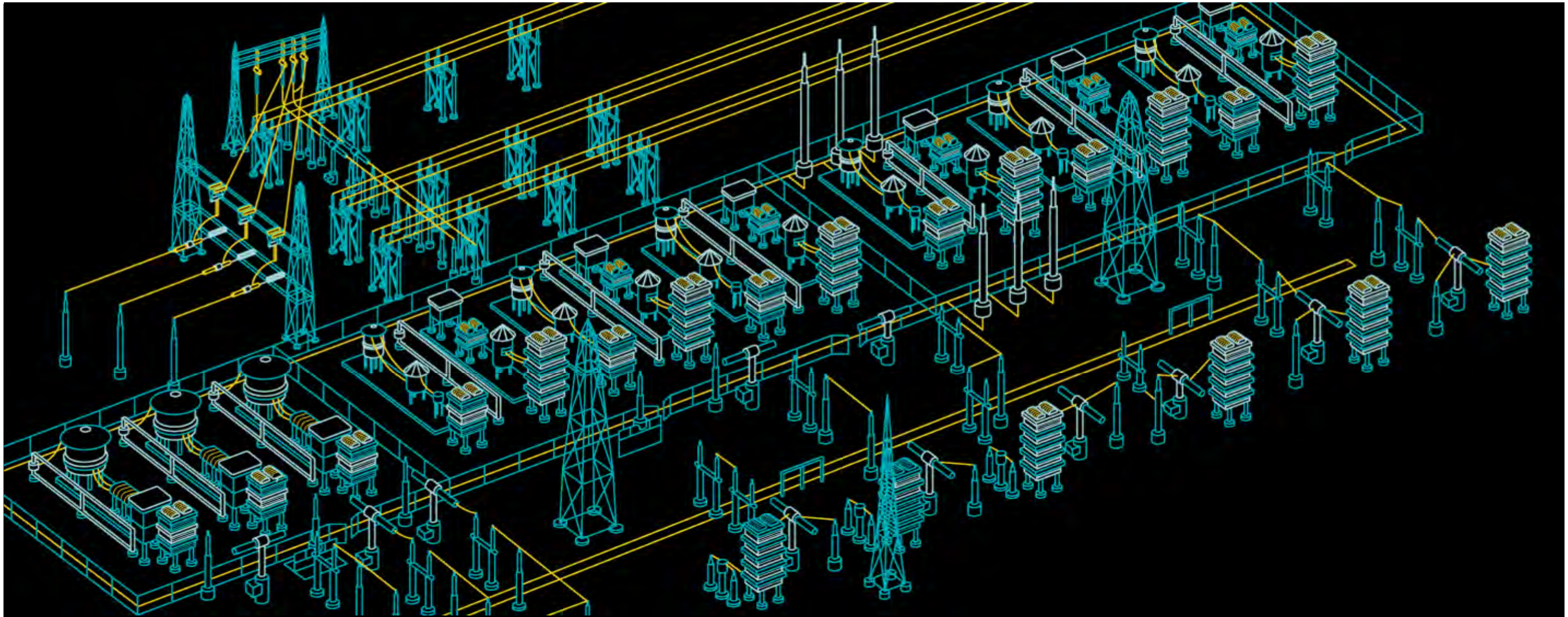
Presented at the COMSOL Conference 2010 Paris



Simulation and verification of Thomson actuator systems

COMSOL Conference Paris 2010

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KTH VETENSKAP OCH KONST

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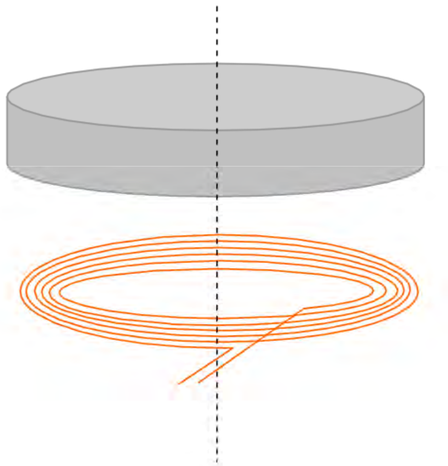
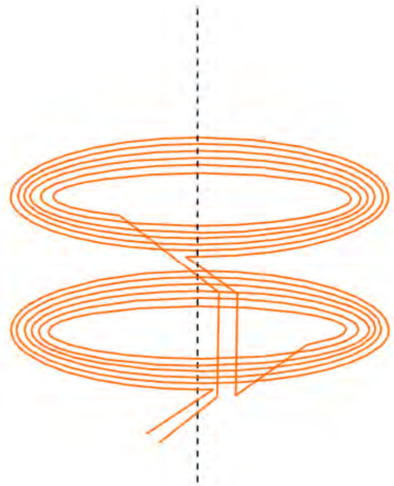
Introduction

- Increased need for high speed actuators
- Diverse applications like: Smart grids, electrical switches, robotics, drilling machinery, etc…
- Thomson Coils (TCs) can exert massive forces within fractions of a millisecond
- It is important to model and simulate (TCs) to design or accurately predict the performance of TC based high speed actuators

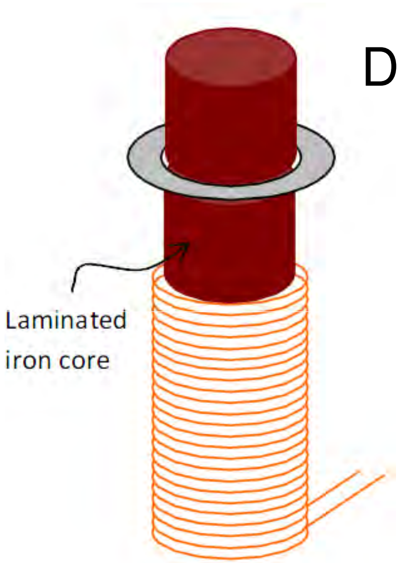
What is a TC?



