Modelling the Dynamic Charging Process of High-T_c Coils by Dynamo-type Flux Pump

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- Test Case
- Results and Discussion
- Summary and future work

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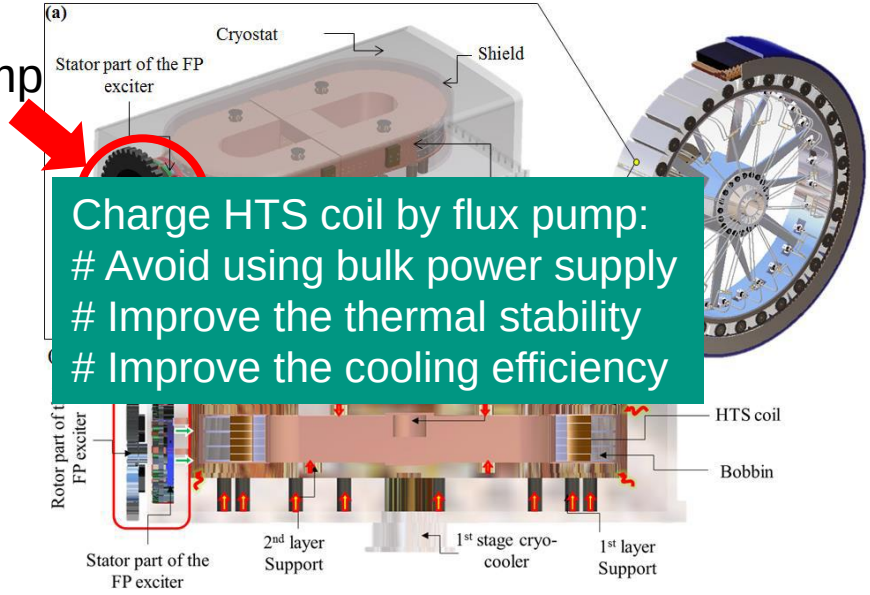
Motivation

#Current leads for HTS application

Flux pump

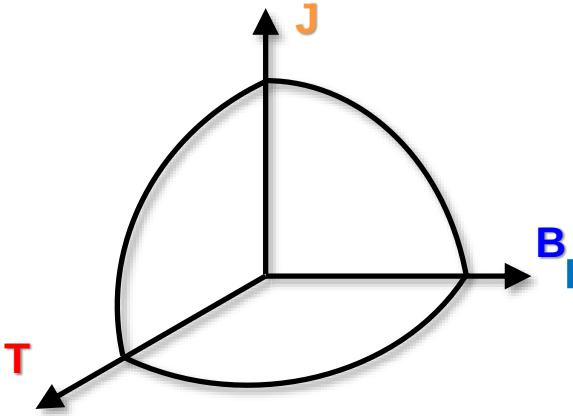


Charge HTS coil by flux pump:
Avoid using bulk power supply
Improve the thermal stability
Improve the cooling efficiency

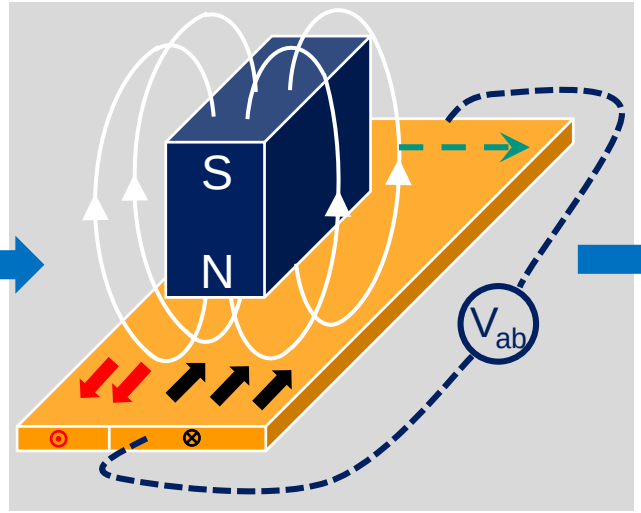
#HTS generator with dynamo[1]

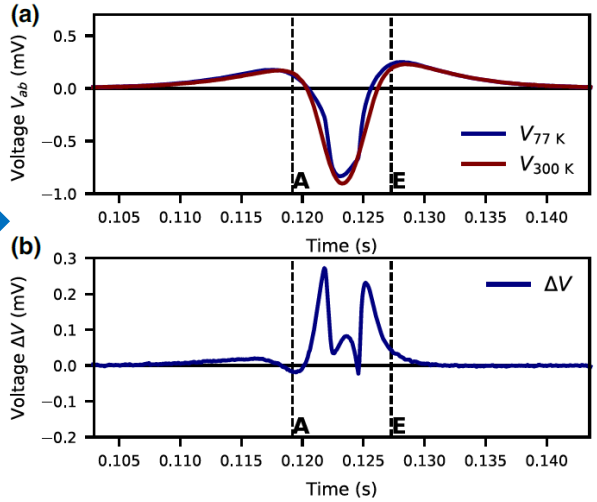
[1] Tuvdensuren et al. 2018, Journal of Physics: Conference Series

