the 25th International Conference on Magnet Technology (MT25)
27 August – 1 September, 2017
Amsterdam, The Netherlands
Tue-Af-Or18-3 (August 29, Tuesday)

Effect of striating coated conductors on reducing shielding-current-induced fields in pancake coils exposed to normal magnetic fields

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Motivation and objective

Motivation

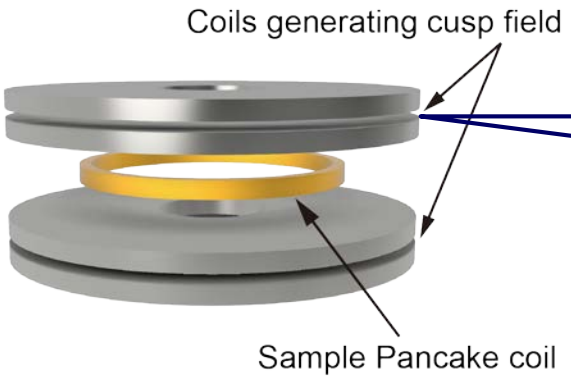
- The striation of a coated conductor to divide its superconductor layer into filaments is one of the approaches to reduce the magnetization, *i.e.* shielding-current-induced field (SCIF).
- The striation is effective to reduce the magnetization, *i.e.* SCIF, only after the decay of the coupling current, which is the shielding current flowing through superconducting filaments and normal conductor between them.

Objective

- Characterization of shielding-current-induced fields in pancake coils wound with striated and copper-plated coated conductors, which are more robust against local defect and local normal transition exposed to normal magnetic fields

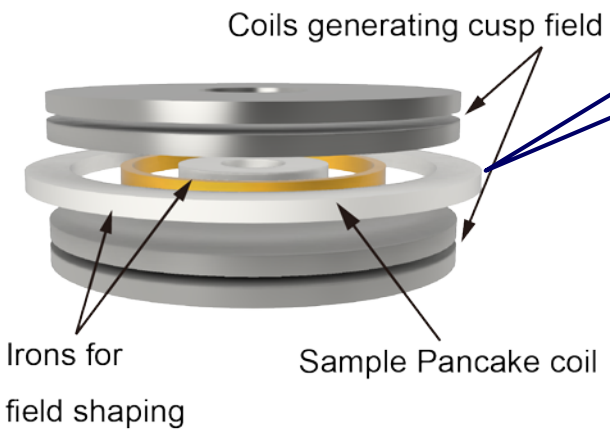
Sample configuration and numerical method

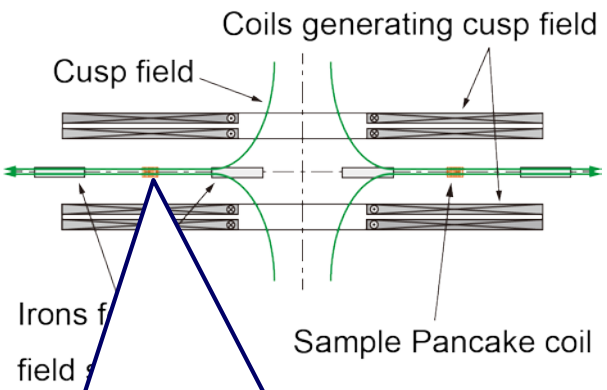
Configuration and sample pancake coil and coils generating cusp field



Cusp magnetic field is generated a pair of DPs.

The magnetic field is shaped by two iron rings.