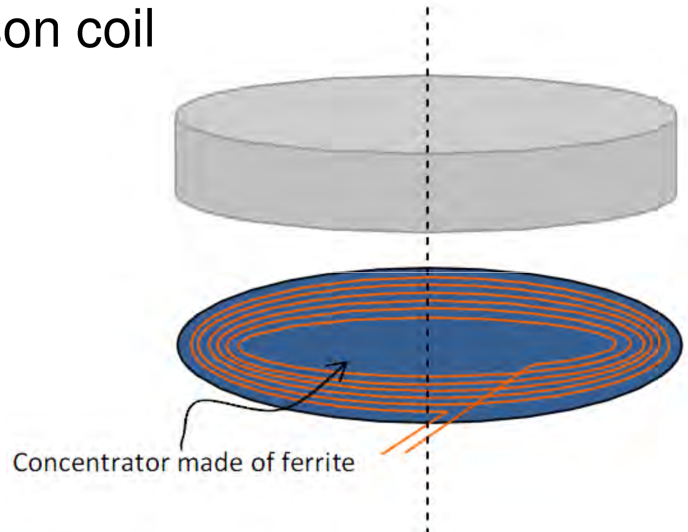
Single sided
Thomson Coil



Double sided Thomson coil



Helix- shaped
Thomson coil



Single sided Thomson Coil with
a concentrator

Theory

$$i_c = I_c sin(\omega t)$$

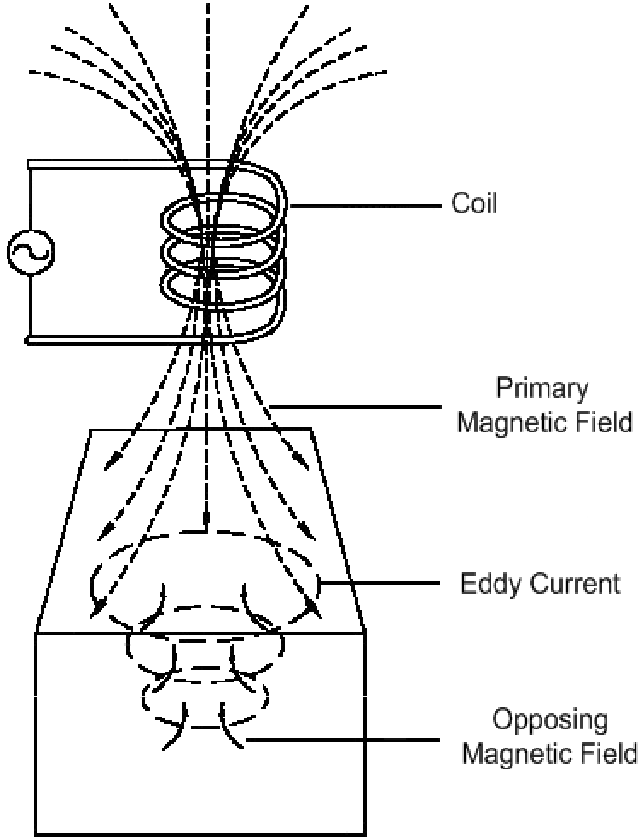
$$B(t) = \hat{B}_c(r, z) sin(\omega t)$$

