Wed-Af-Po3.12-19

Comparison between AC loss measurements and analyses in coil assemblies with different geometries and conductors

Y. Sogabe, *N. Amemiya* (Kyoto Univ.),
Z. Jiang, S. C. Wimbush, N. M. Strickland,
M. Staines, N. J. Long (RRI, VUW)

1. Background and objective

Coil assembly using multiple conductors with different I_c

High I_c conductor at high normal magnetic field (I_c grading) can reduce whole ac loss in coil assembly

Low I_c conductor is relatevely cheap compared with high I_c conductor

Complicated ac loss density distribution

Ac loss characteristics in coil assemblies are complexity related to distribution of magnetic field seen by conductors

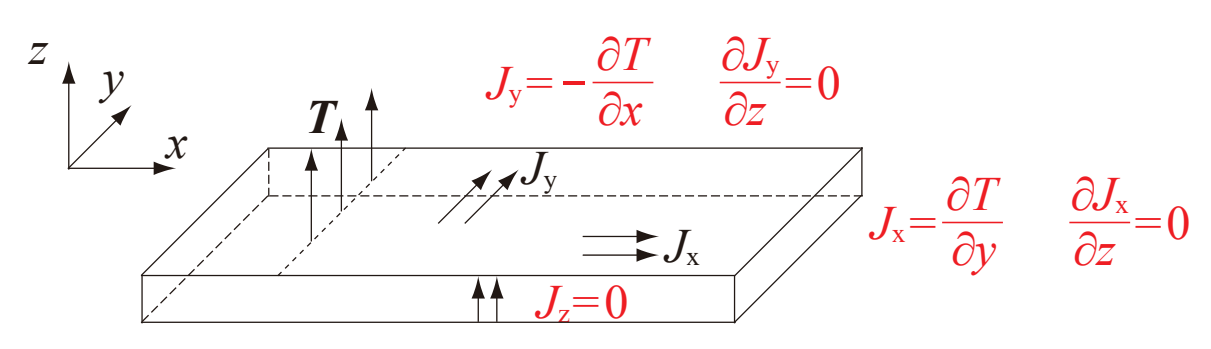
- **Conducting cross-sectional electromagnetic field analyses for coil assemblies**
- **Revealing how coil geometries and conductors affect ac loss density distribution**

2. Analysis method and analyzed coils

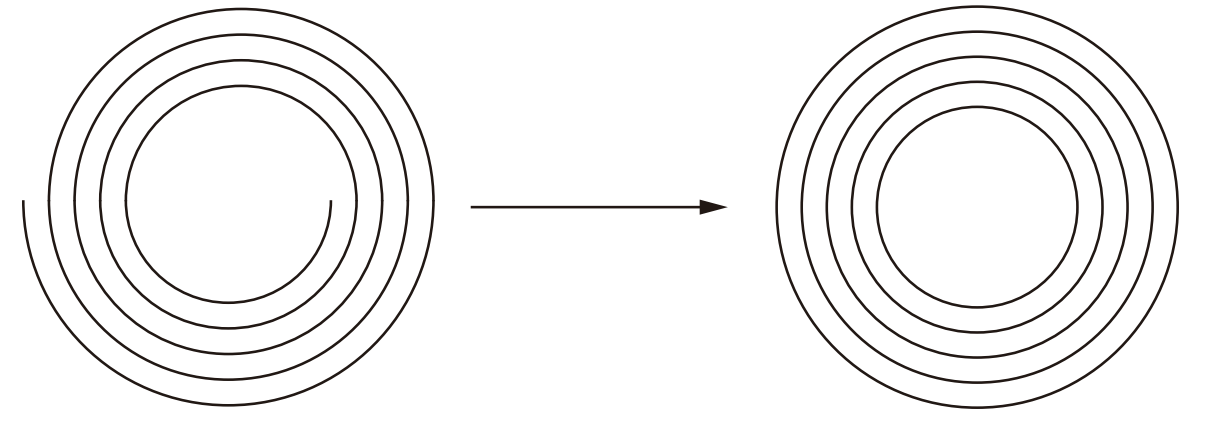
Equation to be solved in cross-sectional model

$$-\frac{\partial}{\partial y}\frac{1}{\sigma}\frac{\partial T}{\partial y}\boldsymbol{n}+\frac{\partial}{\partial t}\left(\sum\int \boldsymbol{B}_{\mathrm{s-f}}\cdot\boldsymbol{n}\frac{\partial T'}{\partial y'}\boldsymbol{n}' t_{\mathrm{s}}\mathrm{d}y'\right)=\boldsymbol{0}.$$

