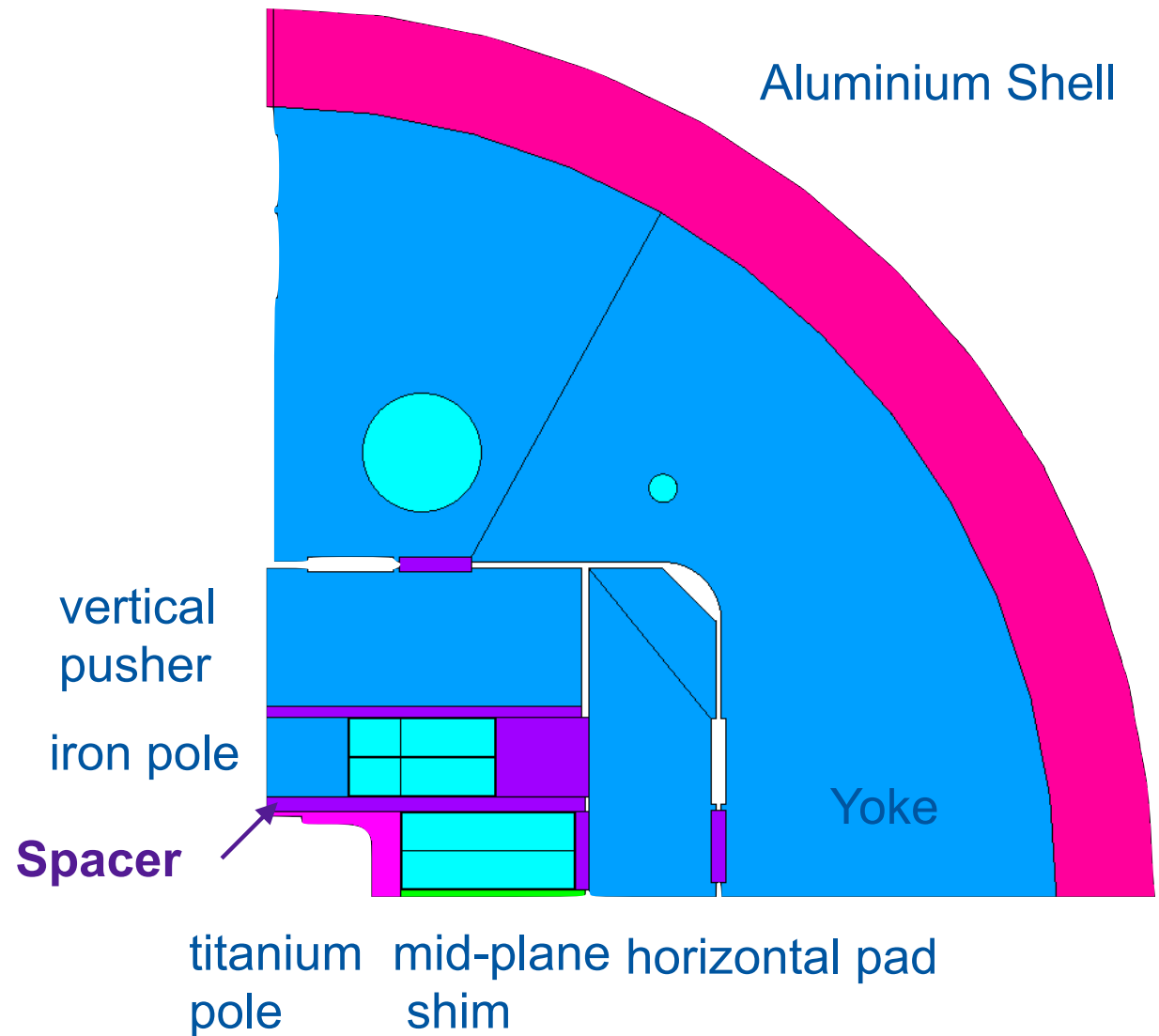# HEPDipo

Introduction of the inter-coils shim Semi-Analytical Model for Eddy Current Computation

D. Martins Araujo

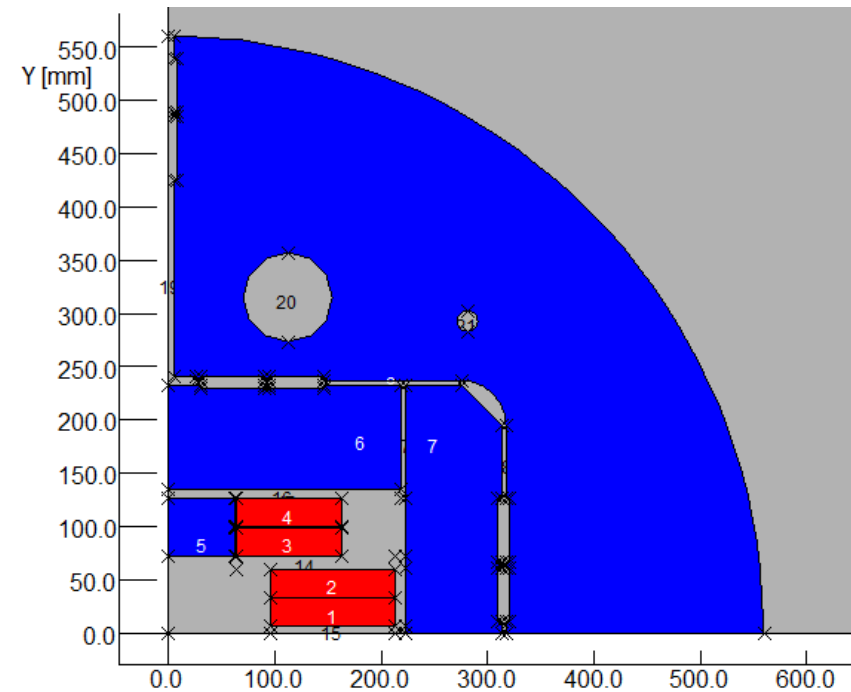MSC-MDT

Specification and 4 coils option cross-section

	Goal
B center	15 T
% SS	85%
temperature	4.2 K
apperture	'rectangular' 150x100
length	~ 2 m