$$B_z = \hat{B}_z sin(\omega t)$$

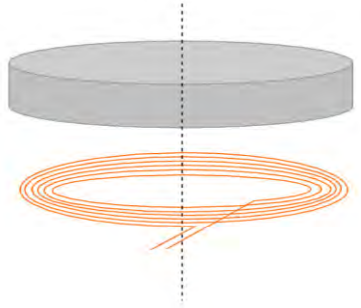
$$B_r = \hat{B}_r sin(\omega t)$$

$$F_z = i_\phi B_r$$

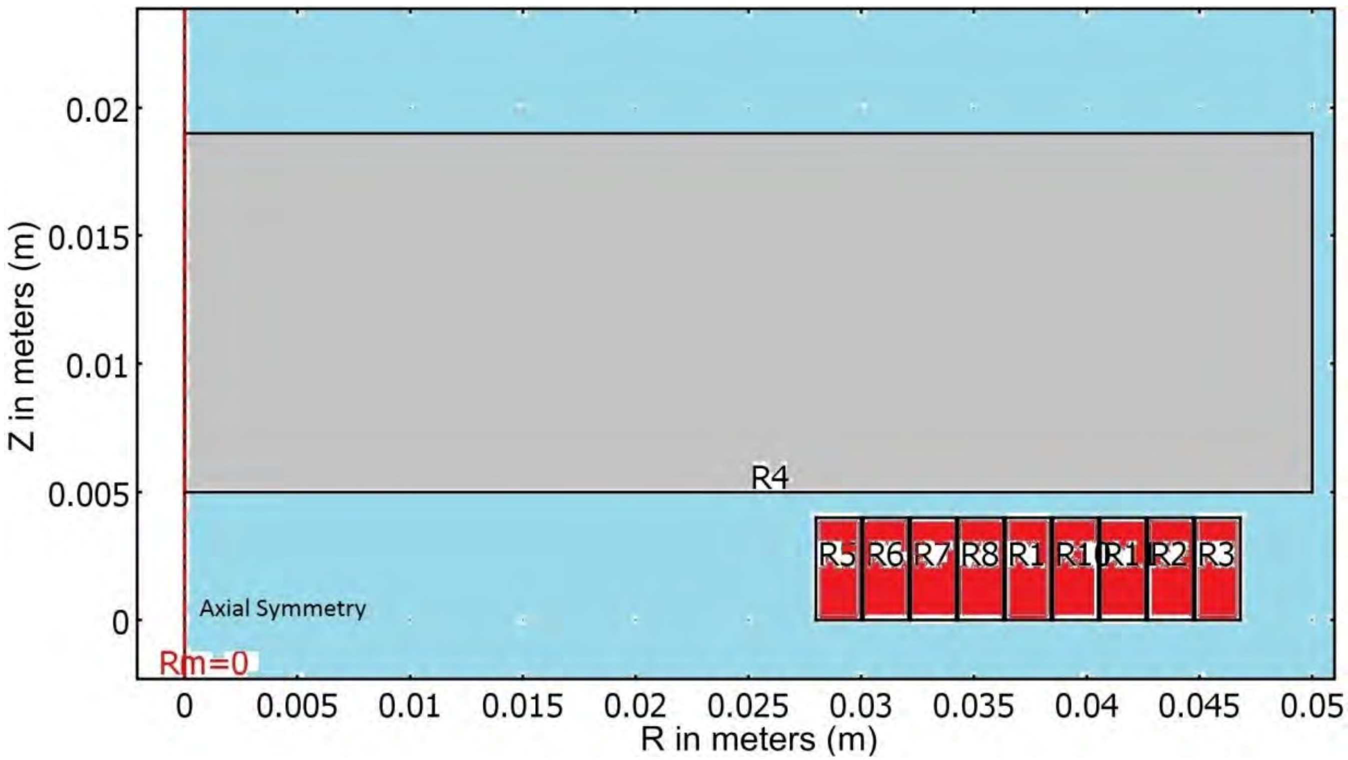
$$F_{Total} = ma$$



Modelling

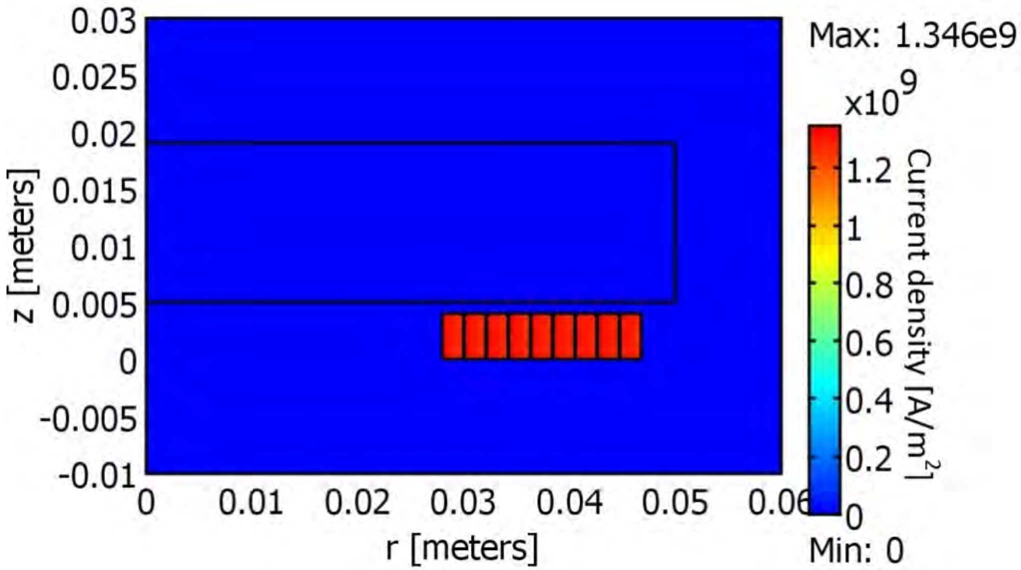


- 2D axisymmetric model
- The Aluminum is in silver color, the coil turns are in red surrounding air in light blue

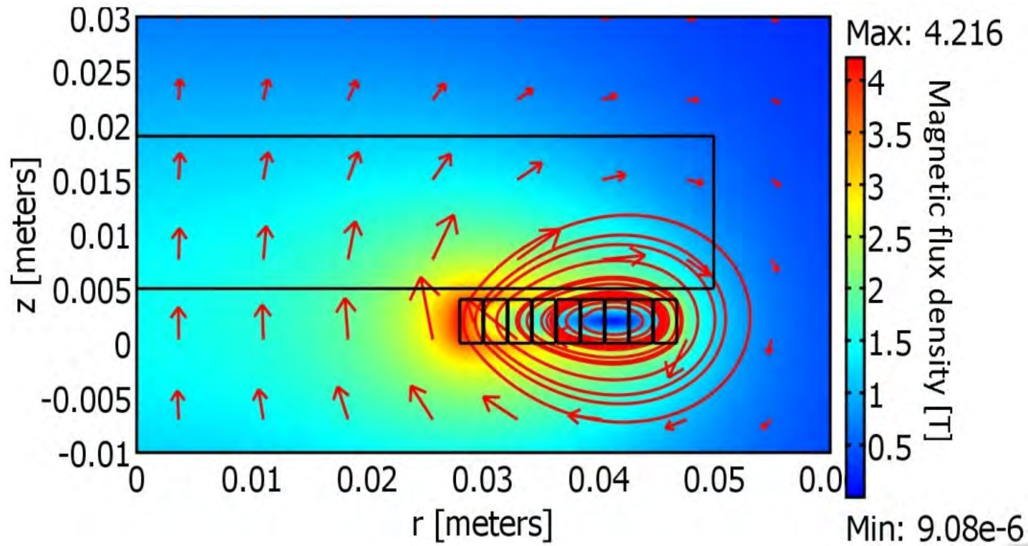


Static model (DC)

- 10kA constant current source connected across the terminals of a TC
- Constant magnetic field will be generated
- No eddy currents are induced in the aluminum disk