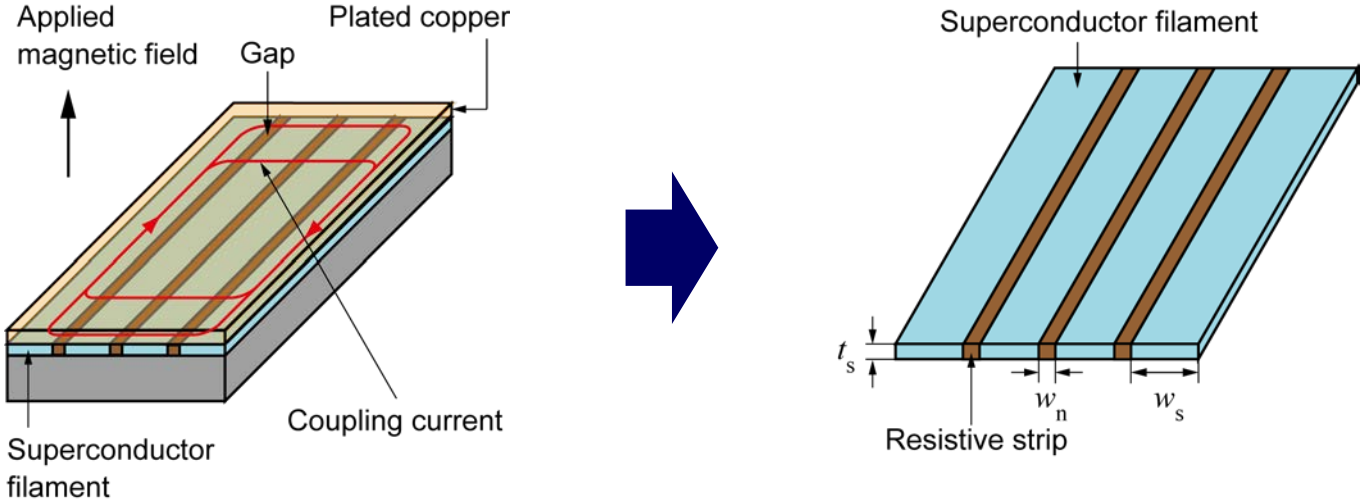




All experiments and calculations were done at 30 K.

A normal magnetic field is applied to the sample PC.

Model and method analyses



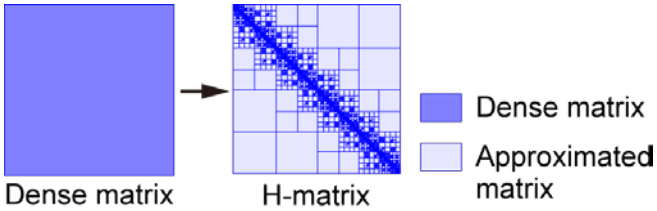
Governing equation

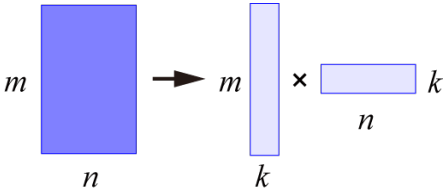
$$\nabla\times\left(\frac{1}{\sigma}\nabla\times\boldsymbol{n}T\right)\cdot\boldsymbol{n}+\frac{\partial}{\partial t}\left(\frac{\mu_0 t_s}{4\pi}\int_{S'}\frac{(\nabla\times\boldsymbol{n}'T')\times\boldsymbol{r}\cdot\boldsymbol{n}}{r^3}\mathrm{d}S'+\boldsymbol{B}_{\mathrm{ext}}\cdot\boldsymbol{n}\right)=0$$

E-J characteristics

$$\sigma=J/E=\frac{(J_c(B_n))^n}{E_0 J^{n-1}} \qquad J_c(B_n)=J_{c0}\frac{B_0}{B_0+B_n}$$

H-matrices with low-rank approximation





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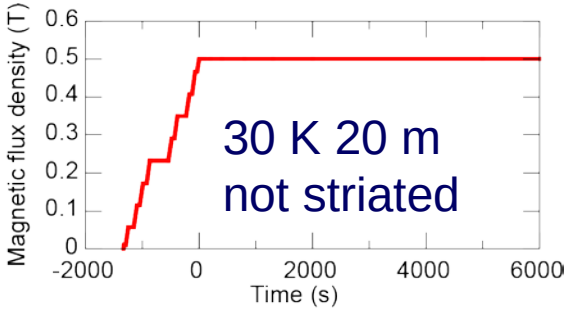
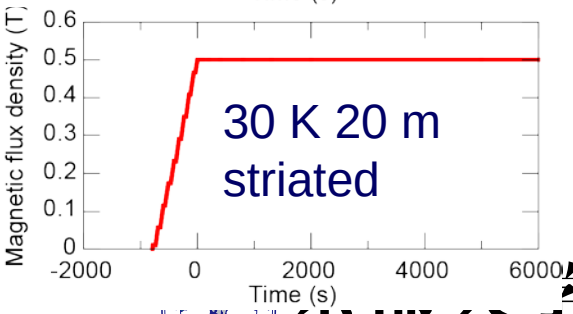
Specifications of conductors and coils; temporal profiles of applied magnetic field

Specifications of coated conductor	
Width	4.0 mm
Thickness	0.94 mm
Superconductor thickness (t_s)	1.7 μm
Gap between SC filaments (w_g)	50 μm
Number of SC filaments	4

Specifications of pancake coils	
Inner radius	55 mm
Number of turns	54.2
Conductor length	20 m
Separation between turns	25 μm

	30 K
Power law *E–J* characteristic E_0	1×10^{-4} V m^{-1}
Power law *E–J* characteristic n	50
Critical current density at zero field (J_{c0})	9.97×10^{10} A m^{-1}
Constant B_0 in Kim's model	1.43 T
Conductivity of resistive strip in model for electromagnetic field analyses (σ_n)	5.69×10^{9} Ω^{-1} m^{-1}