Motivation



$$R_{sc} = \frac{1}{S}\int \left(\frac{T_c - T}{T - T_0}\right) E_c \frac{J^n}{(J_c(B))^{n-1}} dl$$



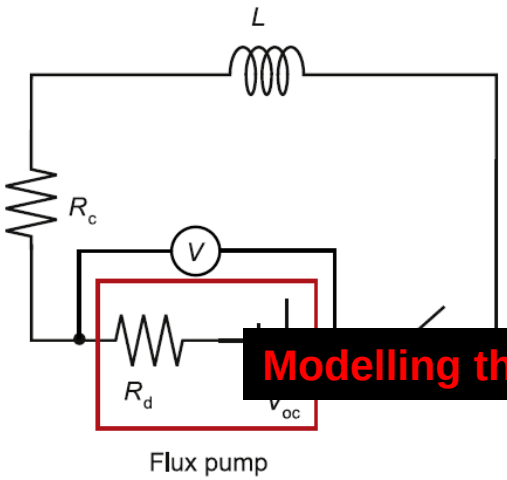


Open circuit voltage[1]

Non-linearity of HTS's resistivity enables the HTS to work like a "**switch**", leading to the rectification effect.

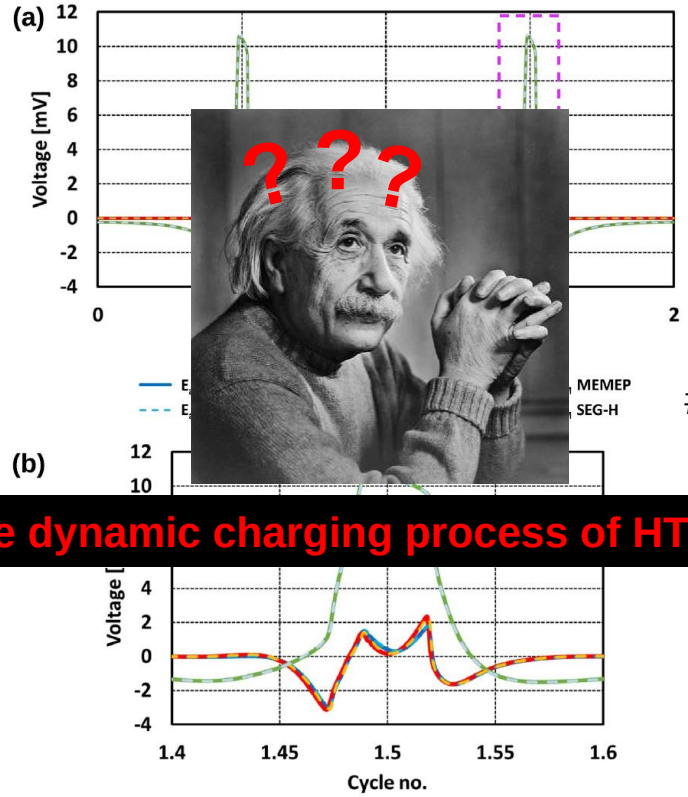
[1] Mataria et al. 2020, PRA

Motivation



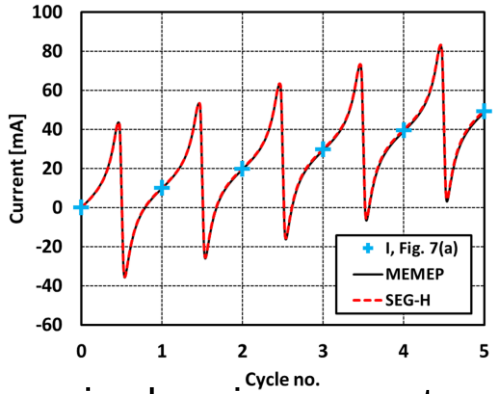
Flux pump

Equivalent circuit[1]

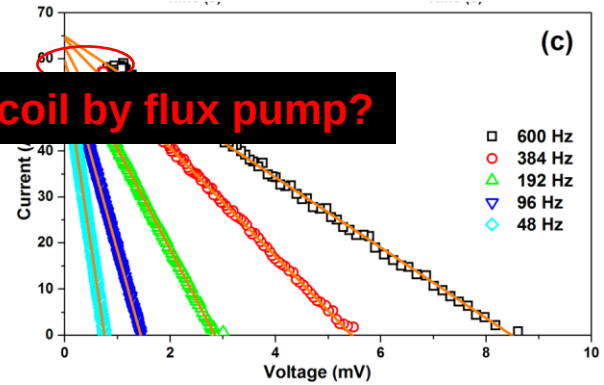


Output voltage of flux pump[2]

Modelling the dynamic charging process of HTS coil by flux pump?