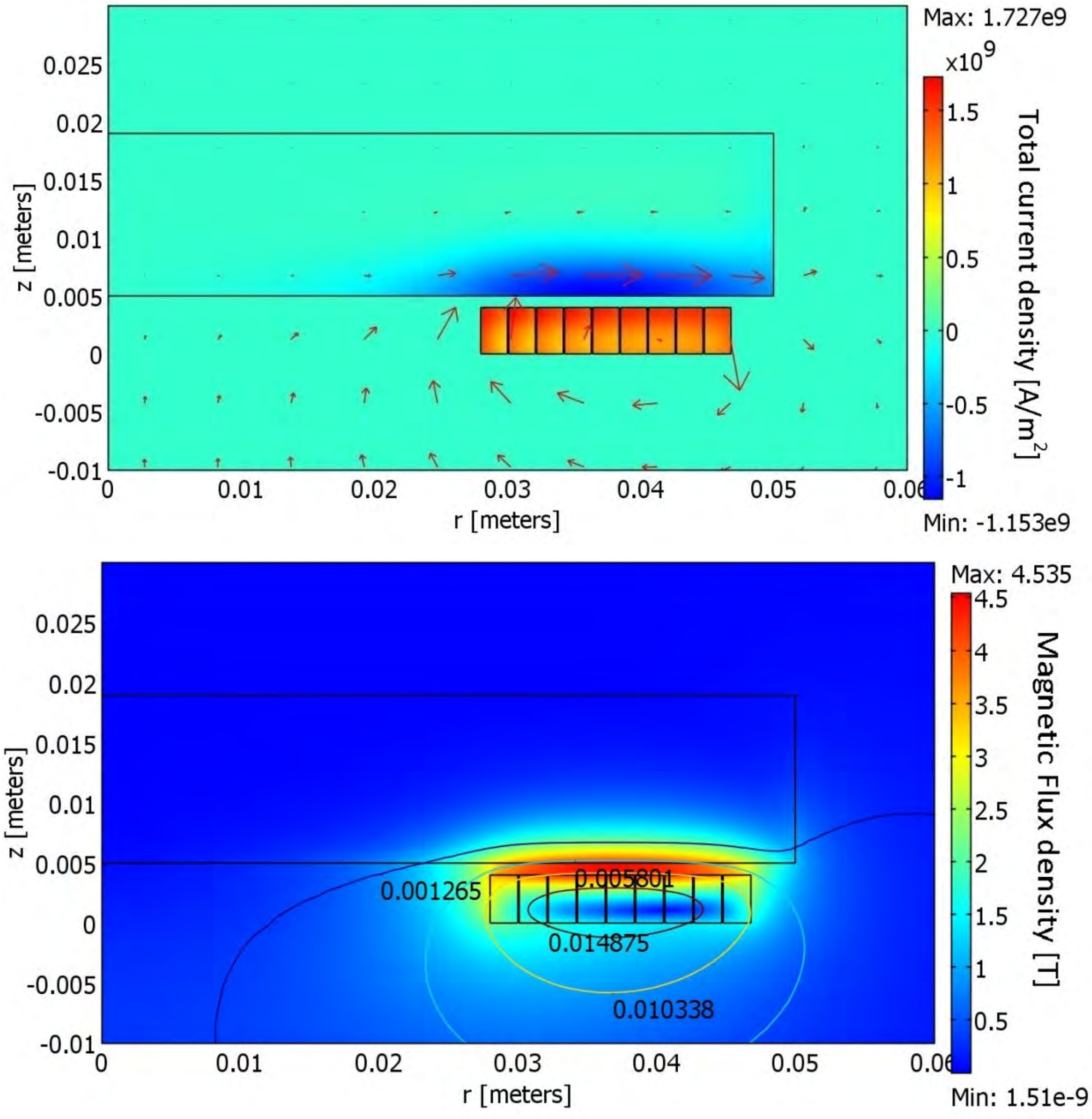
Surface: Total Current density [A/m^2]



Surface: Magnetic flux density [T]
Contour: Magnetic vector potential [Wb/m]
Arrow: Magnetic flux density

Stationary model (AC)

- Applied current: 10 kA
- Frequency: 1kHz
- Skin effect
- Proximity effect
- The magnetic flux density is concentrated in the air gap region between the coil and the aluminum disk