Aluminium Shell

vertical pusher

iron pole

Spacer

Yoke

titanium pole
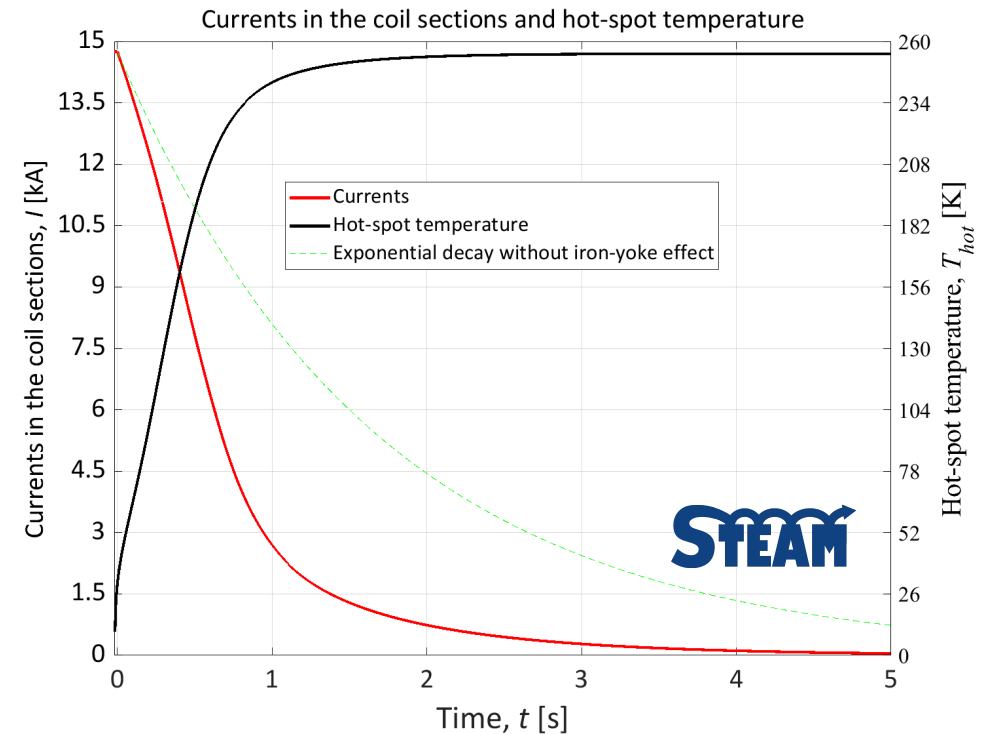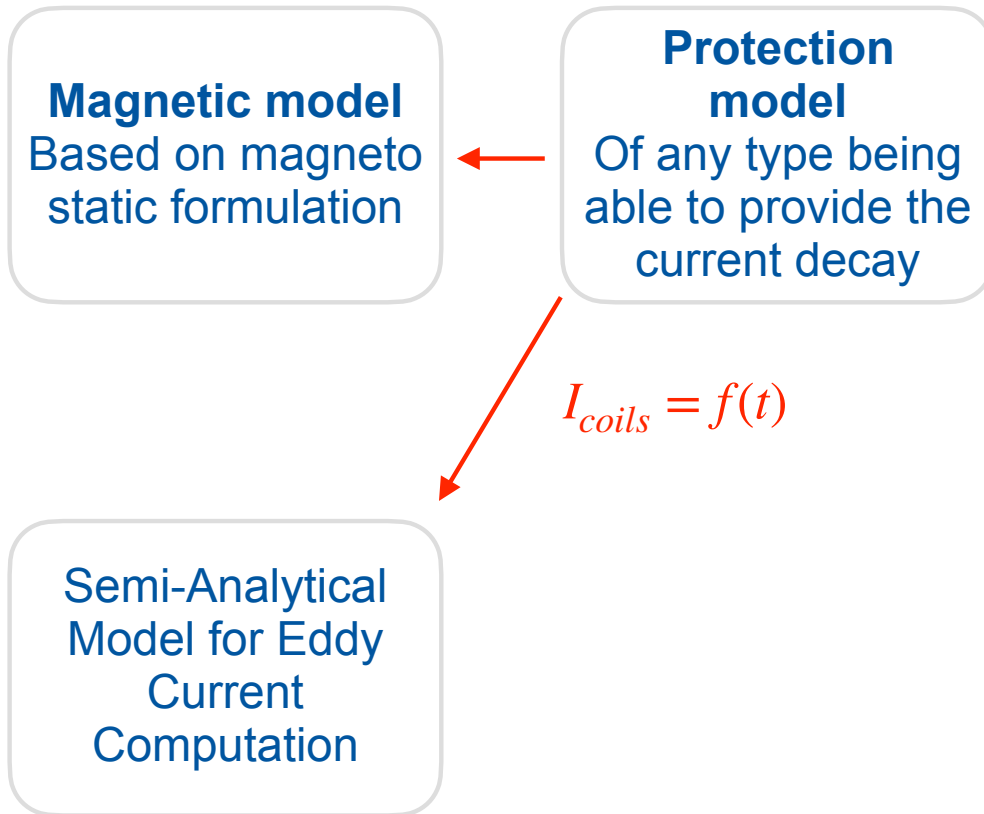
mid-plane shim

horizontal pad

2.5 dimensions semi-analytical approach

Magnetic model
Based on magneto static formulation

Opera model

2.5 dimensions semi-analytical approach

Magnetic model
Based on magneto static formulation

Protection model
Of any type being able to provide the current decay

$$I_{coils} = f(t)$$

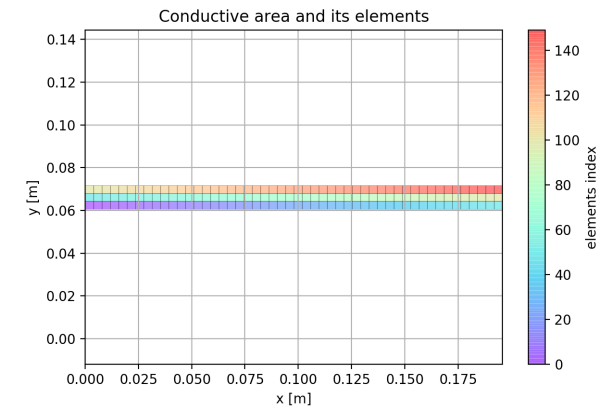Semi-Analytical Model for Eddy Current Computation

Curve obtained with STEAM-LEDET model

2.5 dimensions semi-analytical approach

Magnetic model
Based on magneto static formulation

Protection model
Of any type being able to provide the current decay

$I_{coils} = f(t)$

Semi-Analytical Model for Eddy Current Computation

Provides mesh information for field computation

Conductive area and its points
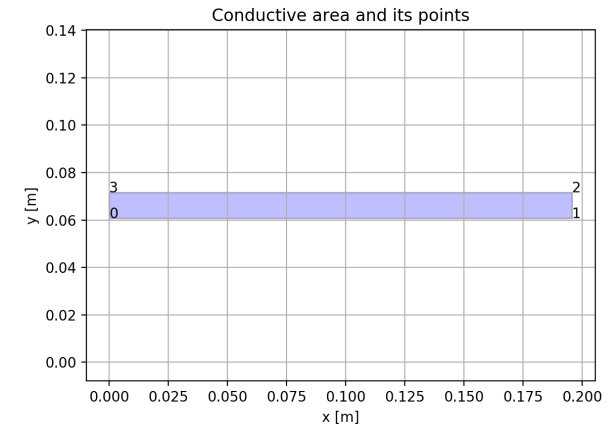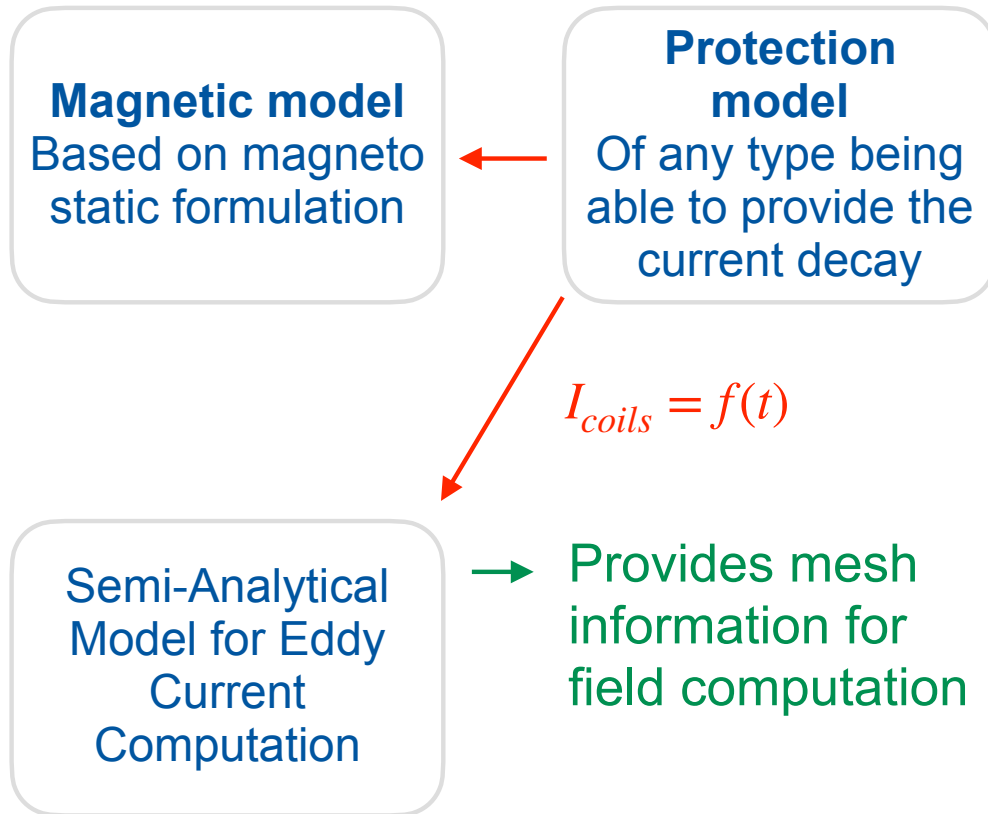
Modelling the conductive area