Dynamic charging current curve[2]



V-I curve of flux pump[3]

[1] Jiang et al. 2015, SUST
[2] Ghabeli et al. 2020, SUST
[3] Jiang et al. 2014, APL

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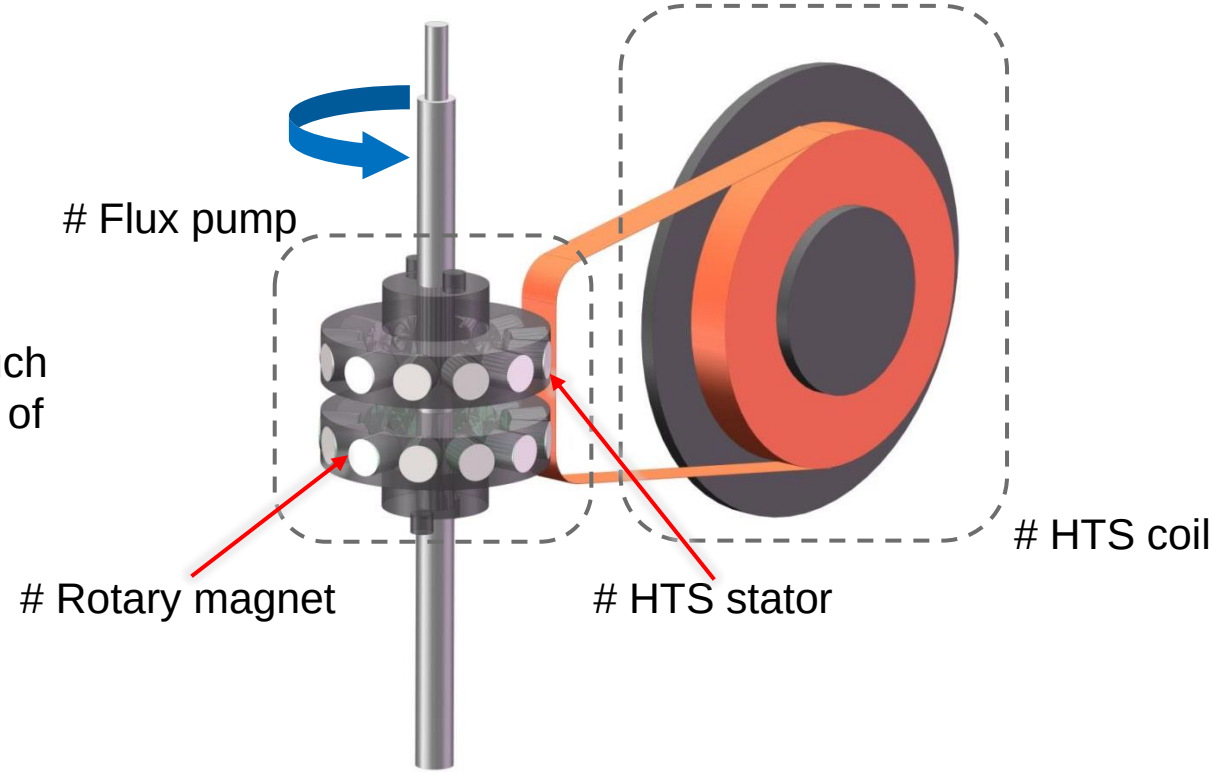
Model description

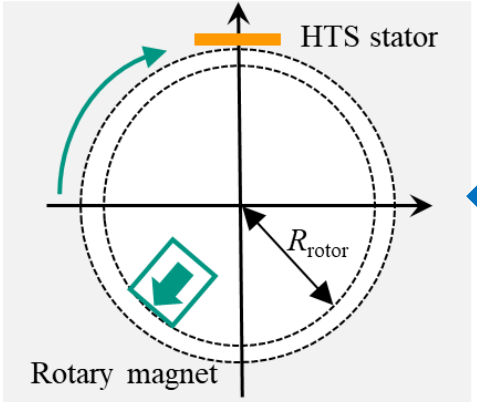
To present the local effect such as AC losses, critical current of HTS, Finite-element method (FEM) is preferable.