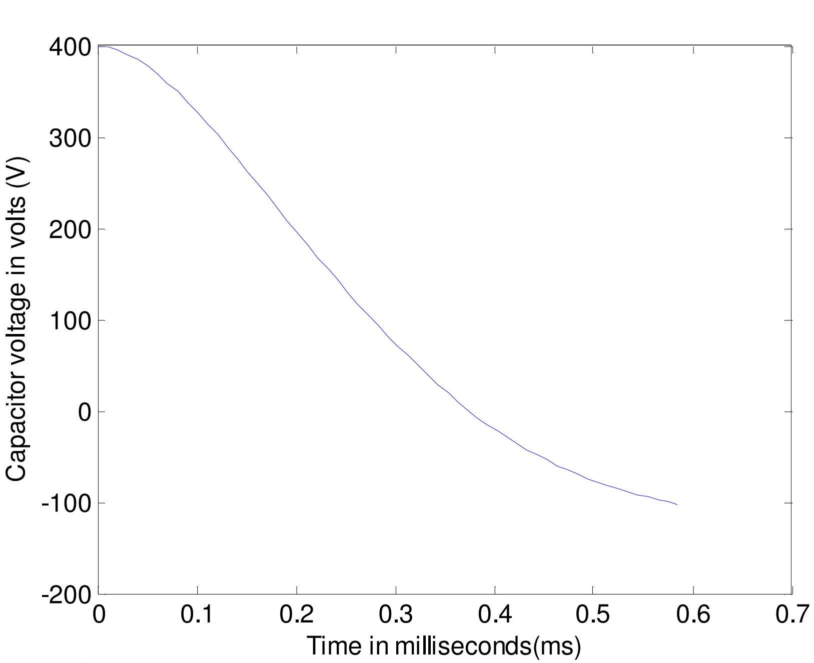


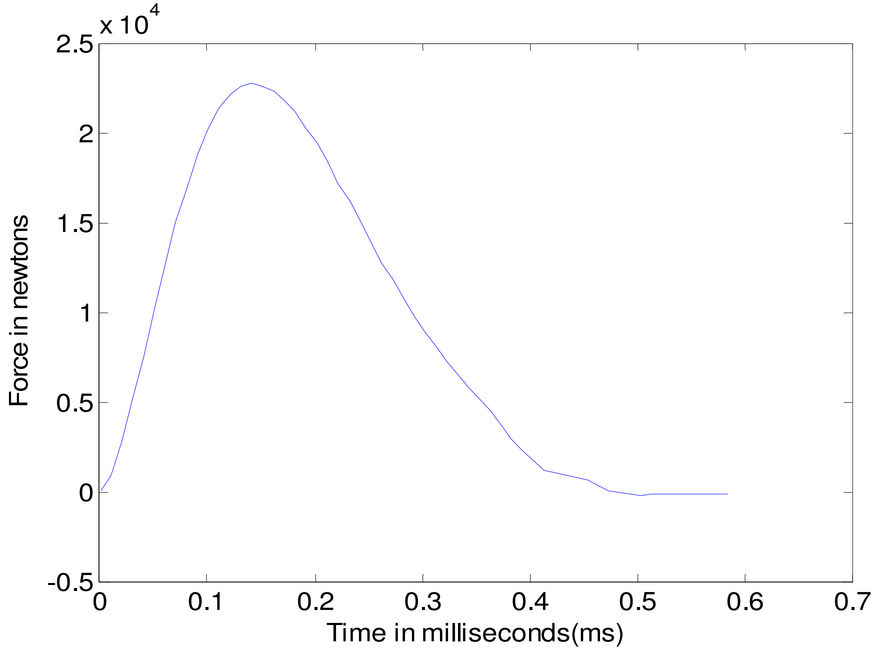
Transient multiphysics model

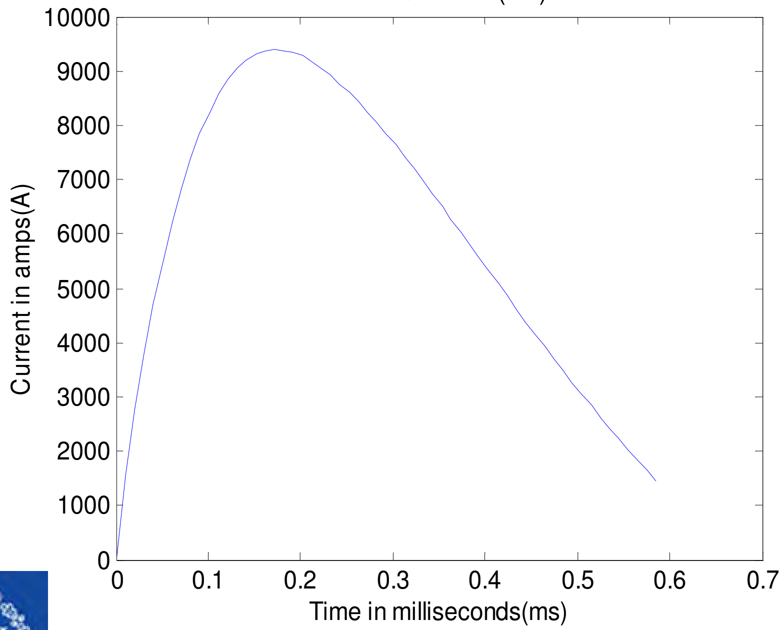
- The single sided TC is highly dependent on position of the aluminum disk
- As the disk moves away, the inductance, resistance, and induced currents change greatly influencing the exerted force
- A multiphysics model with a moving mesh is indispensible.
- COMSOL modules used: “Azimuthal induction currents”, and “moving mesh (ALE) with dynamic remeshing”.

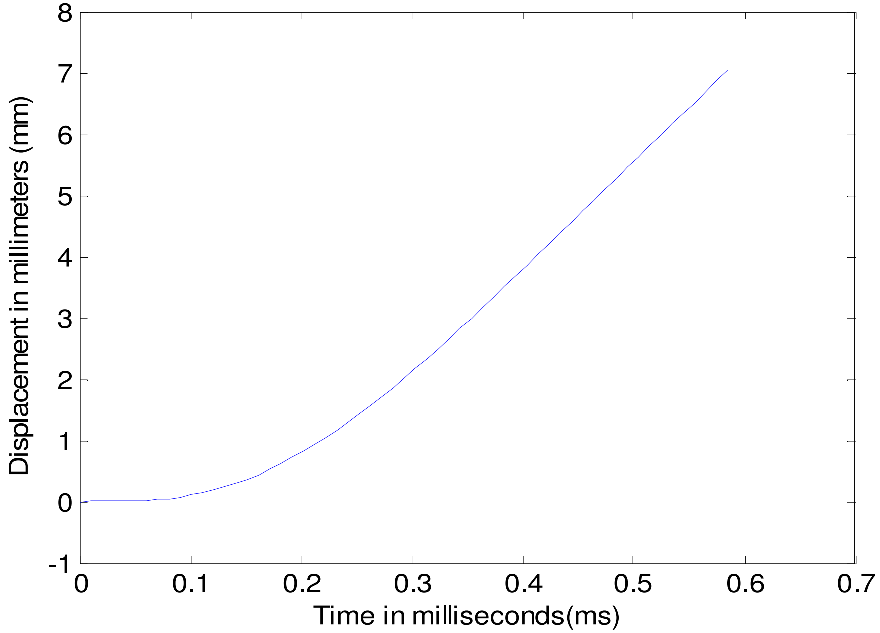
Setup Characteristics	TC
Capacitor bank	7 mF
Initial voltage	400 V
Al Cross section area in (mm^2)	50 x 14
Coil cross section area	2 mm x 4mm
Air gap between coil and Al	1 mm
Number of coil turns	9
Inter-distance coil turns	0.1 mm
Stray resistance	10 mΩ
Stray inductance	1 μH

