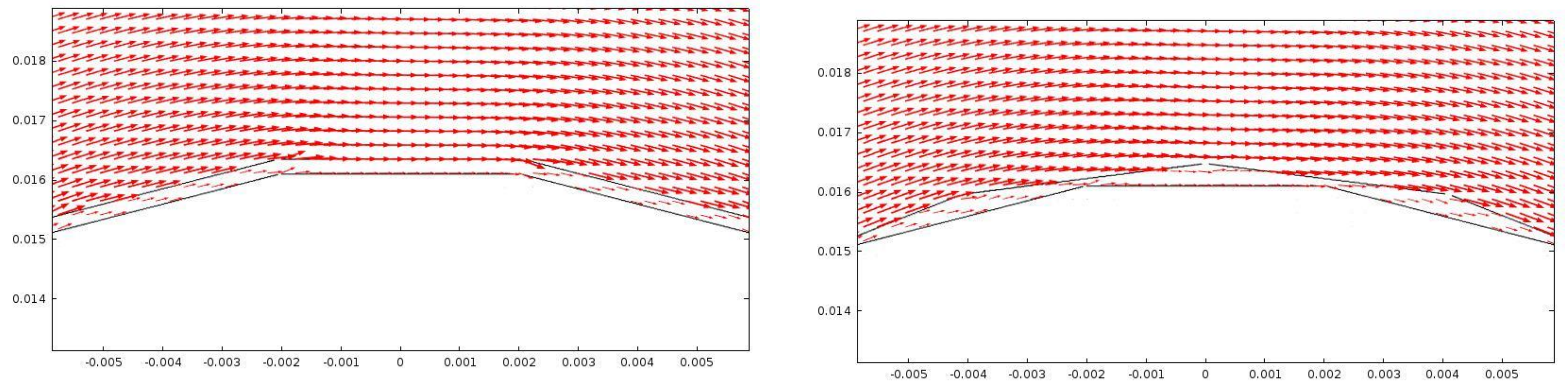


Fig. 4 (a) Fig. 4 (b)

Fig. 4 Magnetic field profiles around the tapes in a two-layer cable with $N_1 = N_2 = 25$; (a) $\vartheta/\vartheta' = 0$ and (b) $\vartheta/\vartheta' = 0.5$.

Layer currents vs helical pitch

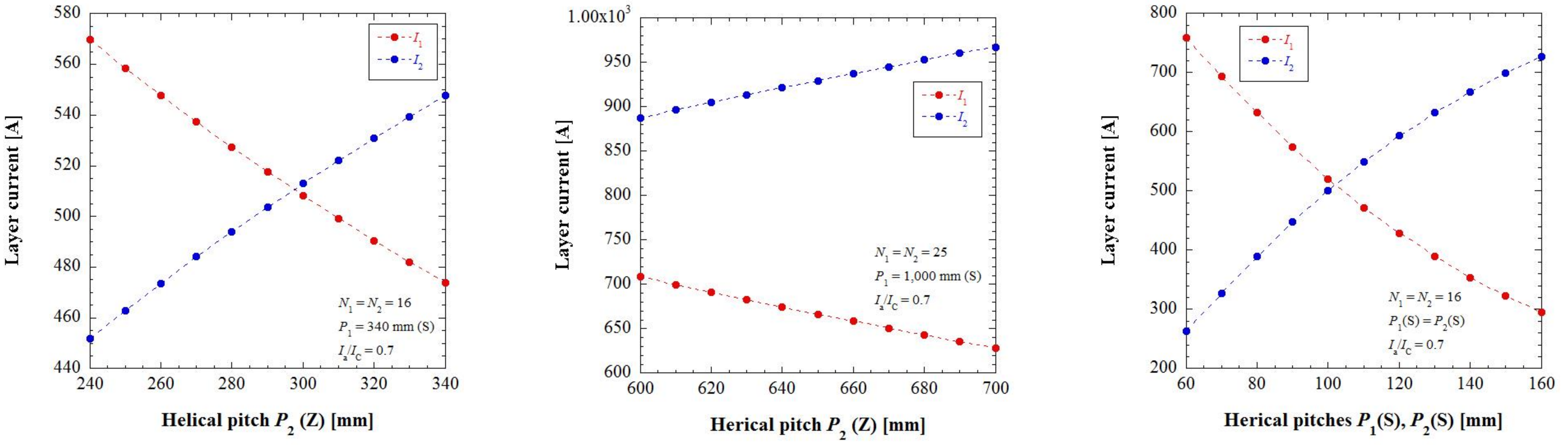


Fig. 5 (a) Fig. 5 (b) Fig. 5 (c)

Fig. 5 Layer currents in a two-layer cable versus helical pitches, fixing $I_a/I_C = 0.7$; (a) $N_1 = N_2 = 16$ and $P_1 = 340$ mm (S-direction), (b) $N_1 = N_2 = 25$ and $P_1 = 1{,}000$ mm (S-direction), (c)) $N_1 = N_2 = 16$ and P_1 (S-direction) = P_2 (S-direction).