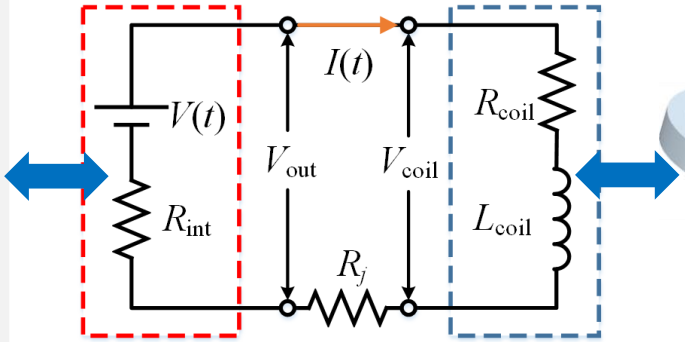
[1] Hoffmann et al. 2011, IEEE TAS

Modelling Strategy

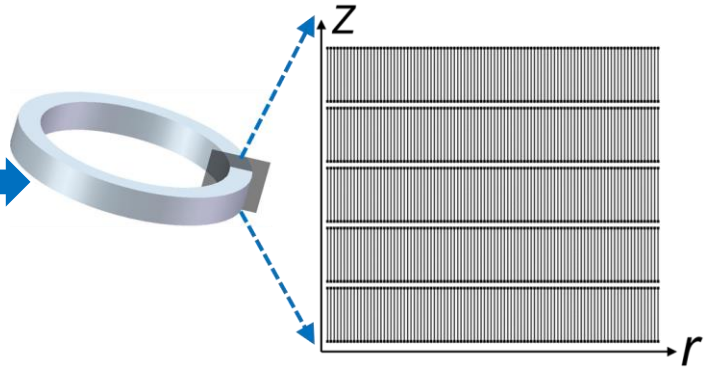
Coupling multiple FEMs



FEM for flux pump

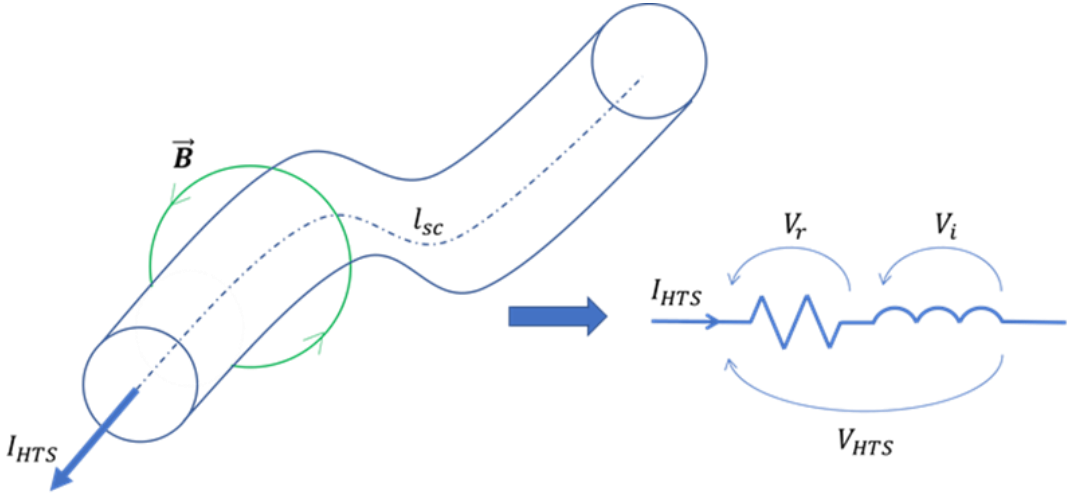


Equivalent circuit



FEM for HTS coil

Modelling strategy



$$V_i = -\int_{l_{sc}} \frac{\partial \mathbf{A}}{\partial t} \cdot dl$$

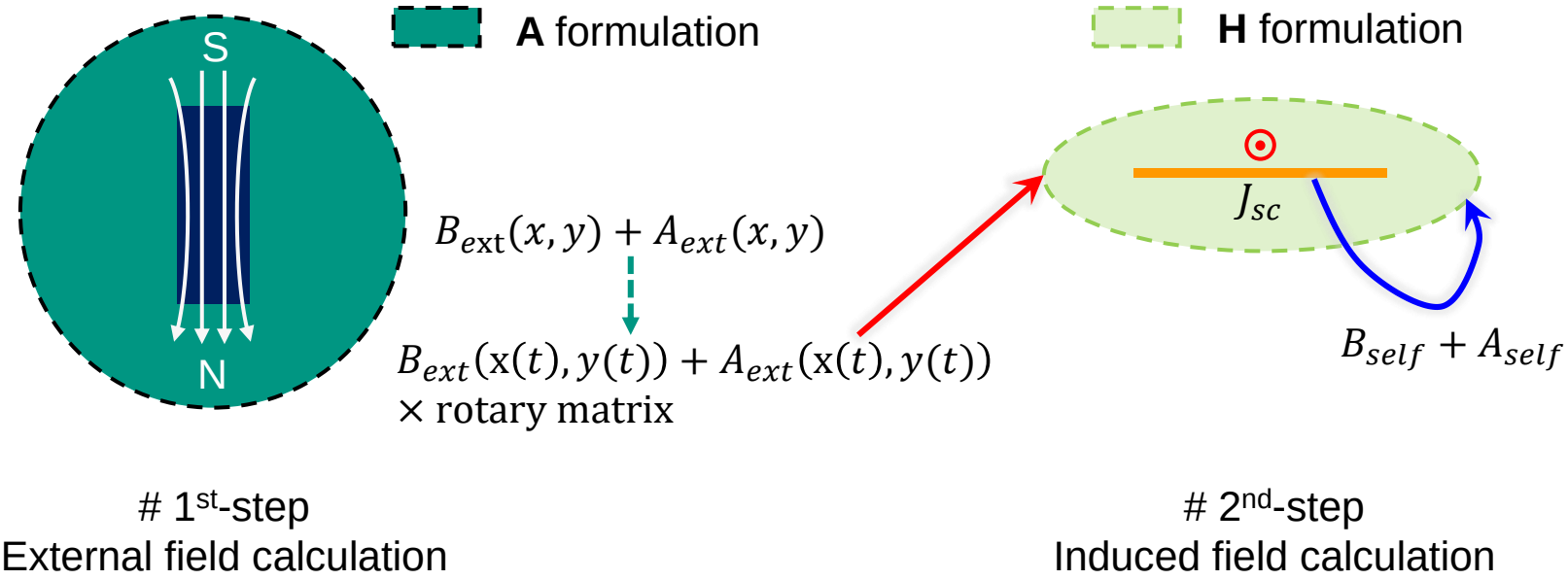
$$V_r = -\int_{l_{sc}} \mathbf{E} \cdot dl$$