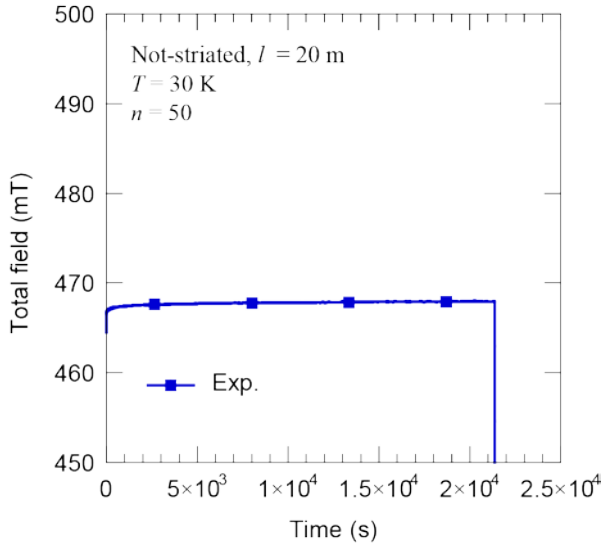


Updated data as of 26/8/17

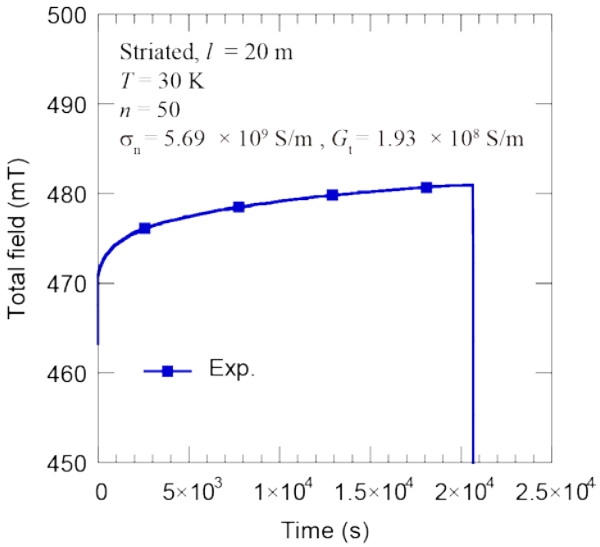
Results

Total measured magnetic field

Total measured magnetic field
when 500 mT of normal field is applied.