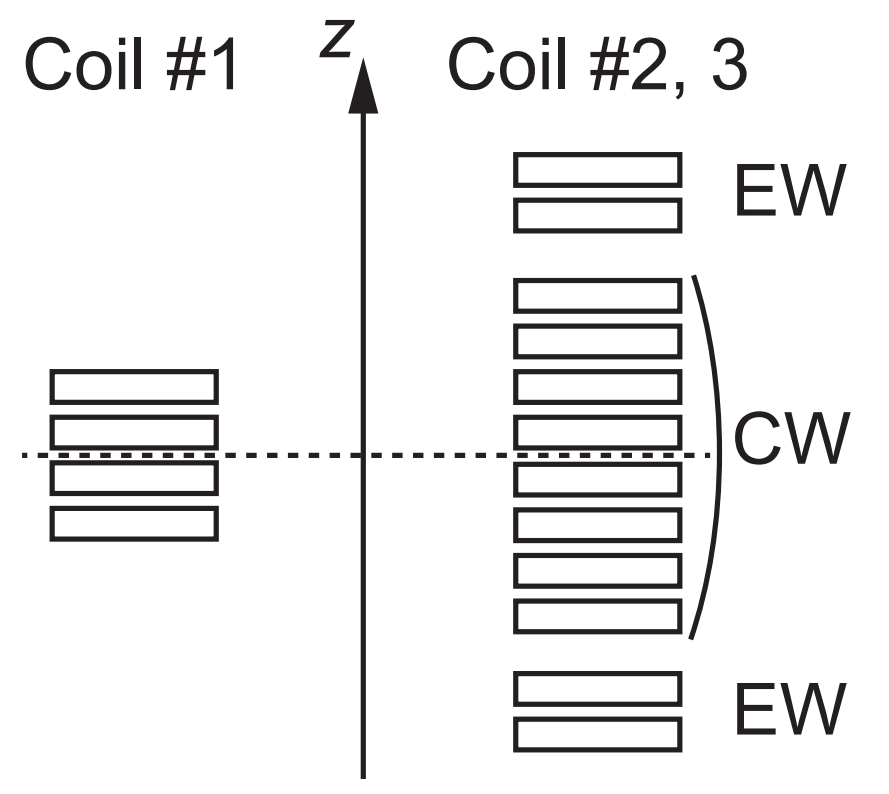
Thin strip approximation



Axisymmetric approximation



Specifications of analyzed coil assemblies			
Coil no.	#1	#2	#3
Number of PCs	4	12	12 (8 in CW / 4 EWs)
Conductor used	#1	#1 (EW) #2 (CW)	#3 (EW) #2 (CW)
Inner / outer radius	30 mm / 36.5 mm		
Overall height	20 mm	64 mm	64 mm
Gap between PCs in EW / CW	1 mm		
Gap between EW and CW	N/A	2 mm	2 mm
Number of turns / PC	20 / PC		
Separation between turns	0.225 mm		
Total conductor length	16.7 m	50.0 m	50.0 m



3. Field dependence of J_c & *n* of conductors

Specifications of conductors

Conductor no.	#1	#2	#3
Manufacturer	SuperPower	SuperPower	SuNAM
Lot no.	SCS4050-AP M3-774-1	SCS4050-AP M4-134-3	HCN04200 14111401
Width	4.0 mm	4.0 mm	4.0 mm
Tape thickness	0.1 mm	0.1 mm	0.1 mm
superconducting layer thickness	1.0 μm	1.0 μm	1.3 μm