$$V_{HTS} = V_r + V_i$$

Coupling FEM with electrical circuit: The idea is to present the HTS component as a global voltage parameter.

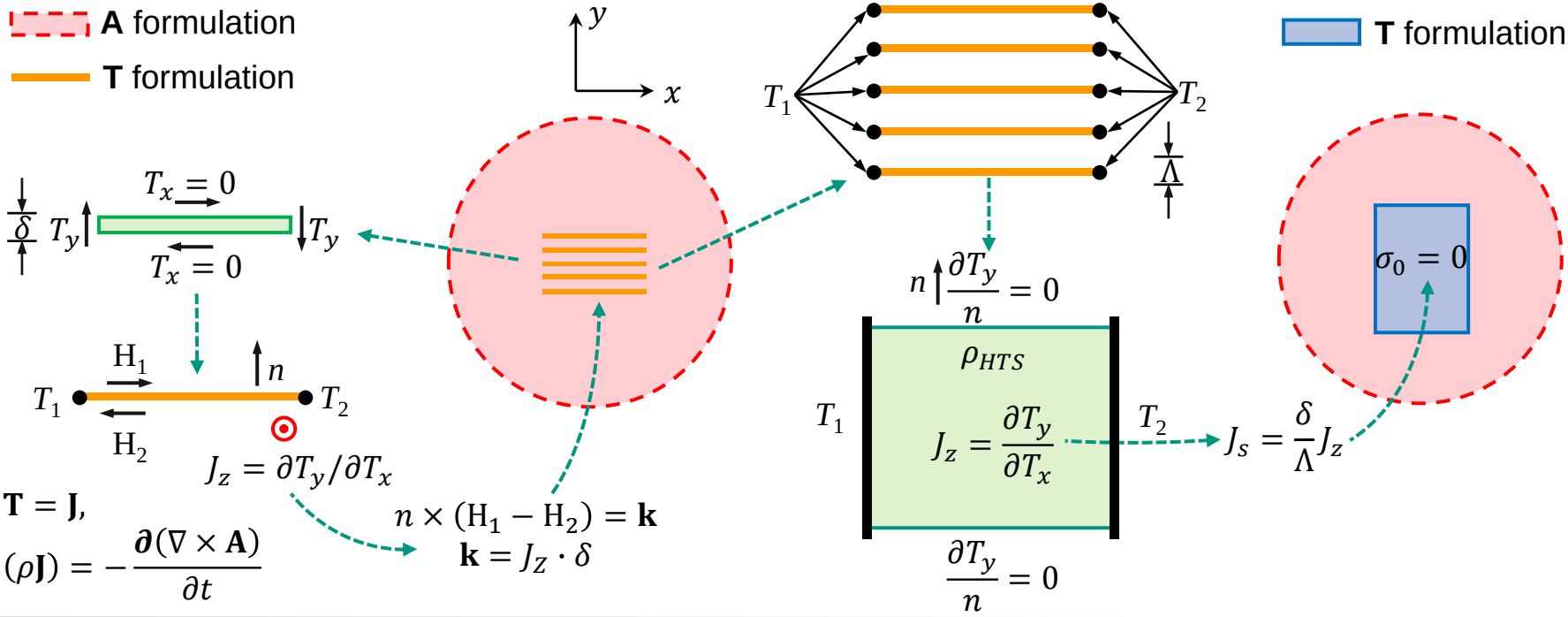
Modelling Strategy

Segregated **H** formulation



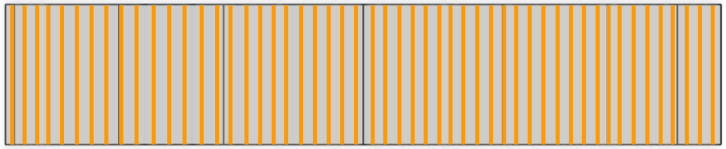
Modelling HTS coil

T-A homogenization



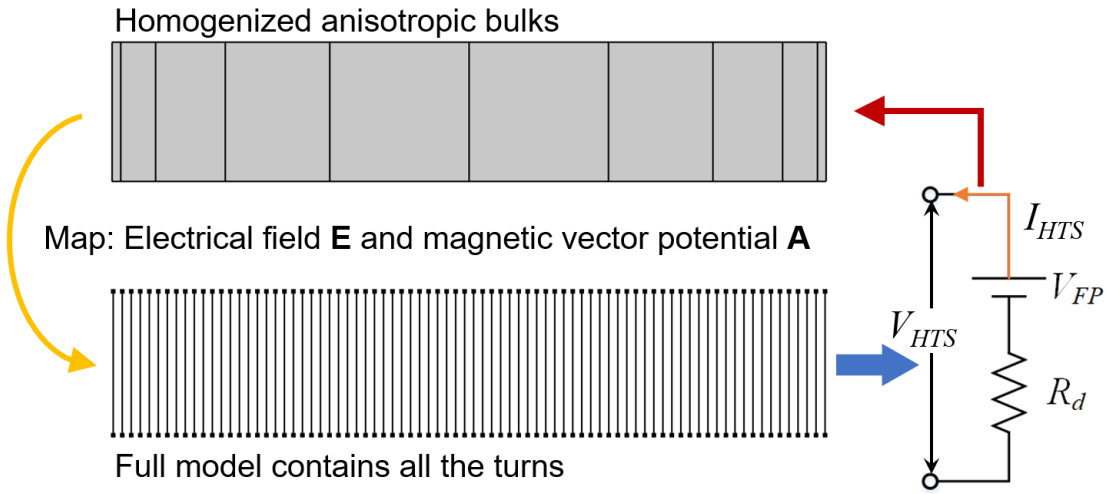
Modelling HTS coil

Coupling the T-A homogenization with electrical circuit



$$V_{HTS,k} = \left(-\frac{d}{dt}\left(\frac{\int_{w_{tape}} \mathbf{A} dz}{\int_{w_{tape}} dz} \right) - \frac{\int_{w_{tape}} \mathbf{E} dz}{\int_{w_{tape}} dz} \right) L_{HTS,k}$$