Conductive area and its elements

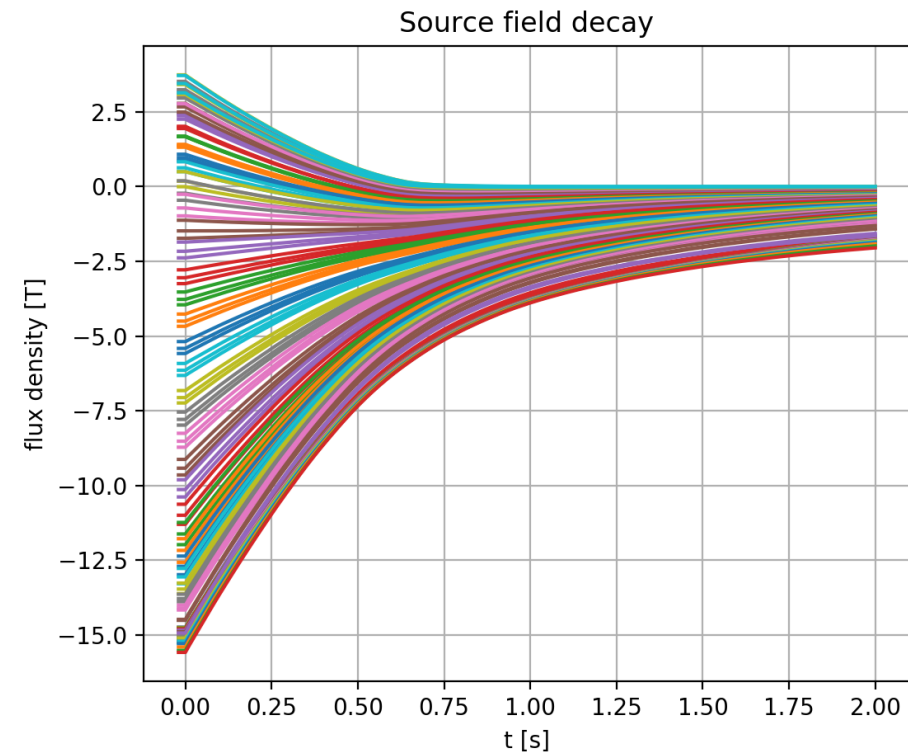**Meshing and indexing**

2.5 dimensions semi-analytical approach

Magnetic model
Based on magneto static formulation

Protection model
Of any type being able to provide the current decay

$b_{shim} = f(I_{coils}, \mathbf{x})$

$I_{coils} = f(t)$

Semi-Analytical Model for Eddy Current Computation

$\rightarrow \mathbf{x}$
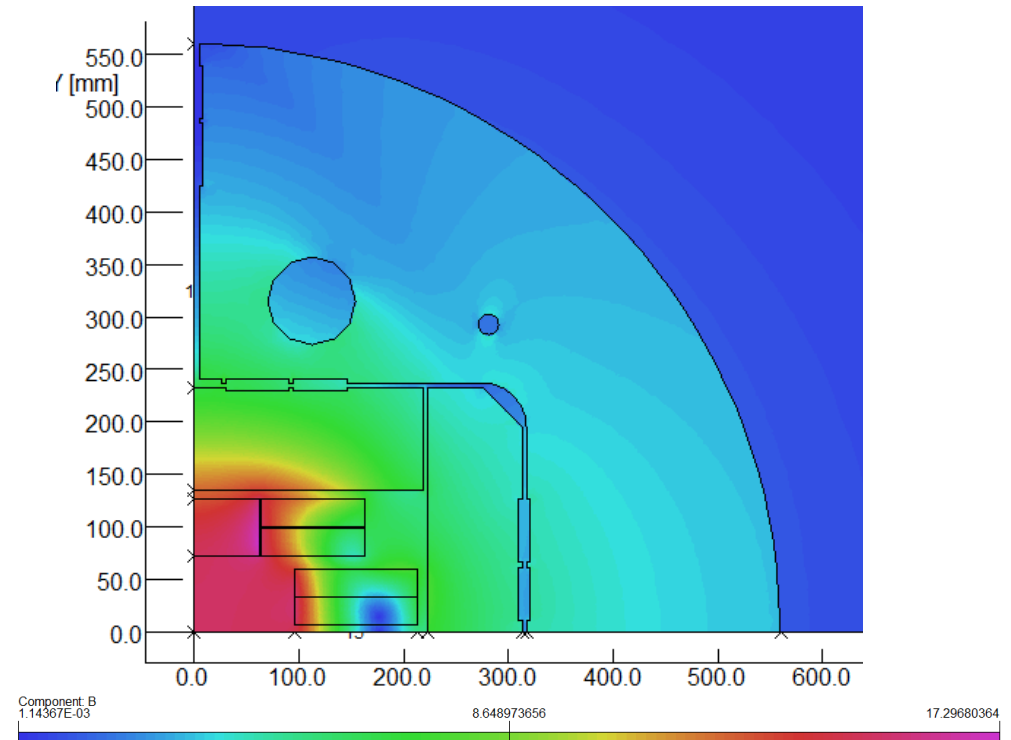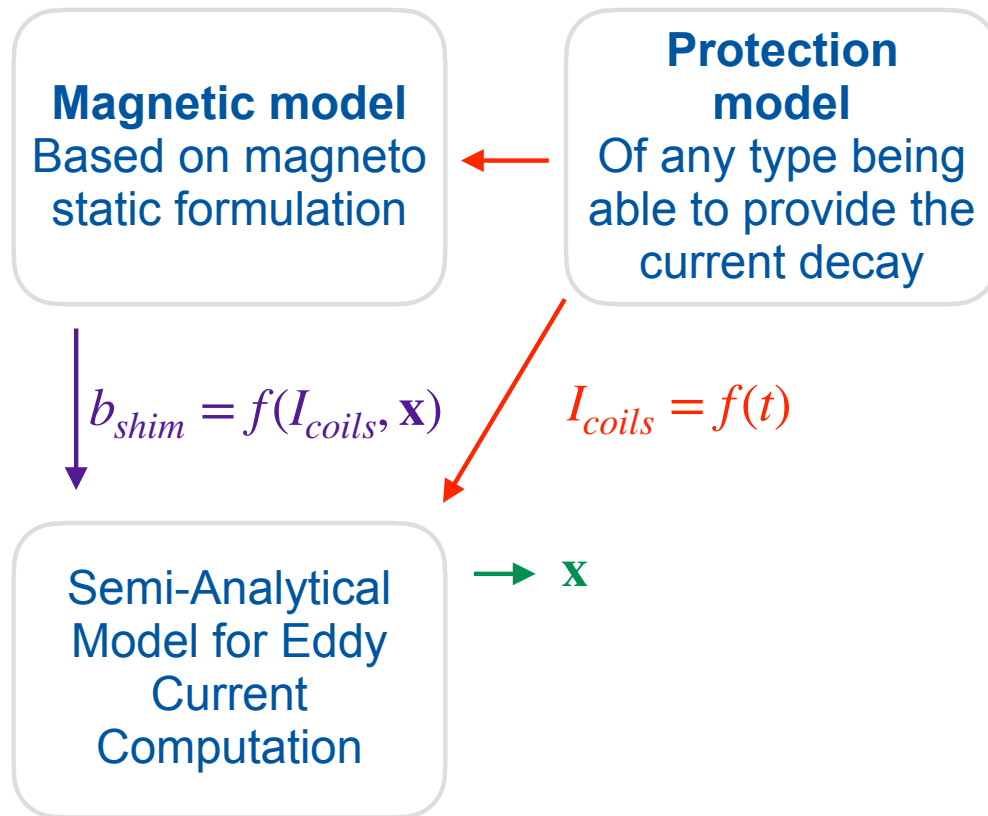
Opera model
Flux density computed