Formulation of $J_c(B,\phi)$ & $n(B,\phi)$

$$x(B,\varphi)=\left(x_{ab}^{m}+x_{c}^{m}\right)^{1/m},$$

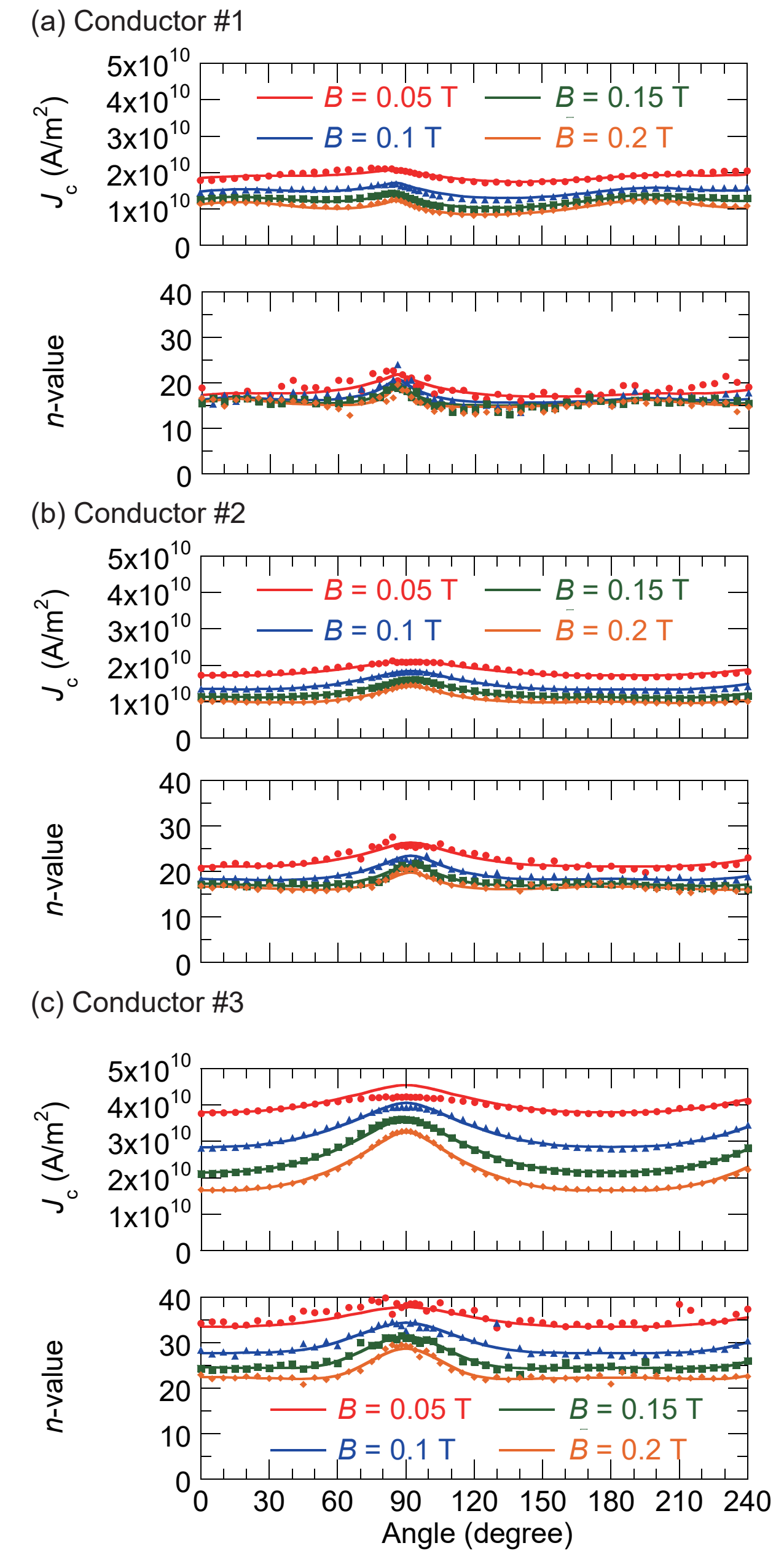
$$x_{ab,c}(B,\varphi)=x_{0ab,c}\Big/\left(1+Bf_{ab,c}(\varphi)\big/B_{0ab,c}\right)^{\beta_{ab,c}}.$$

x means J_c or *n*,
and the subscription *ab,c* means *ab* or *c*

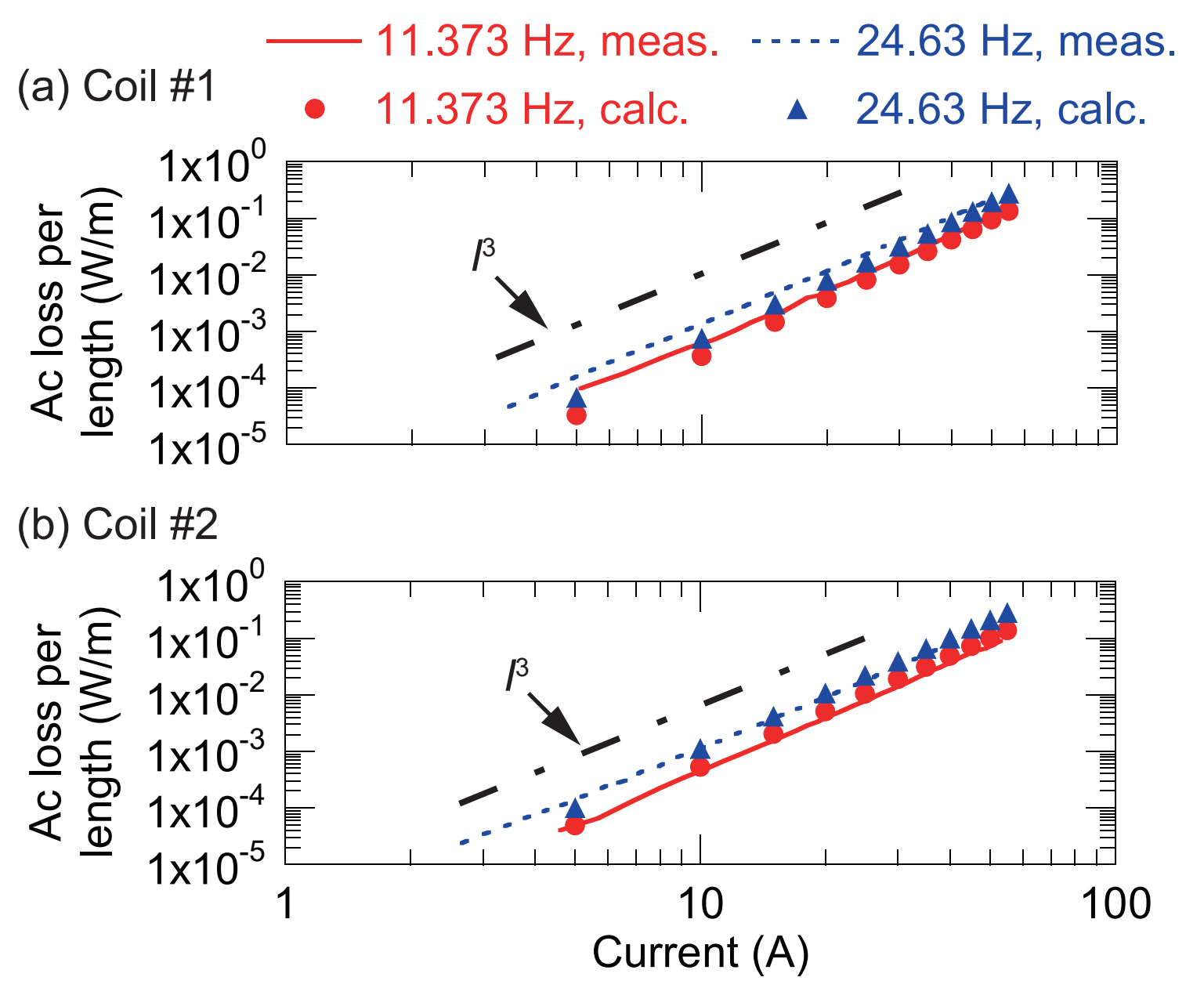
$$f_{ab}(\varphi)=\sqrt{u_{ab}^{\ 2}\cos^2(\varphi-\delta_{ab})+\sin^2(\varphi-\delta_{ab})},$$