AC losses vs position along cable length

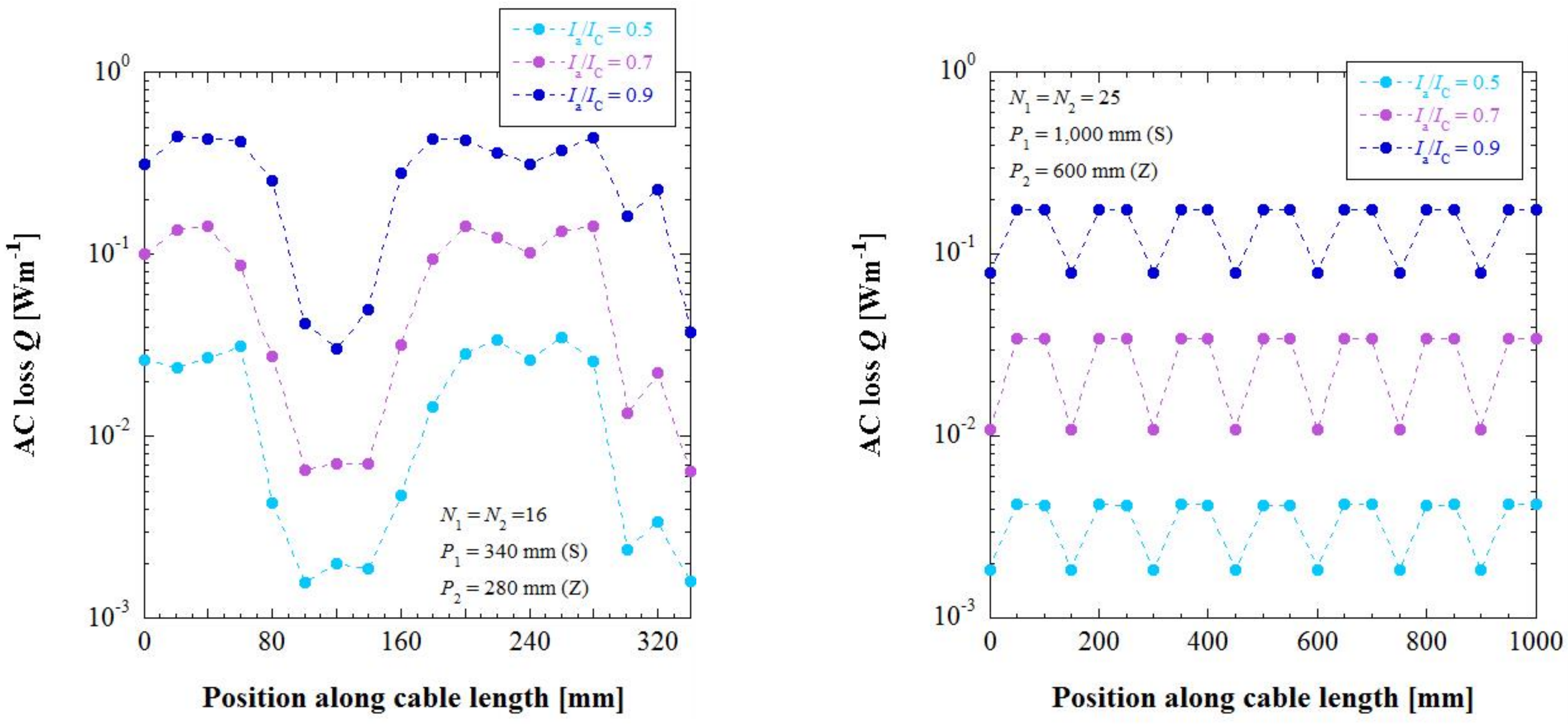


Fig. 6 (a) Fig. 6 (b)