Transient multiphysics model



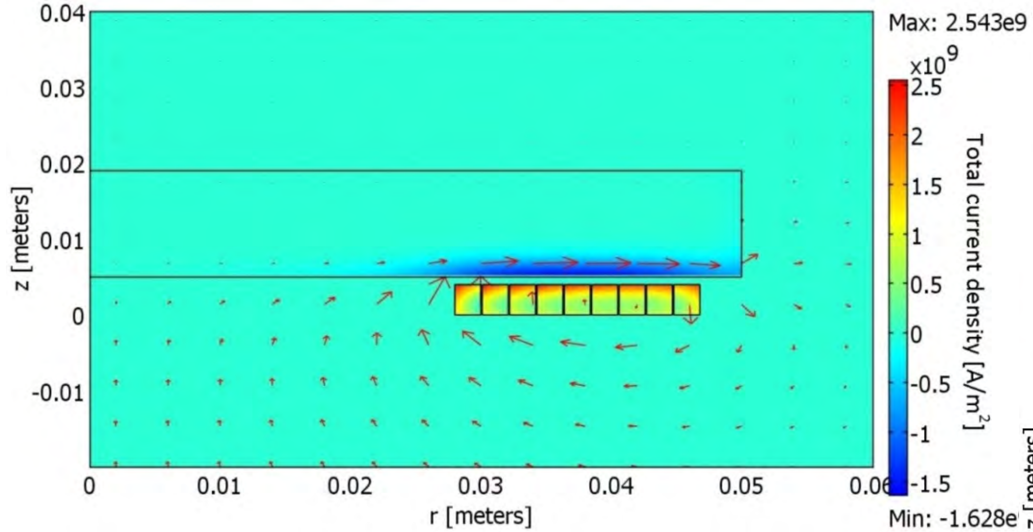




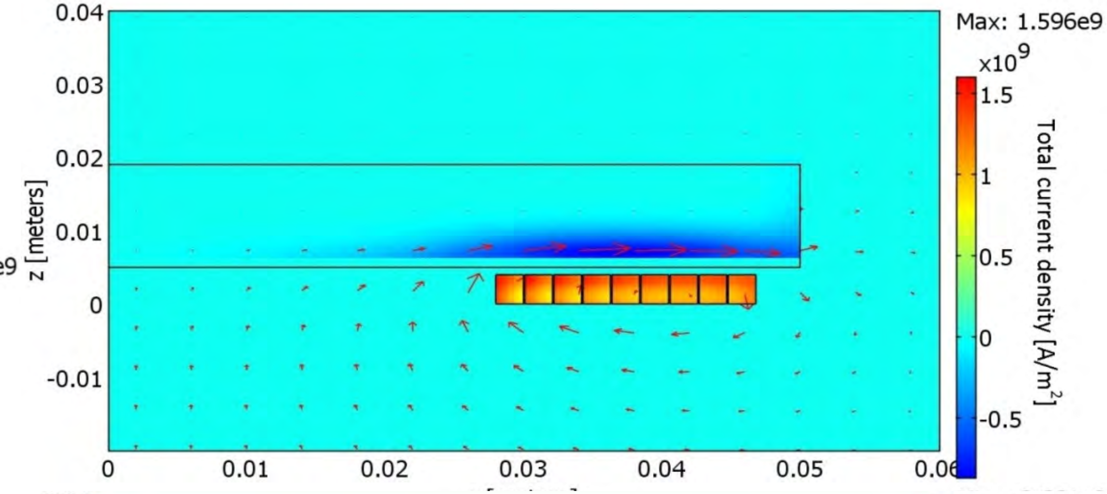


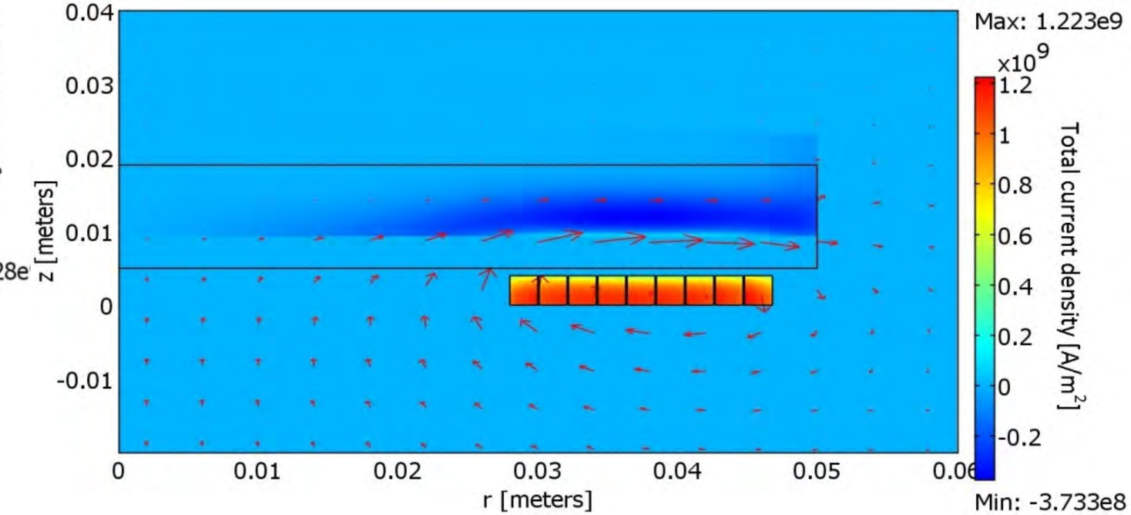
Transient multiphysics model

Time: 0.1ms
Arrow: magnetic field
Surface: Total current density



Time: 0.18ms
Arrow: magnetic field
Surface: Total current density