$$f_c(\varphi)=\begin{cases}\sqrt{\cos^2(\varphi-\delta_c)+u_c^{\ 2}\sin^2(\varphi-\delta_c)} & (-90^\circ+\delta_c\le\varphi\le 90^\circ+\delta_c)\\ \sqrt{v^2\cos^2(\varphi-\delta_c)+u_c^{\ 2}\sin^2(\varphi-\delta_c)} & (otherwise)\end{cases}.$$

$\phi = 0$ is the direction of normal vector of wide face of conductor

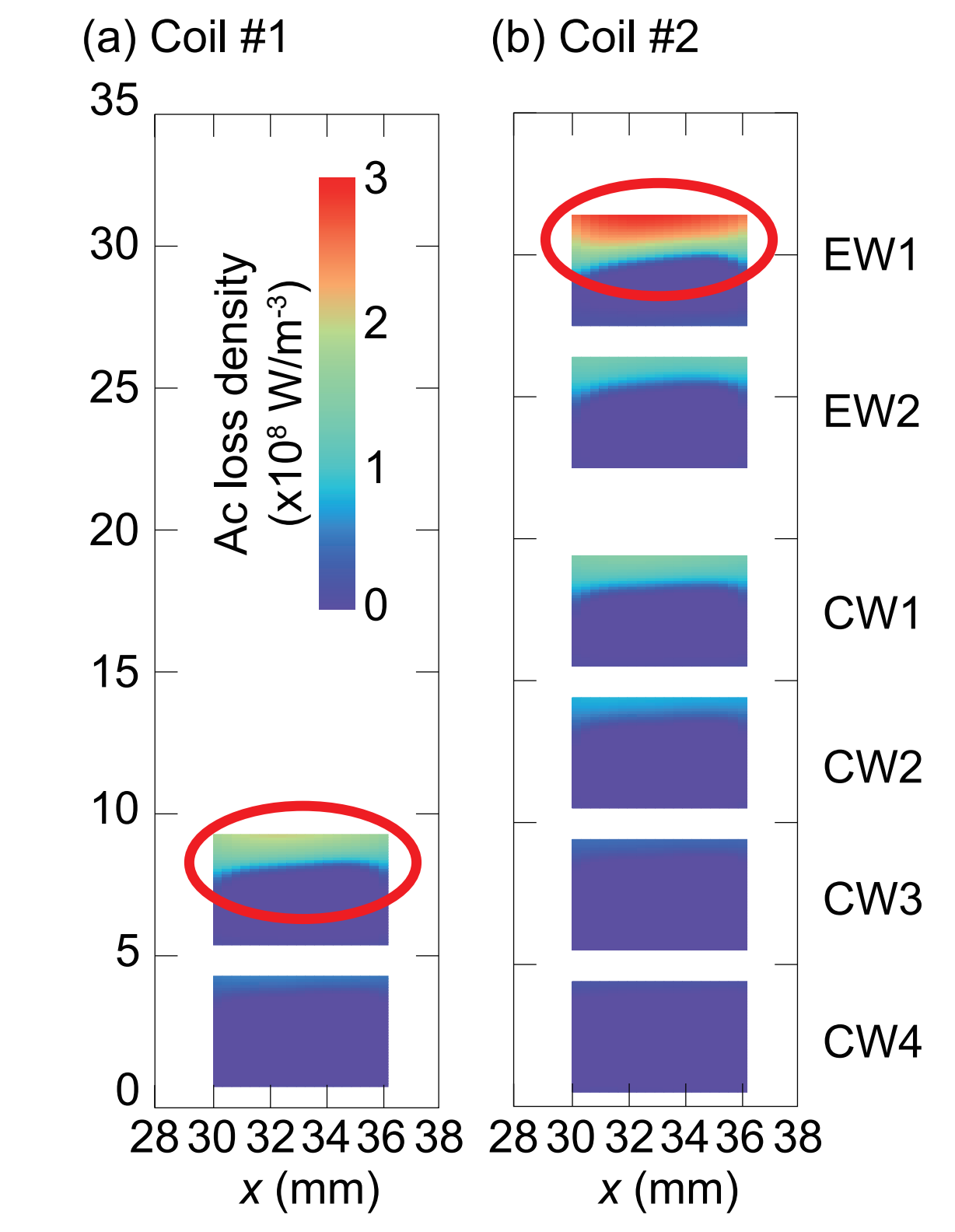