2.5 dimensions semi-analytical approach

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Based on magneto static formulation

Protection model
Of any type being able to provide the current decay

$$b_{shim} = f(I_{coils}, \mathbf{x})$$

$$I_{coils} = f(t)$$

Semi-Analytical Model for Eddy Current Computation

$\rightarrow \mathbf{x}$

$\rightarrow b^s_{shim} = f(t^*, \mathbf{x})$

Source field decay
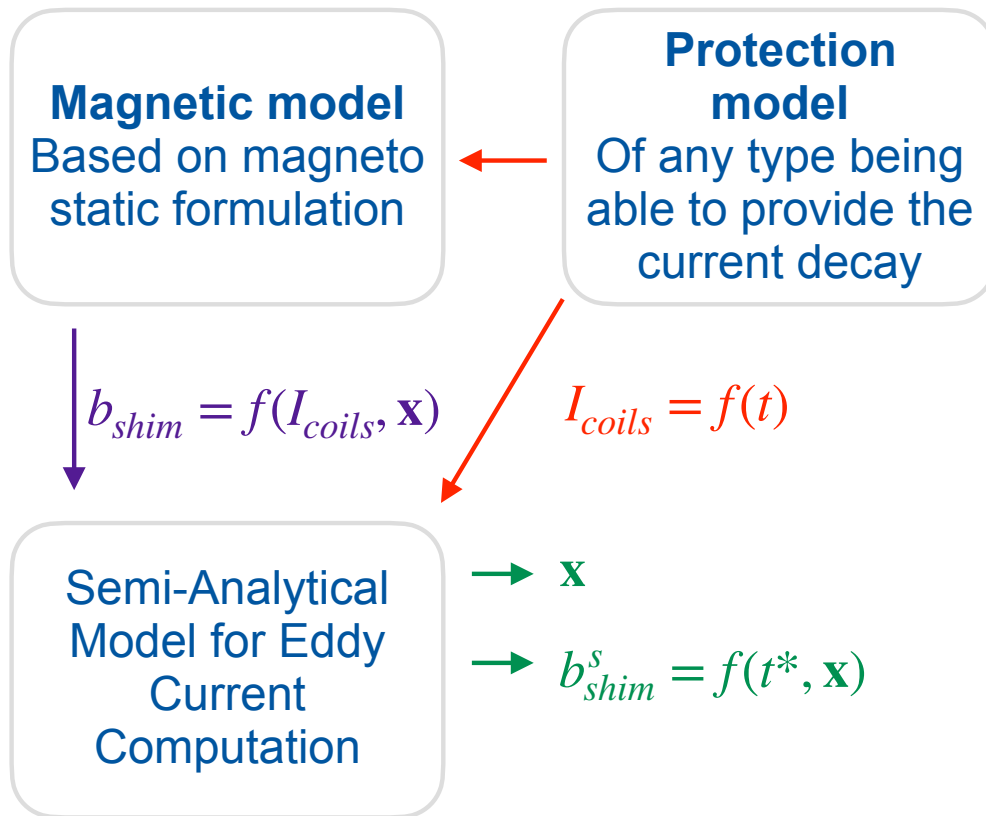
After a given time discretization, **t*, the source flux density** is interpolated
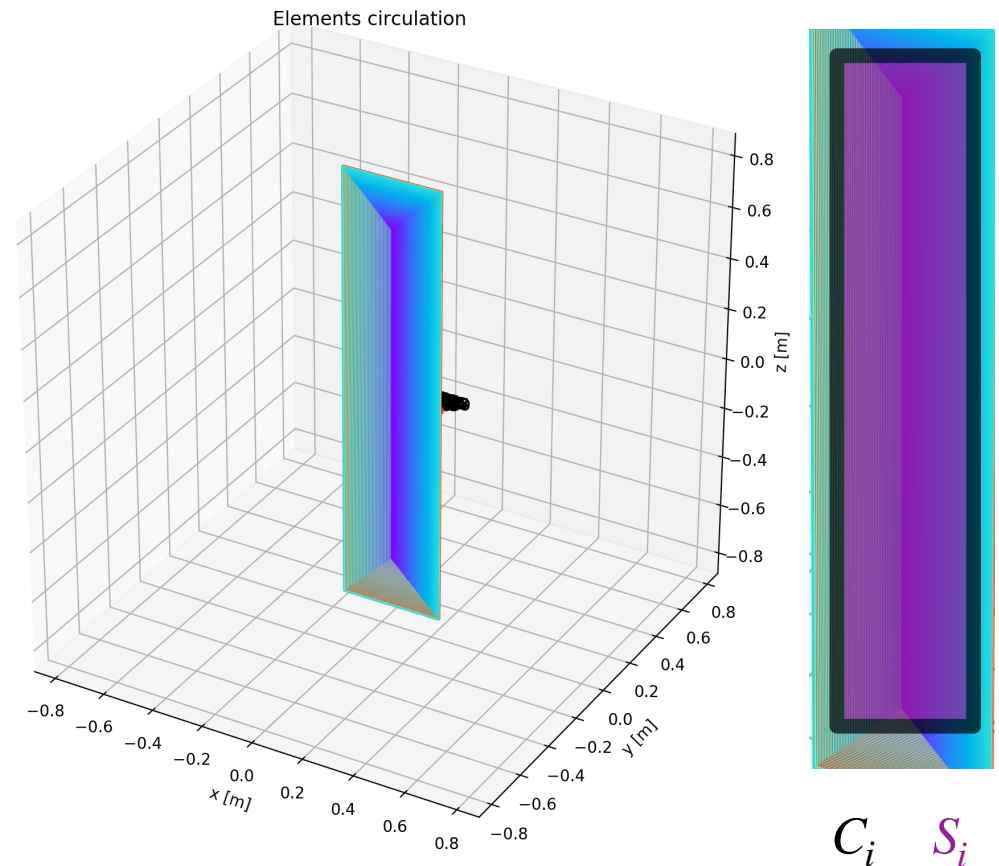
2.5 dimensions semi-analytical approach

Elements circulation
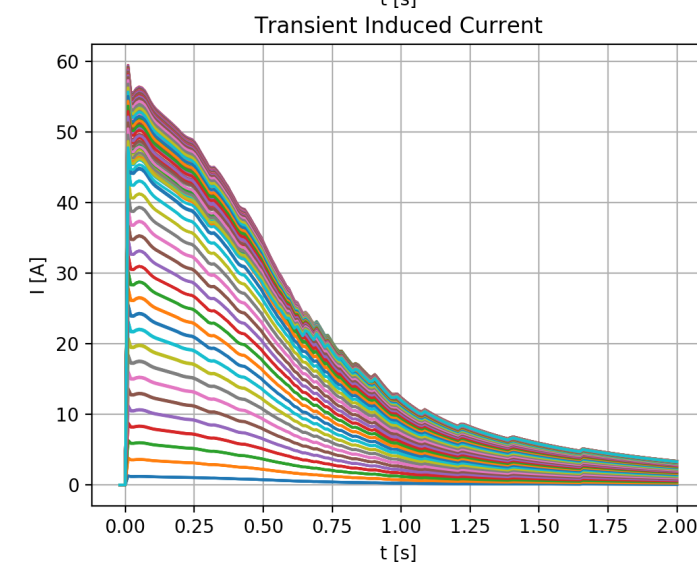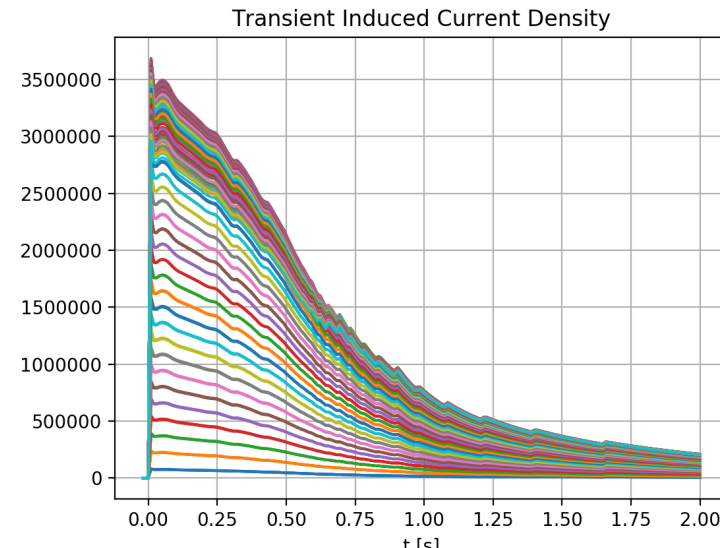
Magnetic model
Based on magneto static formulation