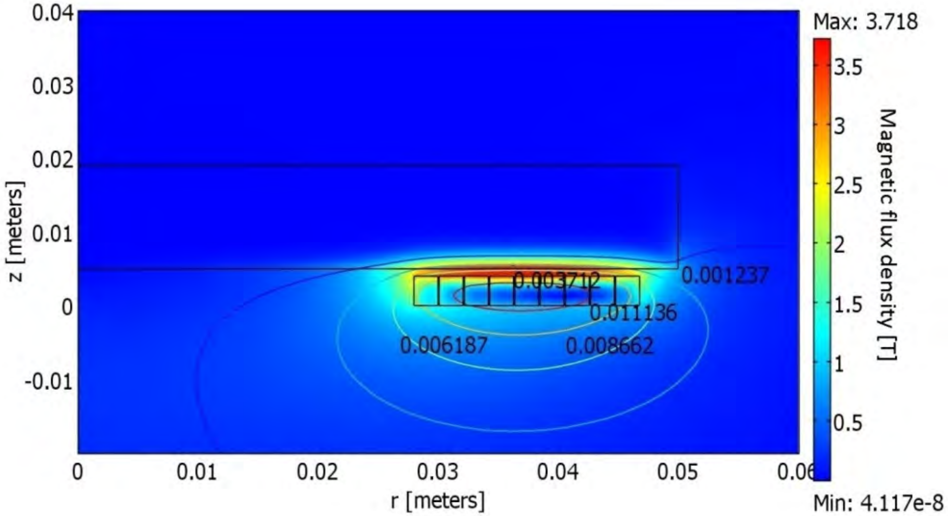




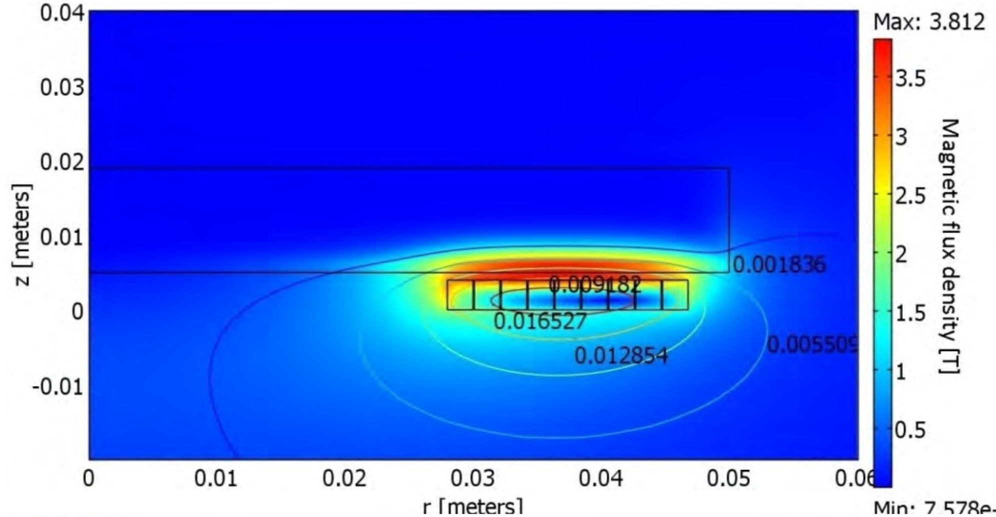
Time: 0.3 ms
Arrow: magnetic field
Surface: Total current density

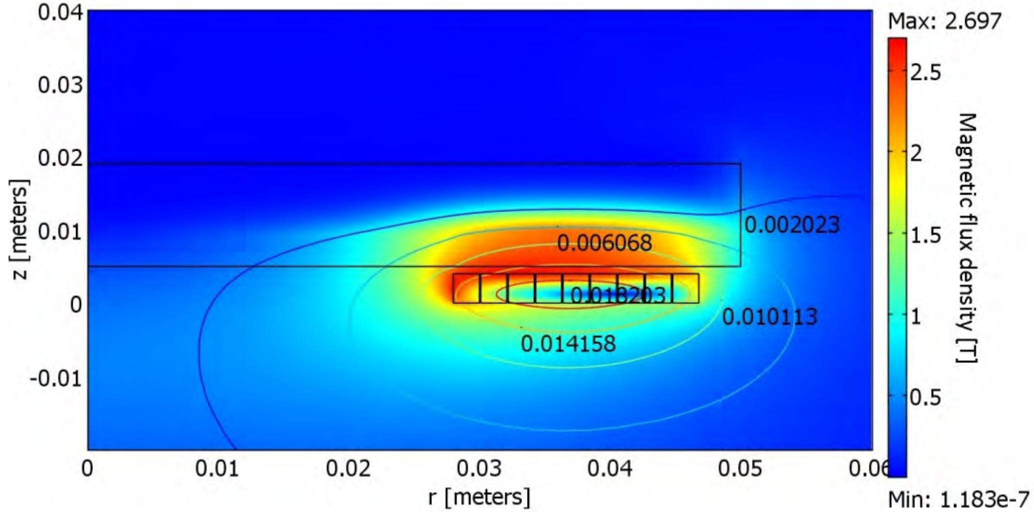
Transient multiphysics model

Time: 0.1ms
Contour lines: A [Wb/m]
Surface: Magnetic flux density [T]



Time: 0.18ms
Contour lines: A [Wb/m]
Surface: Magnetic flux density [T]