$$V_{HTS} = \sum_{k=1}^{N} V_{HTS,k}$$



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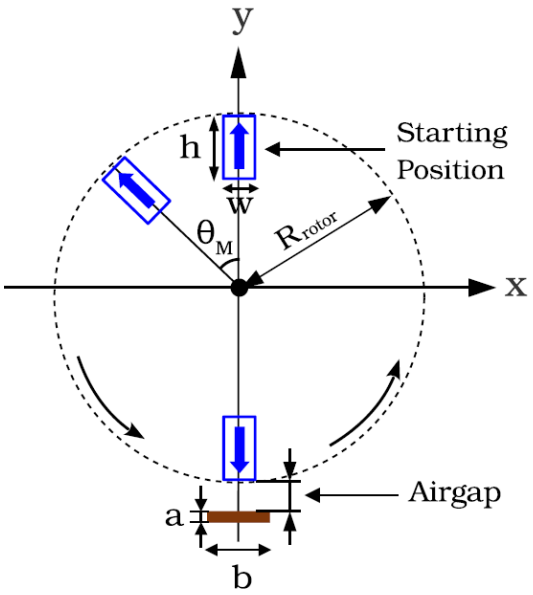
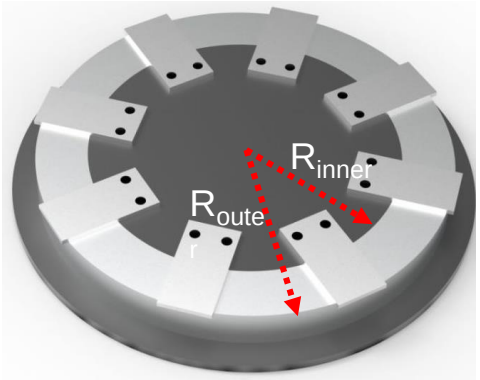
Test case





Superconducting layers considered only,
and is simulated by E-J power law.

Parameters	Value
h [mm]	12
w [mm]	6
B_m [T]	1.25
R_{rotor} [mm]	35
a [um]	1
b [mm]	12
Airgap [mm]	3.7
Freq [Hz]	50
R_{inner} [cm]	5
R_{outer} [cm]	10
Number of turns	50*2
W_{tape} [mm]	4