4. Meas. & Calc. results – coil #1 vs. #2



Meas. and calc. results were in good agreement

Calculated ac losses when I_{peak} = 40 A, *f* = 11.373 Hz		
Coil no.	#1	#2
J/cycle	6.18×10^{-2}	2.14×10^{-1}
J/m/cycle	3.71×10^{-3}	4.28×10^{-3}



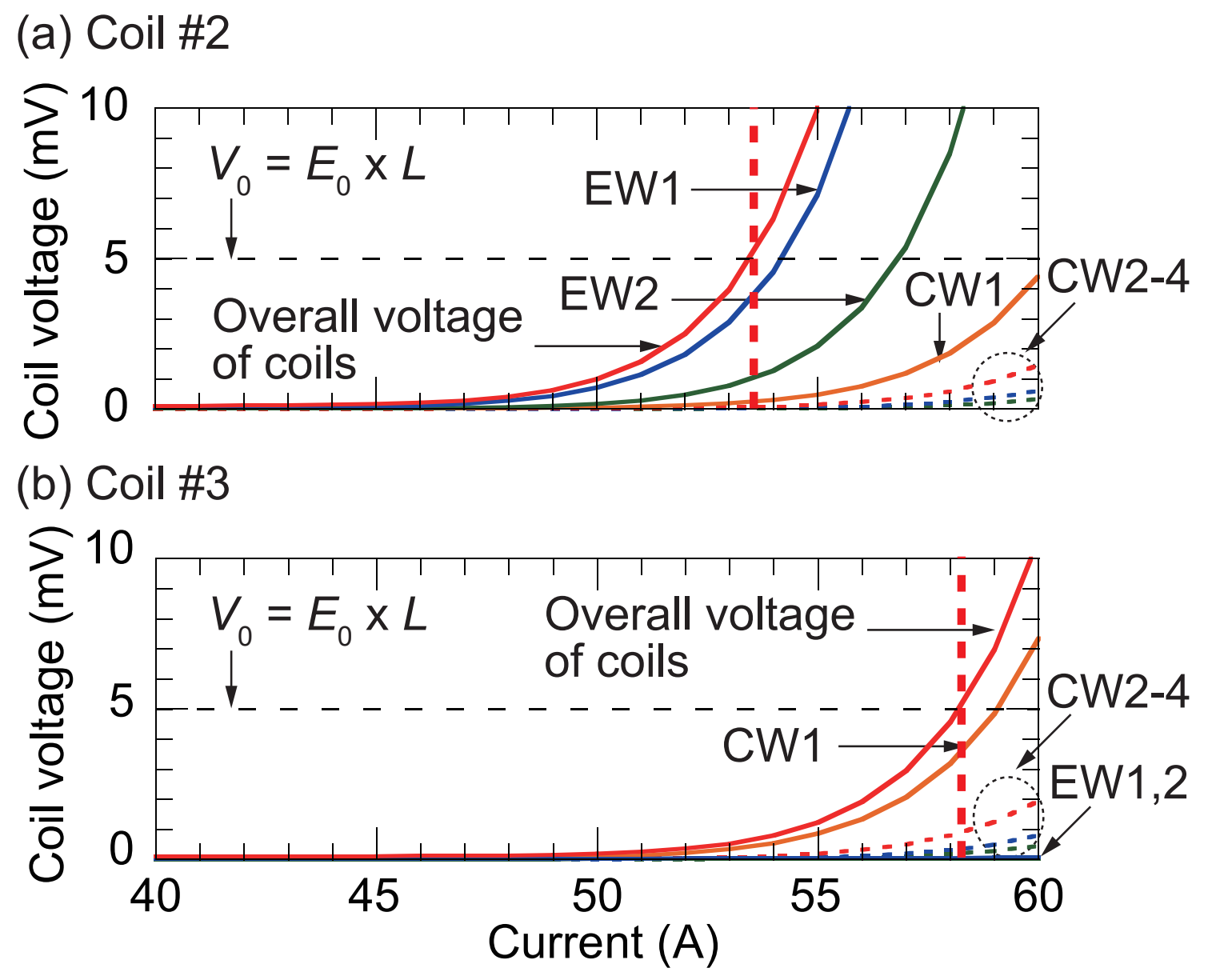
I_{peak} = 40 A, *f* = 11.373 Hz, *t* = 13/8 *T*