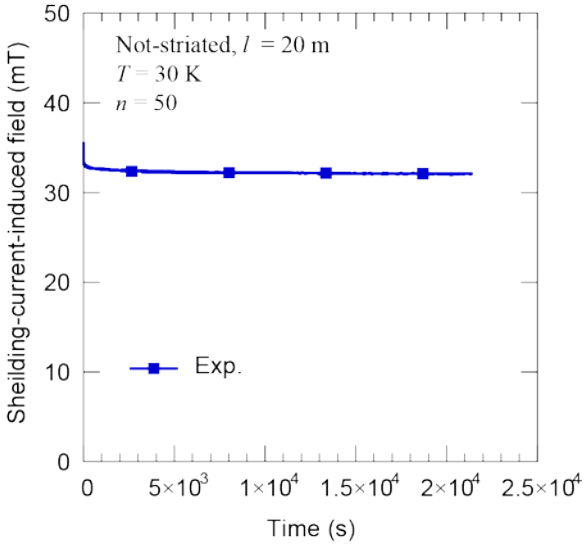
30 K 20 m Not-striated



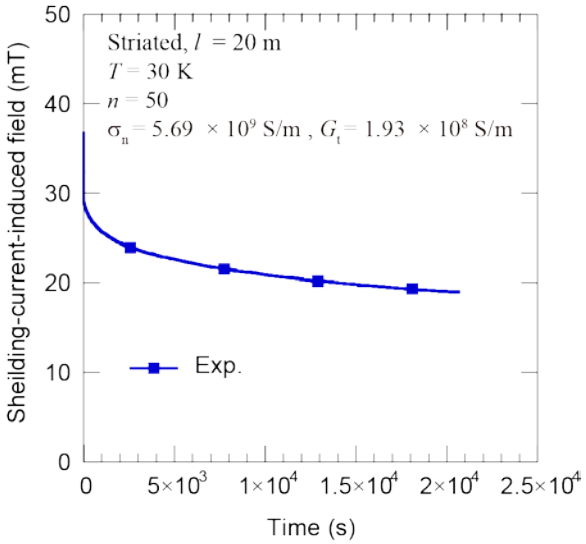
30 K 20 m Striated

Shielding-current-induced field (SCIF) in measured magnetic field

500 mT of applied magnetic field
– total measured magnetic field



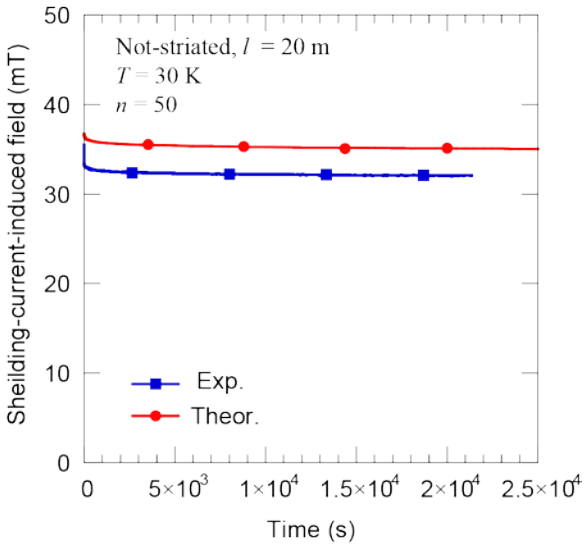
30 K 20 m Not-striated



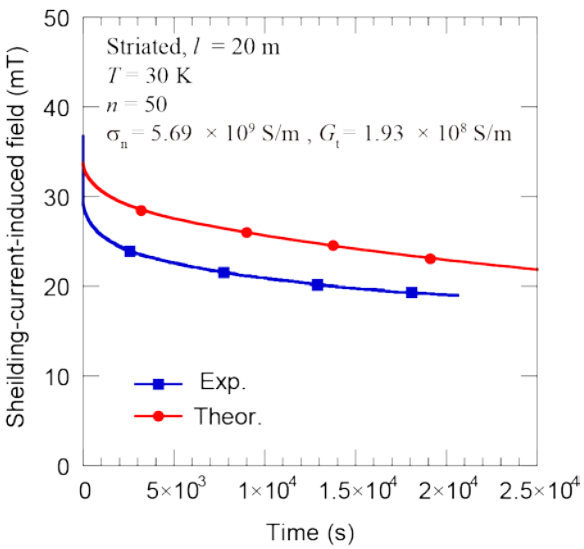
30 K 20 m Striated

Measured and calculated SCIF

- The difference between the measured and calculated SCIF is a couple of millitesla
- Offsets of instruments and / or misalignment of Hall sensor can result in this level of error.

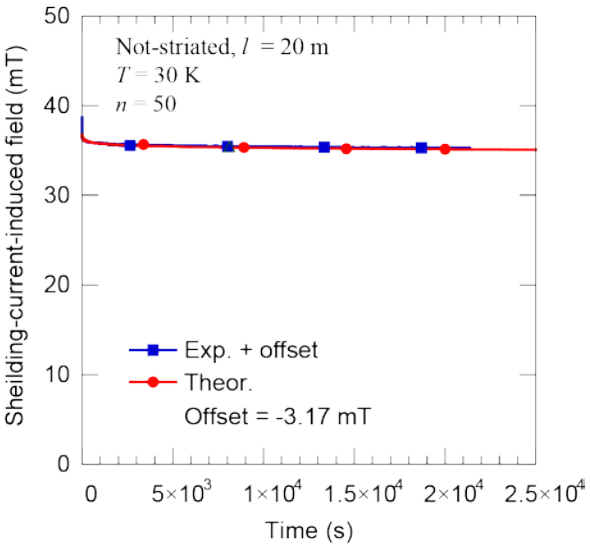


30 K 20 m Not-striated

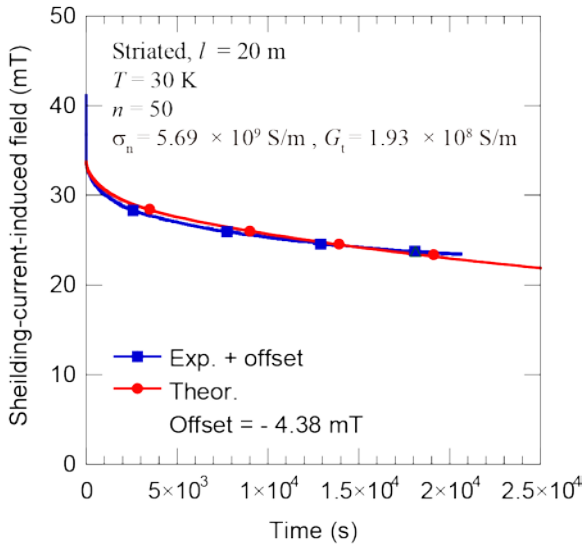


30 K 20 m Striated

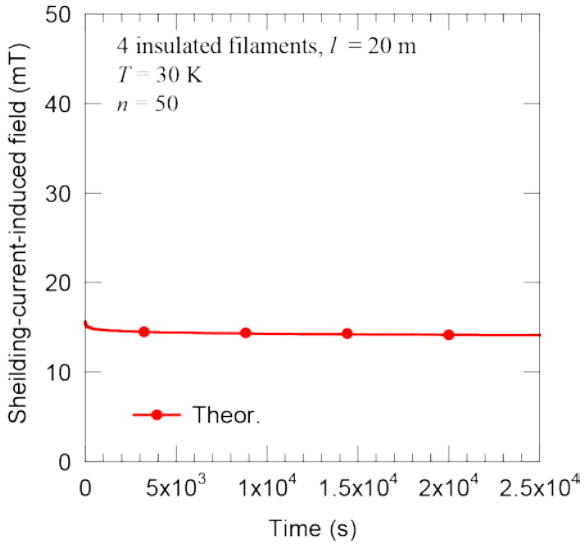
Fitting measured data to calculated data by offset