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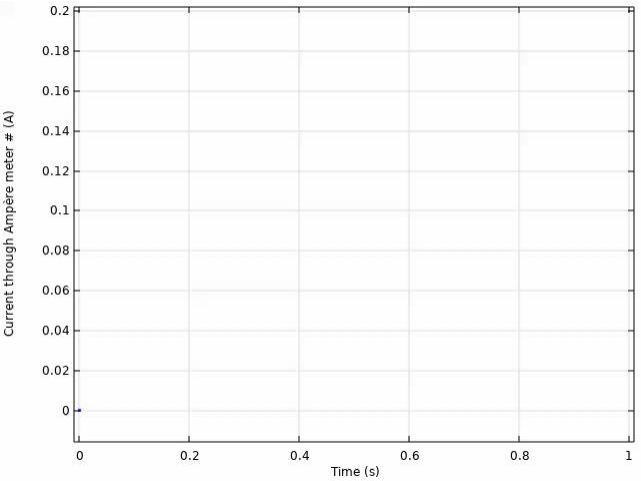
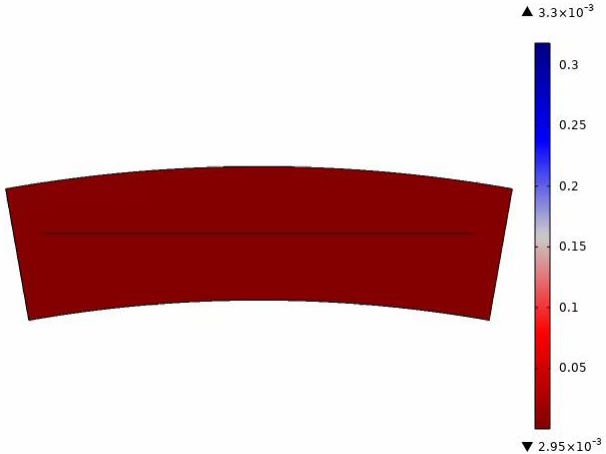
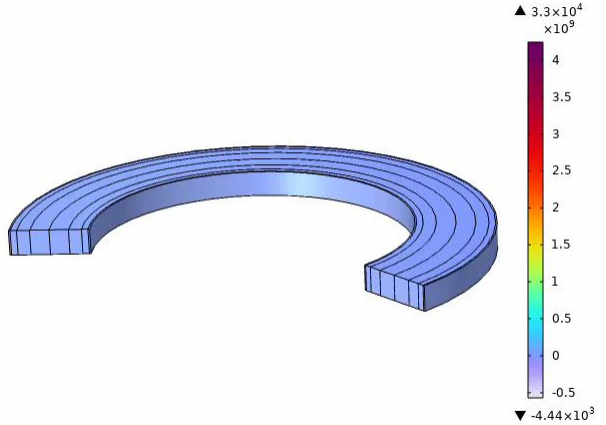
Calculation results