Protection model
Of any type being able to provide the current decay

$$b_{shim} = f(I_{coils}, \mathbf{x})$$

$$I_{coils} = f(t)$$

Semi-Analytical Model for Eddy Current Computation

$\longrightarrow$ $\mathbf{x}$

$\longrightarrow$ $b_{shim}^{s} = f(t^{*}, \mathbf{x})$

$\longrightarrow$ $S_i, C_i = f(l_{mag}, \mathbf{x_i})$

C_i S_i
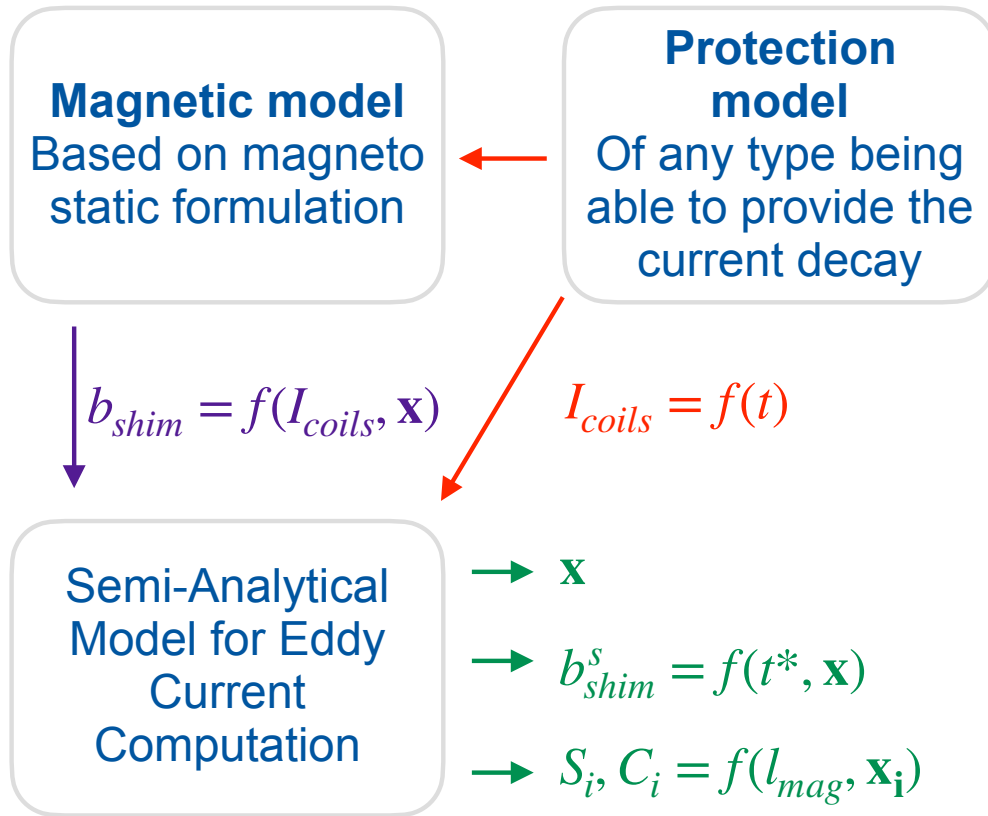
Based on the co-energy ratio (3D/2D) the **magnetic length and elements circulation** is defined
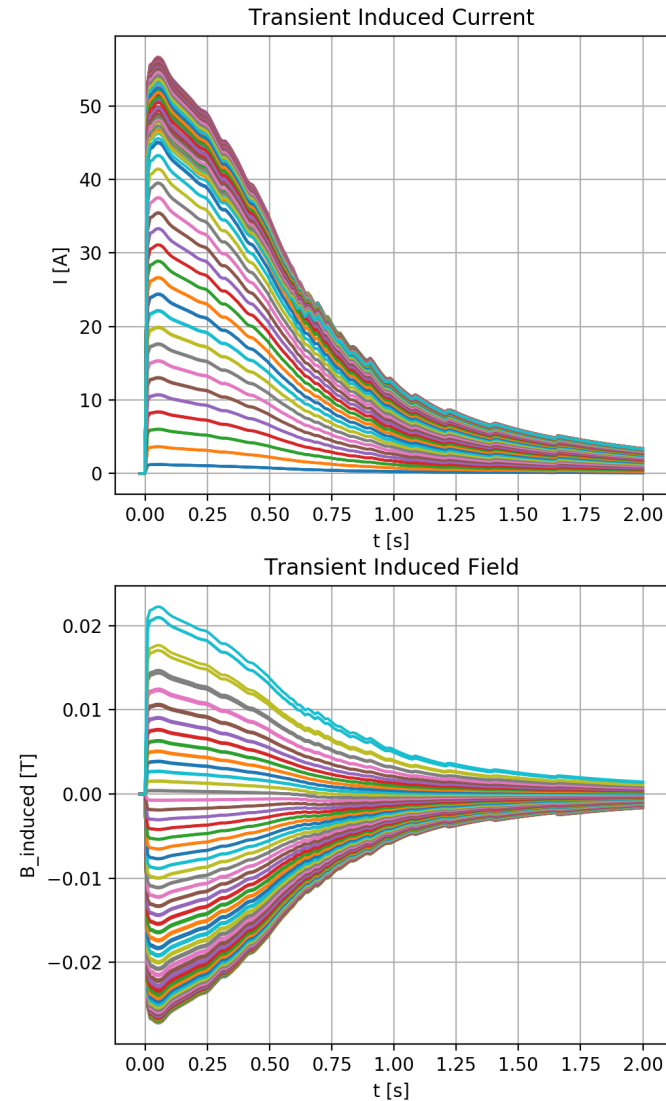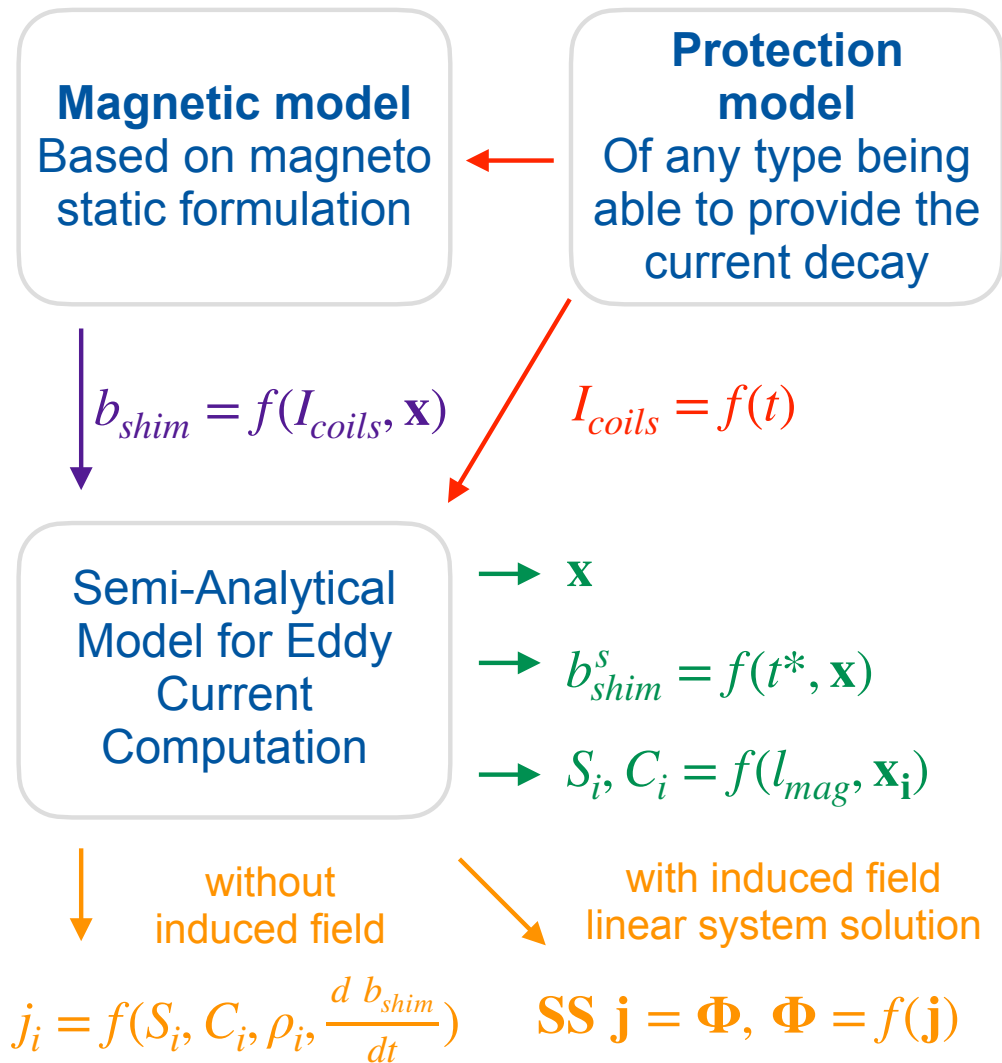
2.5 dimensions semi-analytical approach