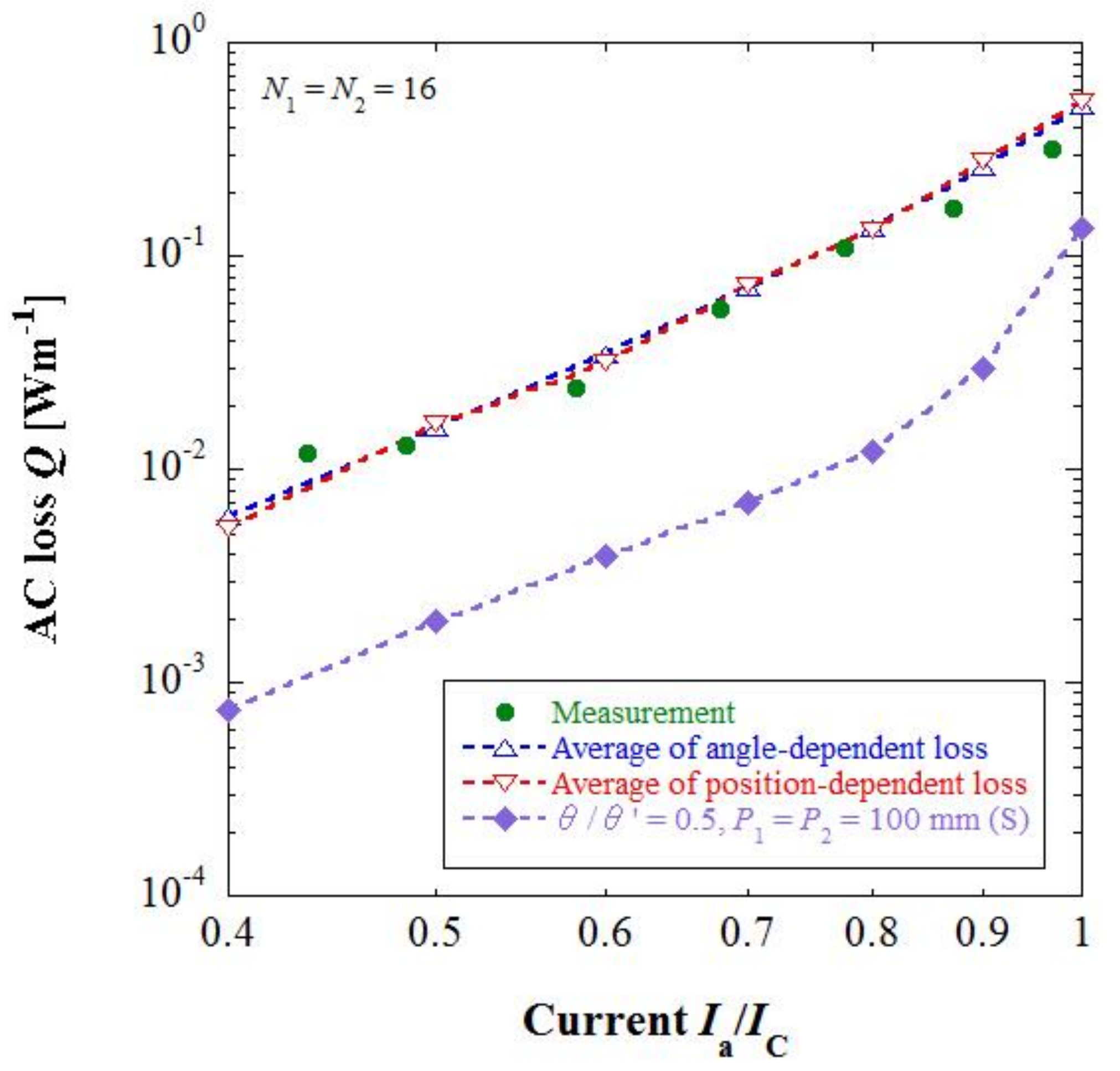


Fig. 7

Fig. 6 AC losses in a two-layer cable versus position along the cable length, determined at various transport currents (normalized by critical current), fixing (a) $N_1 = N_2 = 16$, $P_1 = 340$ mm (S-direction), $P_2 = 280$ mm (Z-direction) and (b) $N_1 = N_2 = 25$, $P_1 = 1{,}000$ mm (S-direction), and $P_2 = 600$ mm (Z-direction).

Fig. 7 AC losses in a two-layer cable versus transport current (normalized by critical current), fixing $N_1 = N_2 = 16$, fixing $P_1 = 340$ mm (S-direction) and $P_2 = 280$ mm (Z-direction), respectively. The calculated losses are also indicated, fixing $\vartheta/\vartheta' = 0.5$ and $P_1 = P_2 = 100$ mm (S-direction).