- **Concentrated ac loss density in the outermost coil**
- Large magnetic field lead to large ac loss density

5. Effect of I_c grading (coil #2 vs. #3) – coil I_c

Coil I_c	
Coil #2	53.4 A
Coil #3	58.2 A

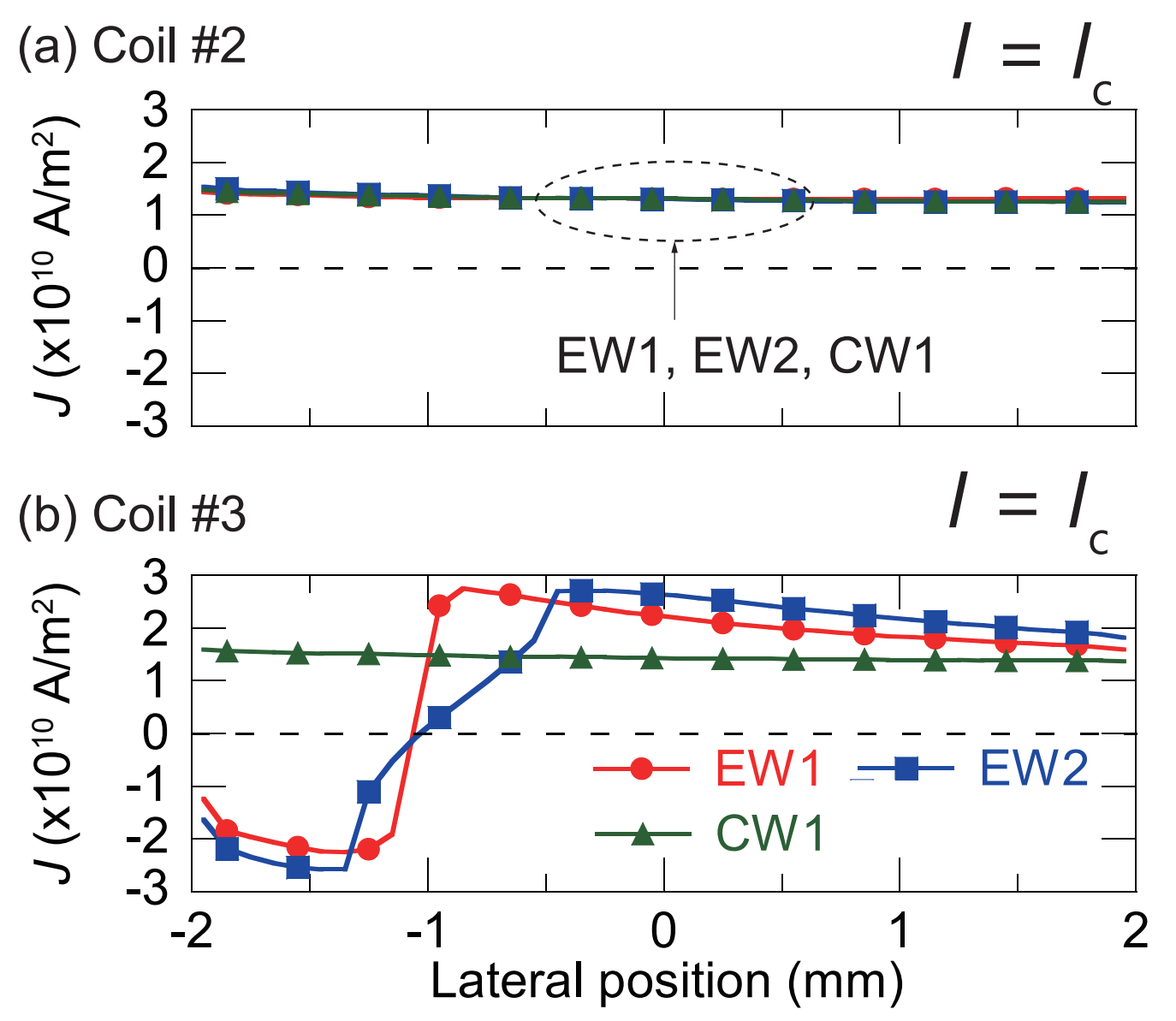
Only 9% increase



No contributions of EW1,2 in coil #3 to overall voltage

Twice higher I_c conductor in EW resulted in only 9% increase in coil I_c.

Why?