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Of any type being able to provide the current decay

$b_{shim} = f(I_{coils}, \mathbf{x})$

$I_{coils} = f(t)$

Semi-Analytical Model for Eddy Current Computation

$\rightarrow \mathbf{x}$

$\rightarrow b^s_{shim} = f(t^*, \mathbf{x})$

$\rightarrow S_i, C_i = f(l_{mag}, \mathbf{x_i})$

without induced field

$j_i = f(S_i, C_i, \rho_i, b^s_{shim})$

Transient Induced Current Density

Transient Induced Current

2.5 dimensions semi-analytical approach

Magnetic model
Based on magneto static formulation

Protection model
Of any type being able to provide the current decay

$b_{shim} = f(I_{coils}, \mathbf{x})$

$I_{coils} = f(t)$

Semi-Analytical Model for Eddy Current Computation

$\rightarrow \mathbf{x}$

$\rightarrow b_{shim}^{s} = f(t^*, \mathbf{x})$

$\rightarrow S_i, C_i = f(l_{mag}, \mathbf{x_i})$

without induced field

with induced field linear system solution

$j_i = f\left(S_i, C_i, \rho_i, \dfrac{d\, b_{shim}}{dt}\right)$

$\mathbf{SS\ j} = \mathbf{\Phi}, \ \mathbf{\Phi} = f(\mathbf{j})$

Transient Induced Current

Transient Induced Field

4 coils option vs FRESCA2 type
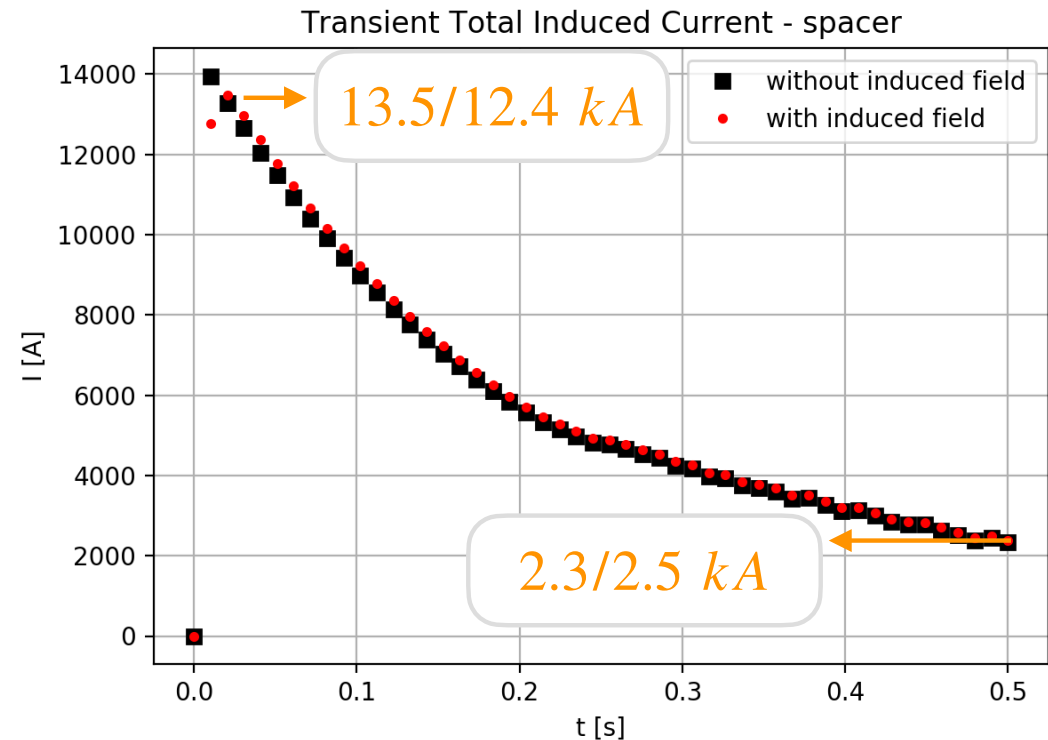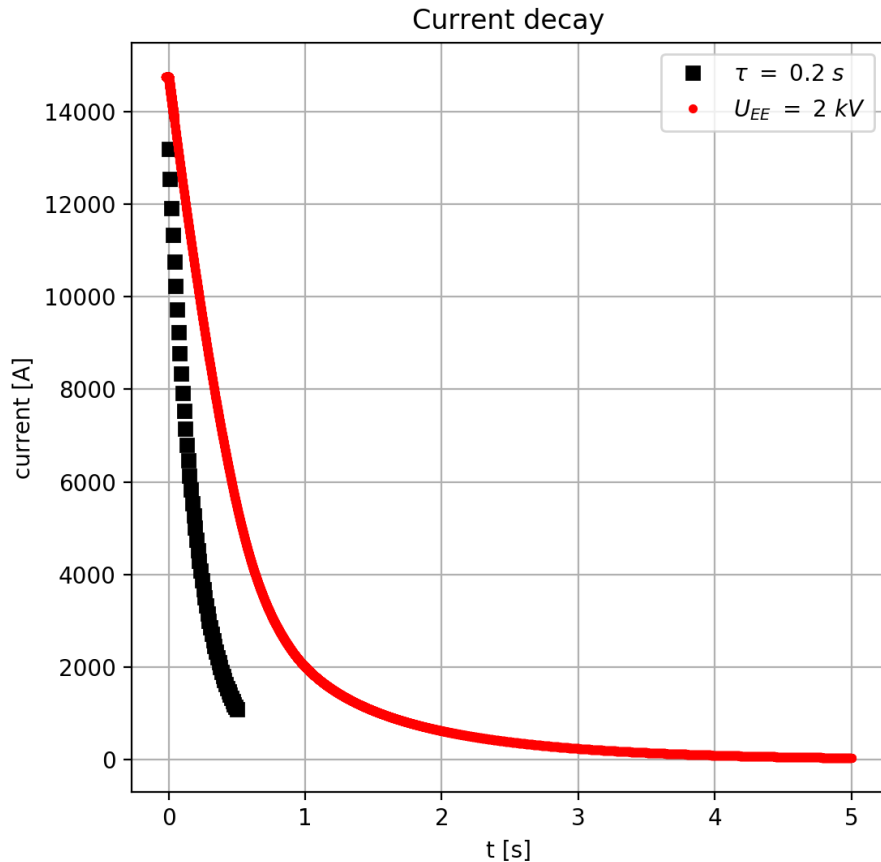
LD type