Not-striated

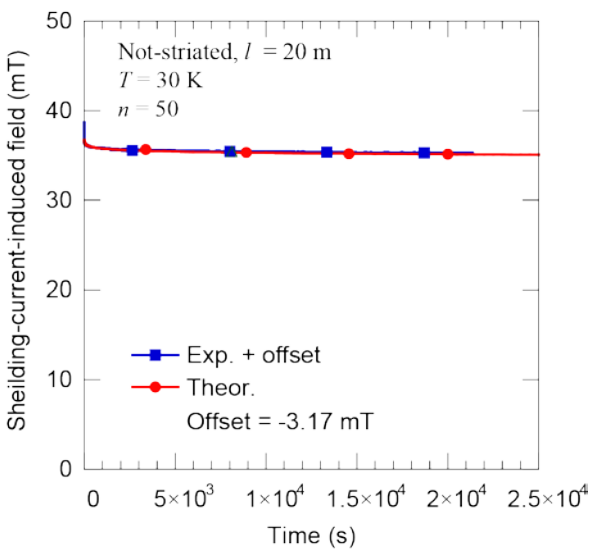


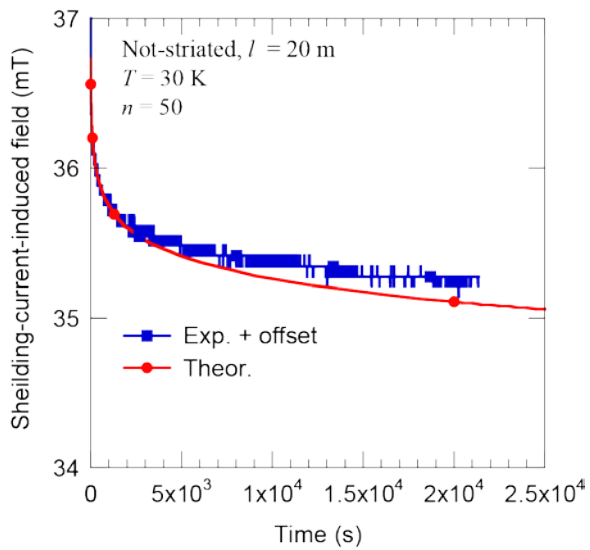
Striated

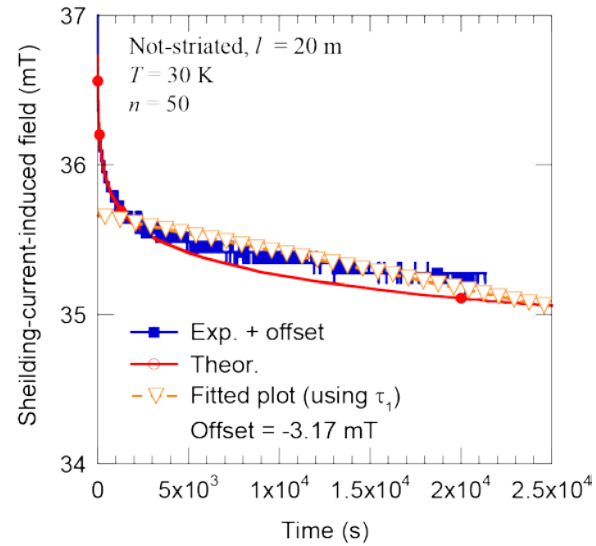


4 insulated filaments

Explanation of decay of SCIF in *not striated* conductor with single time constant







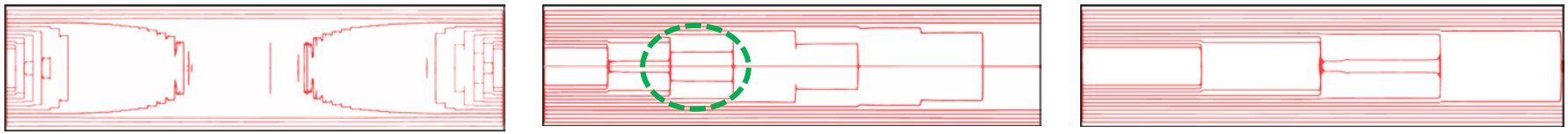
$$\Delta B(t) = \Delta B_0 + \Delta B_1 \exp(-t/\tau_1)$$

Not-striated l =20 m, T=30 K	ΔB_0	ΔB_1 / τ_1
	3.17 mT	32.5 mT / 1.32 × 10^6 s

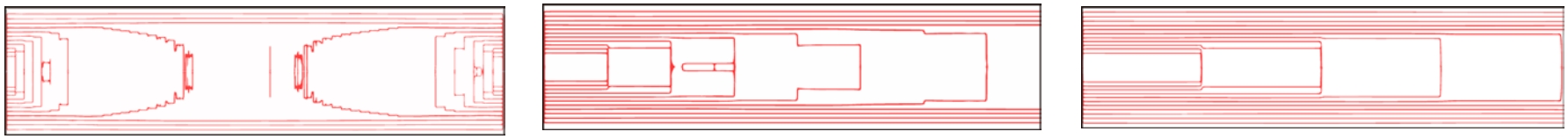
Current lines in *not striated* conductor

t = 0 s (reaching flat top)