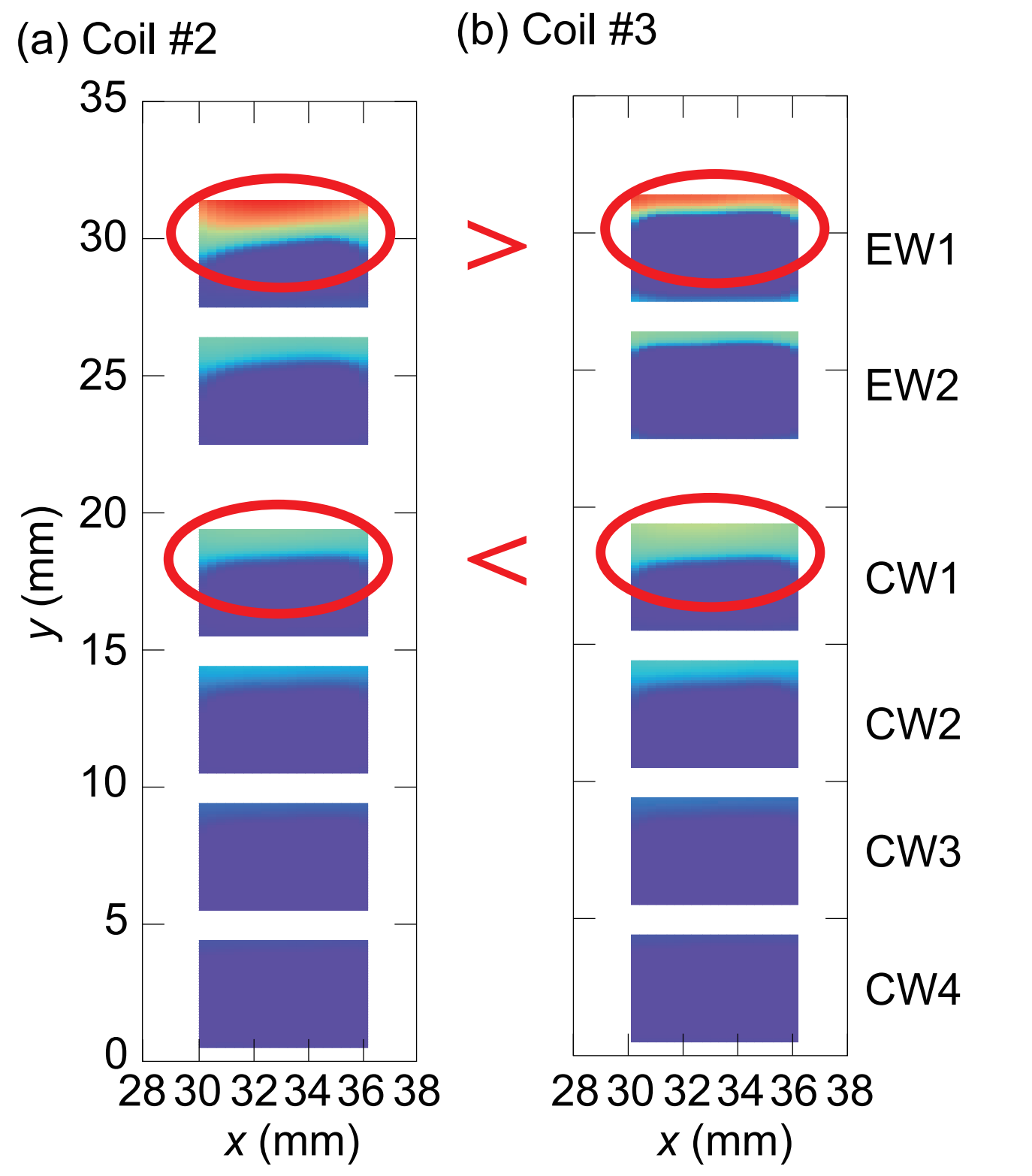
Strong non-uniformity of *J* distribution in EW in coil #3

↓

Increase in the magnetic field at CW1 in coil #3

Increase of voltage in CW1 in coil #3

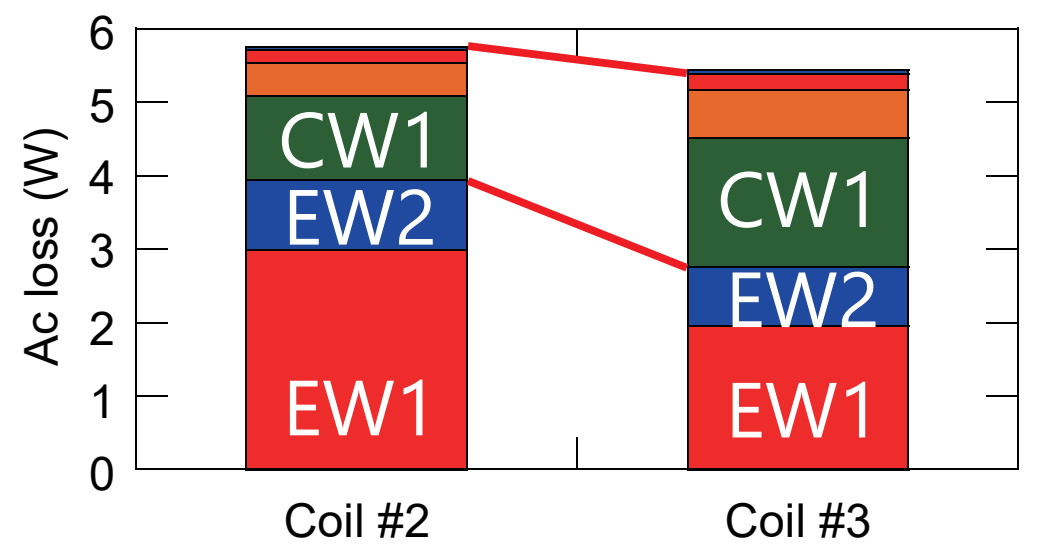
6. Effect of I_c grading (coil #2 vs. #3) – ac loss