FRESCA2 type

inter-coil shim (spacer) 210 mm
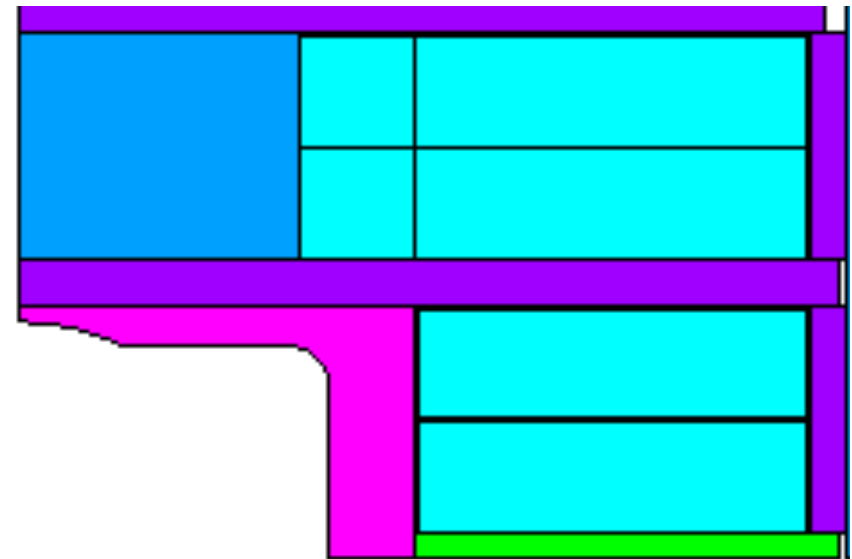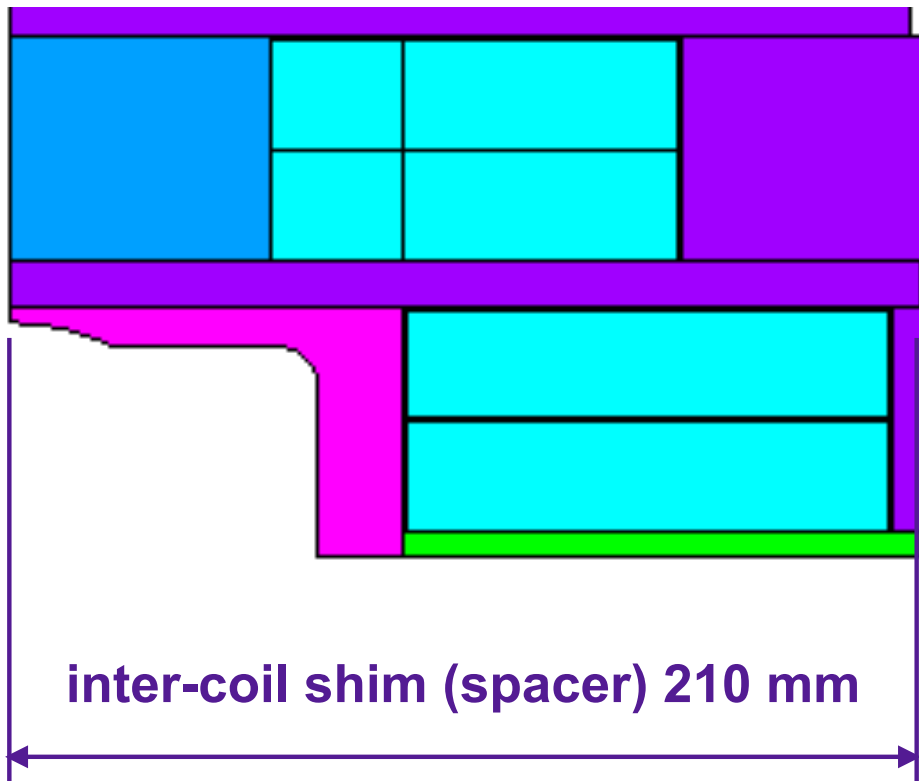
inter-coil shim (spacer) shorter
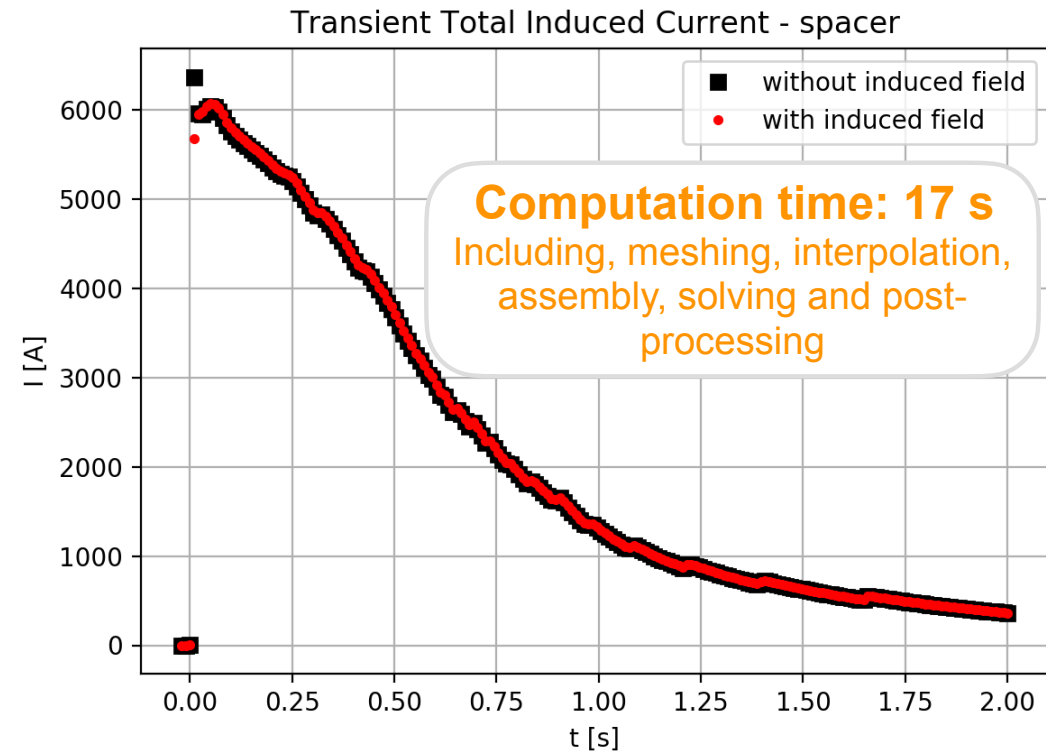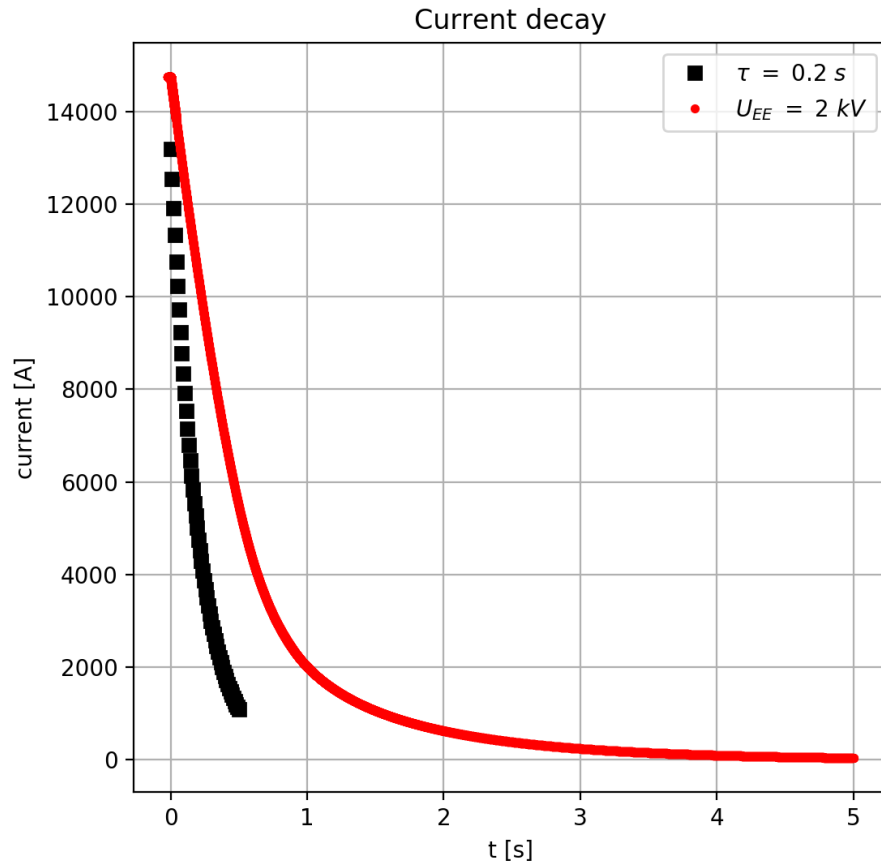
Validation for a time constant of 0.2 s