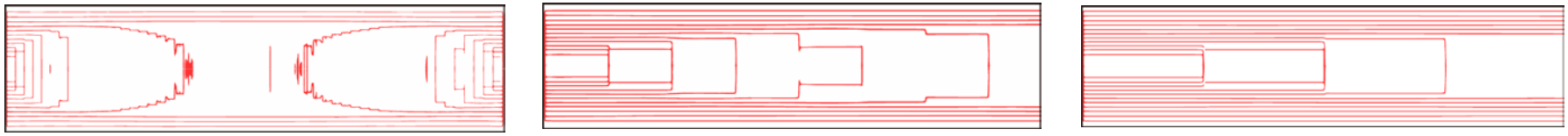
20 m, 30 K 40 A/line



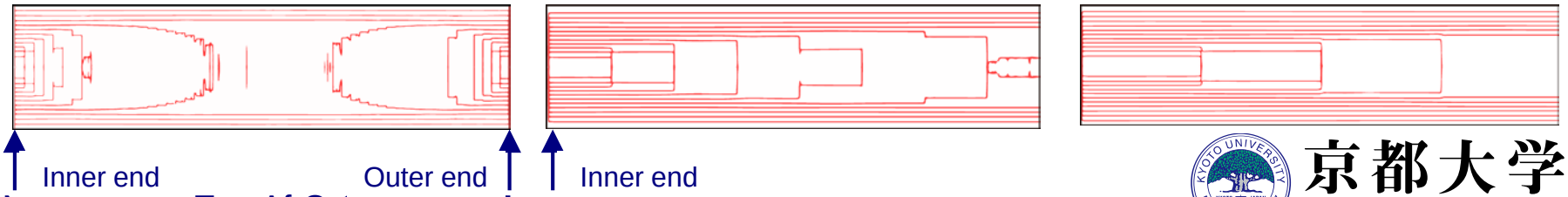
t = 1000 s



t = 10000 s



t = 25000 s



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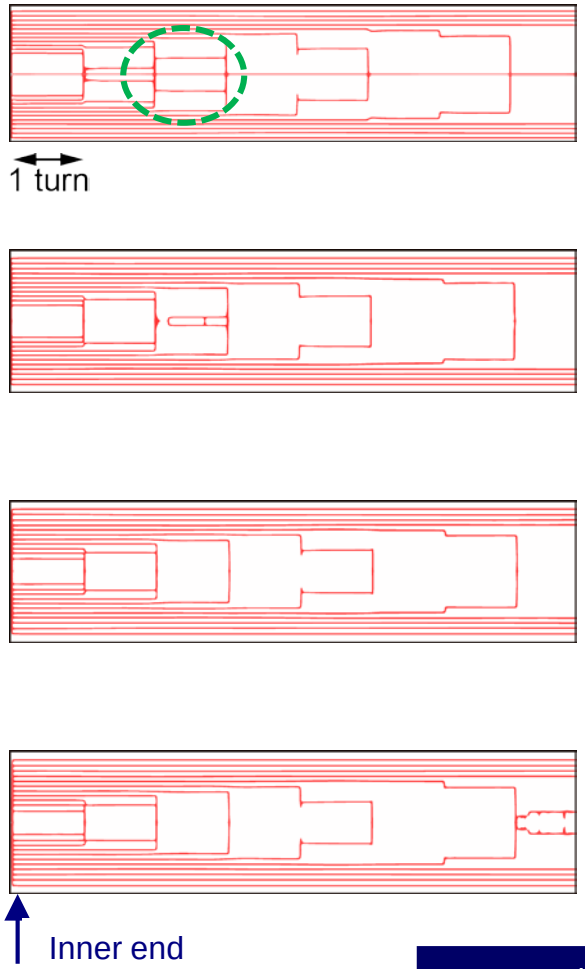
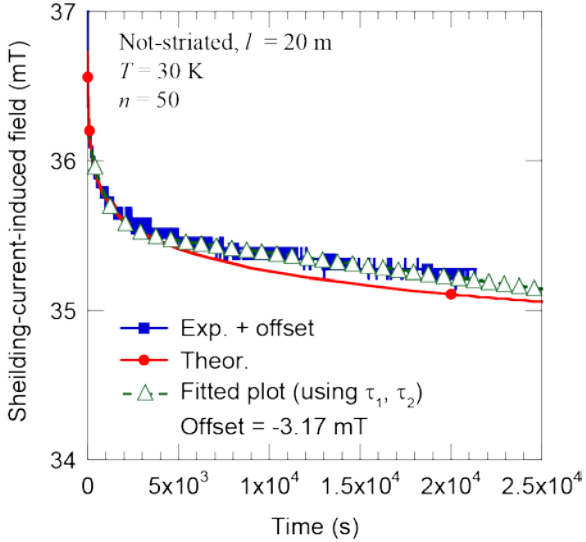
Explanation of decay of SCIF in *not striated* conductor with two time constants