I_{peak} = 40 A, *f* = 11.373 Hz, *t* = 13/8 *T*

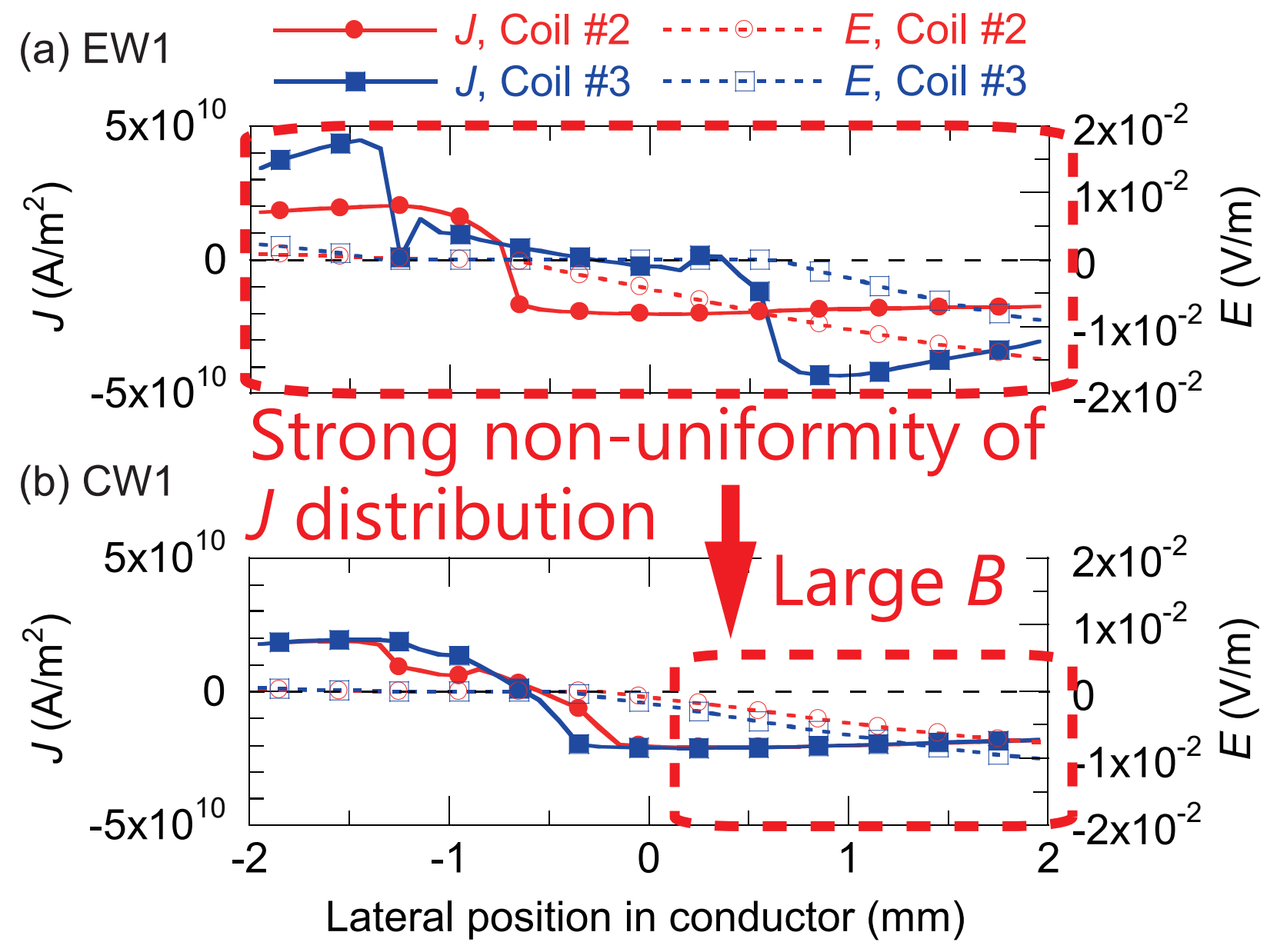
Calculated ac losses when I_{peak} = 40 A, *f* = 11.373 Hz		
Coil no.	#2	#3
J/cycle	2.14×10^{-2}	1.99×10^{-1}
J/m/cycle	4.28×10^{-3}	3.98×10^{-3}

Decrease in ac loss, but small effect



Loss in CW ↑

Loss in EW ↓



High J_c in EW results in strong magnetic interaction between coils, and it deteriorate effect of I_c grading

Acknowledgement

This work was supported in part by the Ministry of Education, Culture, Sports, Science and Technology under the Innovative Nuclear Research and Development Program.