Relevant parameters	Nominal current $I_{nom} = 13.2\ kA$	Magnet length: $l_{mag} = 1.7\ m$	Stainless resistivity $\rho_{ss} = 53.9\ \mu\Omega\ cm$	Time step $t_{step} = 0.01\ s$

Results for a 2 kV EE based protection

Current decay — Transient Total Induced Current - spacer

Computation time: 17 s
Including, meshing, interpolation, assembly, solving and post-processing

Relevant parameters	Nominal current	Magnet length:	Stainless resistivity	Time step
	$I_{nom} = 14.74\ kA$	$l_{mag} = 1.7\ m$	$\rho_{ss} = 53.9\ \mu\Omega\ cm$	$t_{step} = 0.01\ s$

Relevance for magnet protection (2 kV EE)

Peak inter-filament coupling loss per unit volume during the transient
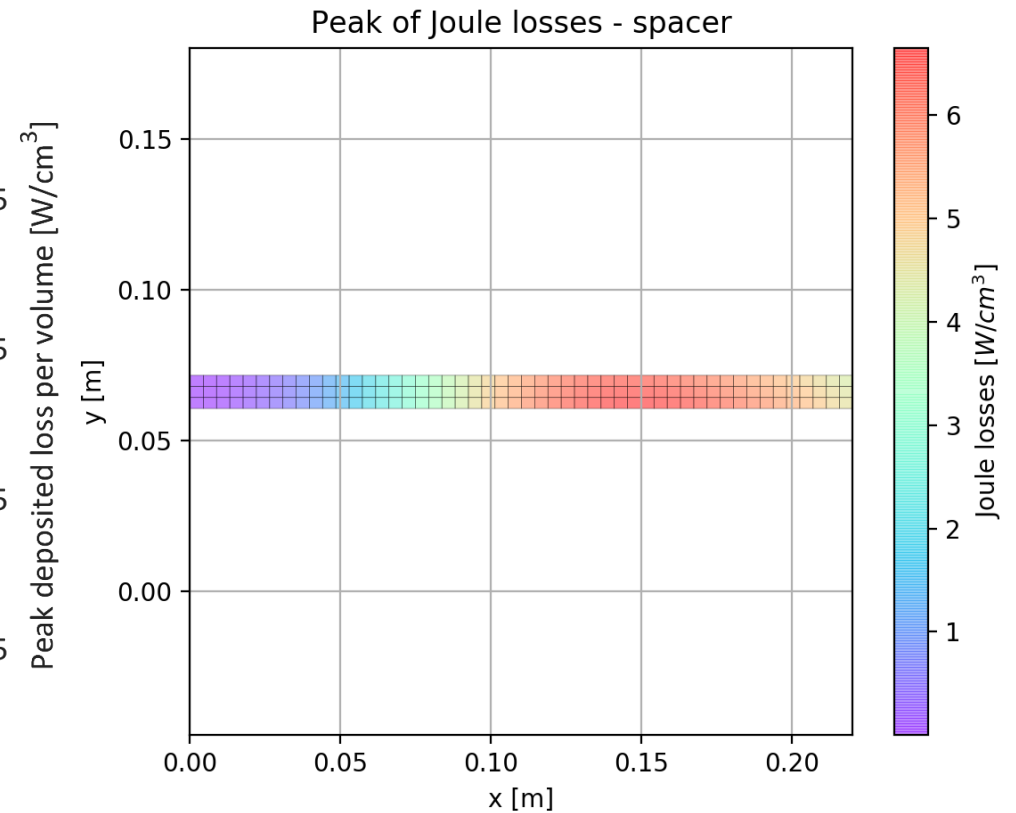

Peak of Joule losses - spacer

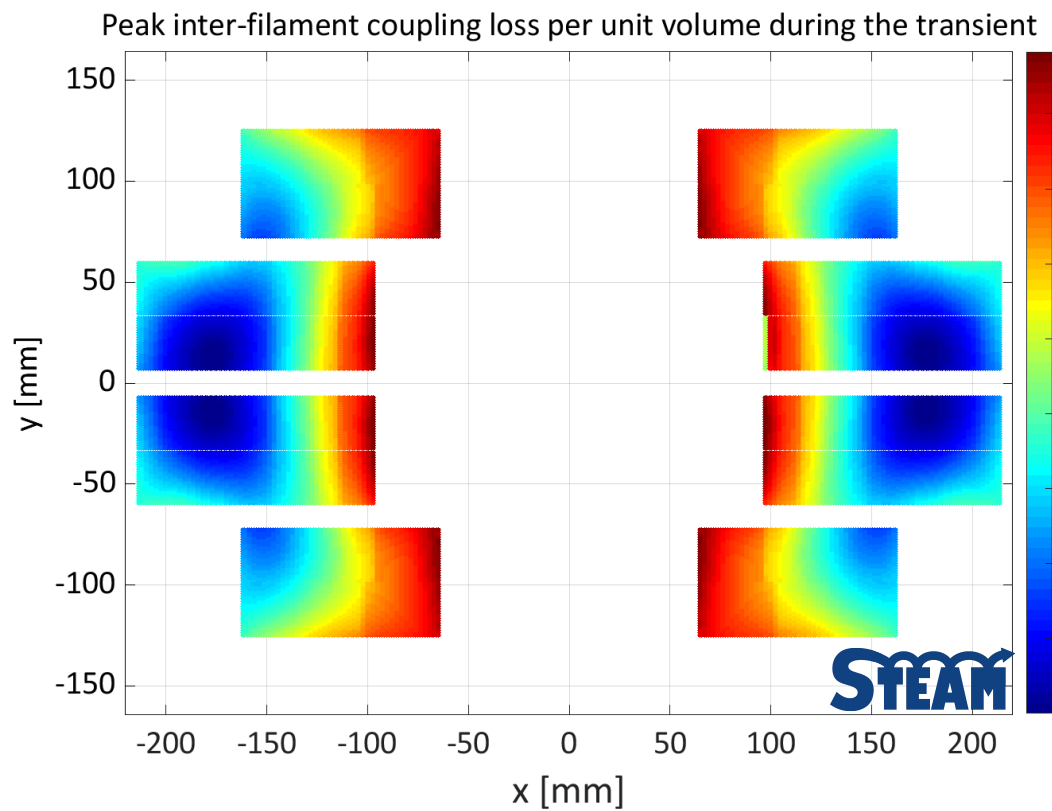| Relevant parameters	Nominal current $I_{nom} = 14.74\ kA$	Magnet length: $l_{mag} = 1.7\ m$	Stainless resistivity $\rho_{ss} = 53.9\ \mu\Omega\ cm$	Time step $t_{step} = 0.01\ s$

Relevance for magnet protection? (2 kV EE)

Relevant parameters

Nominal current

$$I_{nom} = 14.74\ kA$$

Magnet length:

$$l_{mag} = 1.7\ m$$

Stainless resistivity

$$\rho_{ss} = 53.9\ \mu\Omega\ cm$$

Time step

$$t_{step} = 0.01\ s$$

Peak inter-filament coupling loss per unit volume during the transient

Joule losses [W/cm^3]

Peak deposited loss per volume [W/cm^3]

x [mm]