Transport current

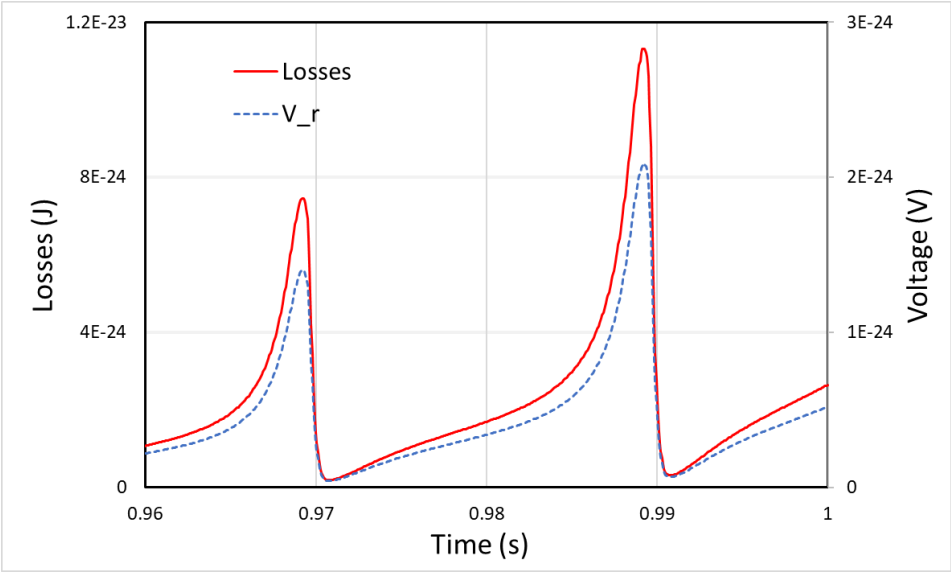


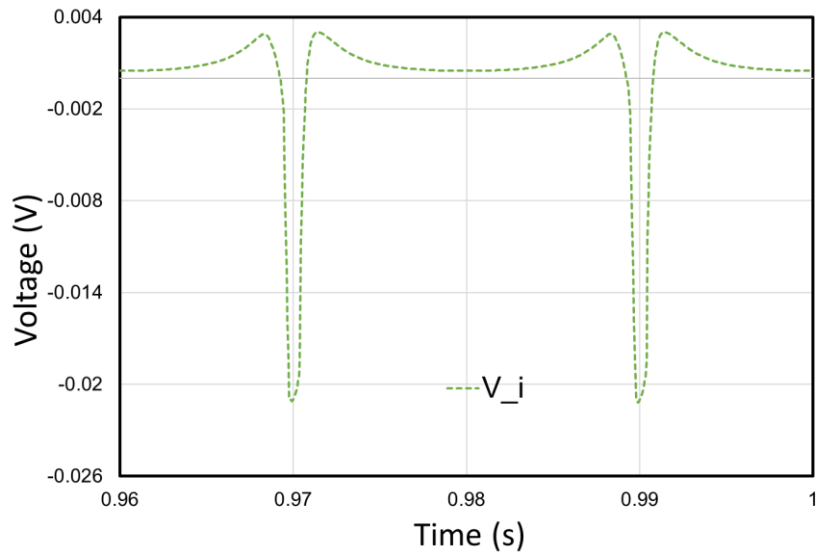
Magnetic field of Stator



Current penetration of coil

Calculation results

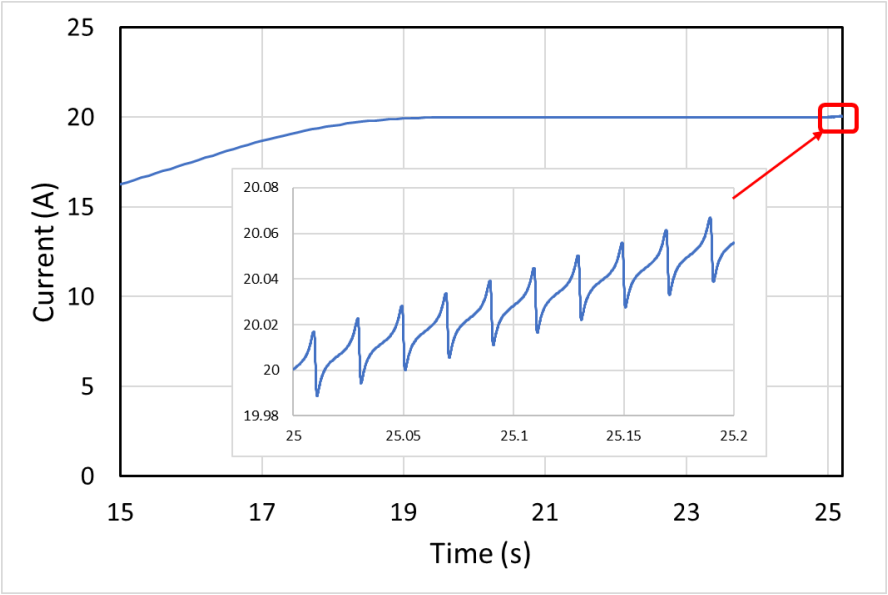


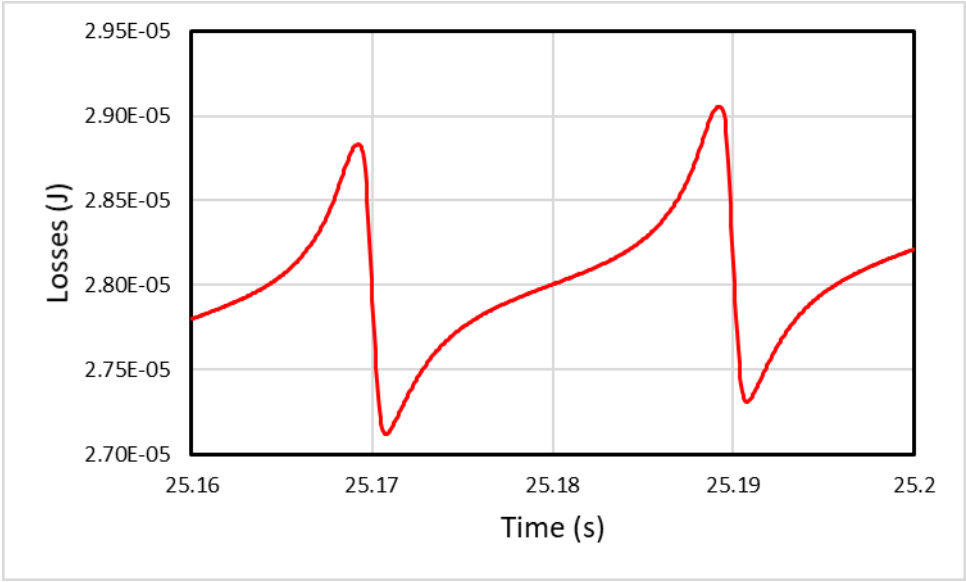


Losses and voltages of the 49 and 50 cycles

Calculation results

Firstly charge the HTS coil to some level, and then open the flux pump to simulate the dynamic charging process in different stages.





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Summary and future work

- A model for simulating the dynamic charging process of HTS coil by flux pump was developed.
- This model realizes the coupling of multiple FEMs, enables the simulation of complex systems involving various HTS components.
- Computation time is too long, while a small HTS coil is considered, and also the stability problem caused by the flux pump model, especially when the magnet approaches the HTS stator.
- A model which could consider the current degradation of closed-loop HTS coil is needed.

Thanks !

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