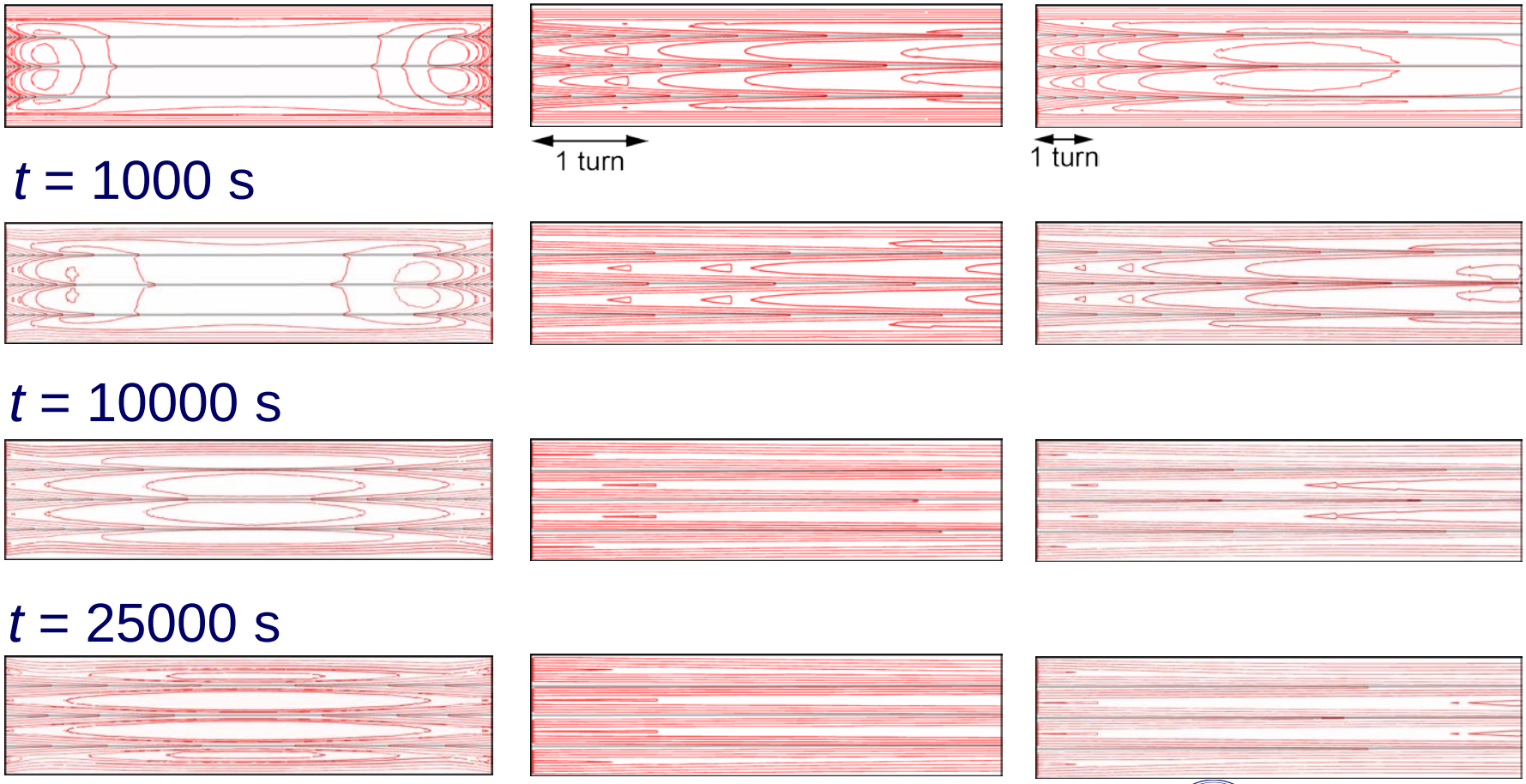
$$\Delta B(t) = \Delta B_0 + \Delta B_1 \exp(-t/\tau_1) + \Delta B_2 \exp(-t/\tau_2)$$

Not-striated l =20 m, T=30 K	ΔB_0	ΔB_1 / τ_1	ΔB_2 / τ_2
	3.17 mT	32.4 mT / 2.02 × 10^6 s	0.662 mT / 935 s

Current lines in *striated* conductor

t = 0 s (reaching flat top)

20 m, 30 K 25 A/line

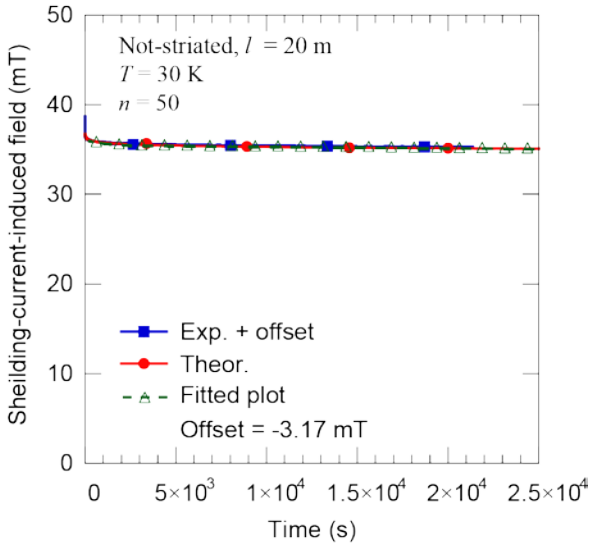


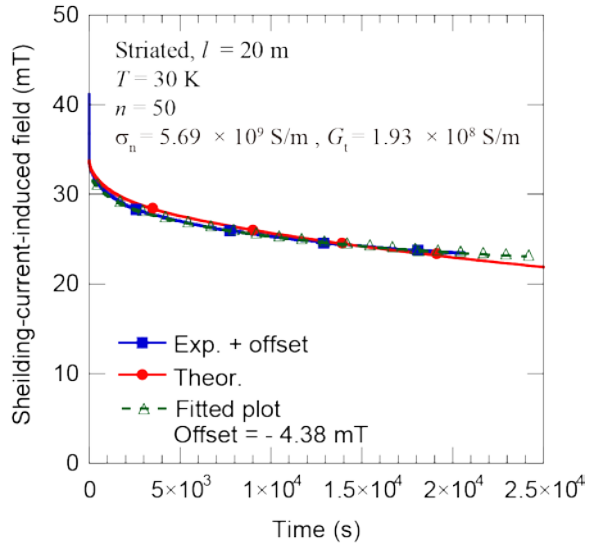
t = 1000 s

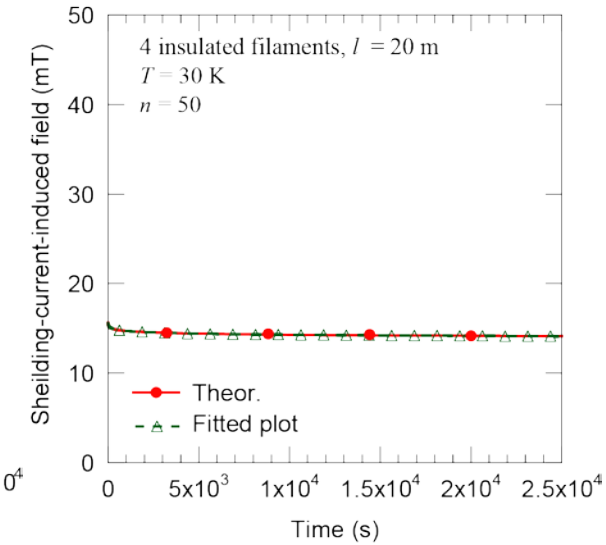
t = 10000 s

t = 25000 s

Explanation of decay of SCIF in *various* conductor with multiple time constants







$$\Delta B(t) = \Delta B_0 + \Delta B_1 \exp(-t/\tau_1) + \Delta B_2 \exp(-t/\tau_2) + \Delta B_3 \exp(-t/\tau_3) + \Delta B_4 \exp(-t/\tau_4)$$

Not-striated l =20 m, T=30 K	ΔB_0	ΔB_1 / τ_1	ΔB_2 / τ_2	ΔB_3 / τ_3	ΔB_4 / τ_4
	3.17 mT	32.4 mT / 2.02 × 10⁶ s	0.662 mT / 935 s		

Striated l =20 m, T=30 K	ΔB_0	ΔB_1 / τ_1	ΔB_2 / τ_2	ΔB_3 / τ_3	ΔB_4 / τ_4
	4.38 mT	19.8 mT / 3.00 × 10⁵ s	5.47 mT / 8660 s	2.94 mT / 1020 s	0.915 mT / 156 s

4 insulated filaments l =20 m, T=30 K	ΔB_0	ΔB_1 / τ_1	ΔB_2 / τ_2	ΔB_3 / τ_3	ΔB_4 / τ_4
	0.0 mT	14.4 mT / 1.22 × 10⁶ s	0.468 mT / 2587 s	0.415 mT / 241 s	0.297 mT / 22.3 s

Summary

- We calculated SCIF in pancake coils exposed to normal magnetic field and compared with experimental results.
  - Pancake coil wound with not striated coated conductor
  - Pancake coil wound with striated and copper-plated coated conductor
- Measured temporal behaviors of SCIF are explained well by calculations.
- The measured and calculated SCIFs are with multiple time constants, which can be explained by the calculated and visualized current lines.