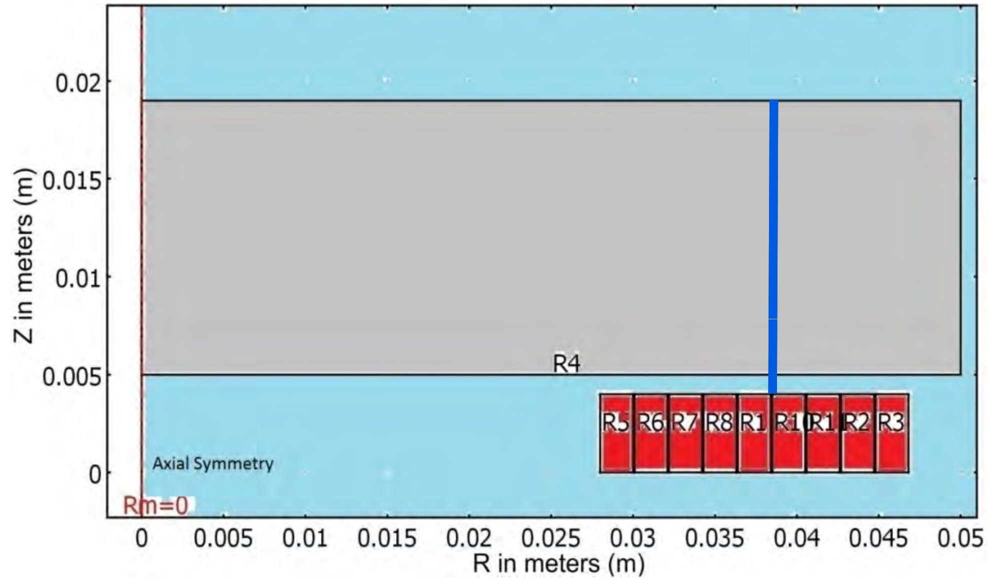


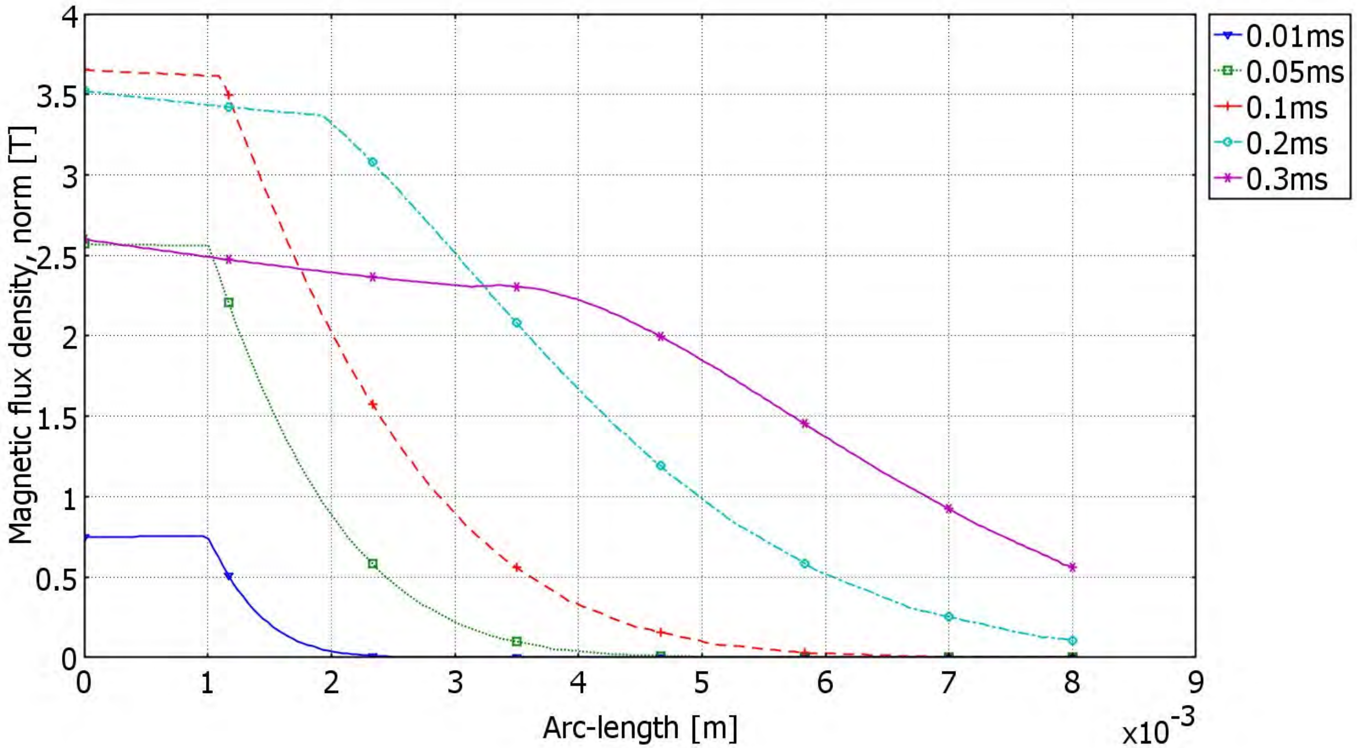


Time: 0.3ms
Contour lines: A [Wb/m]
Surface: Magnetic flux density [T]

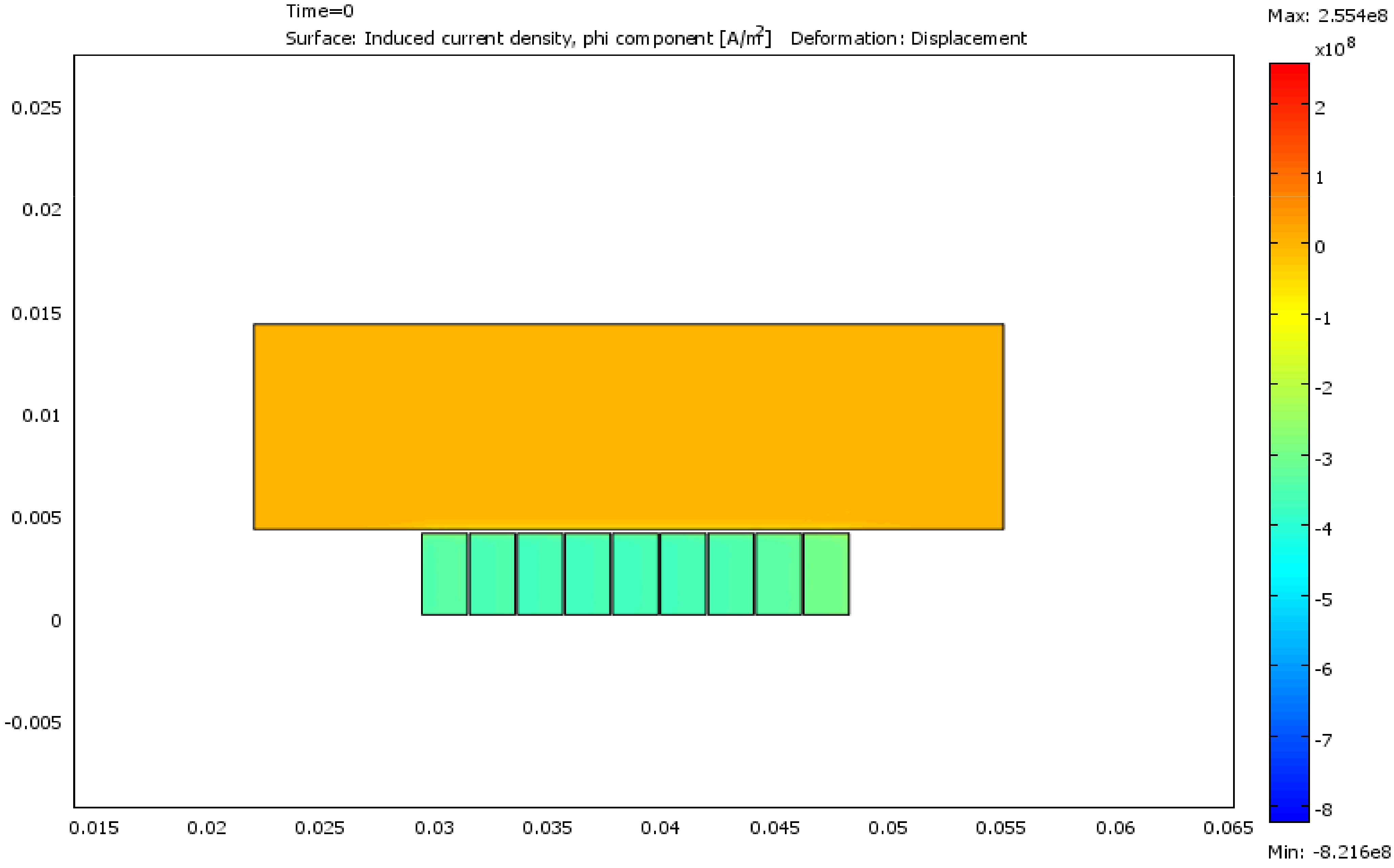
Transient multiphysics model

- Penetration depth wiith respect to time along the blue line

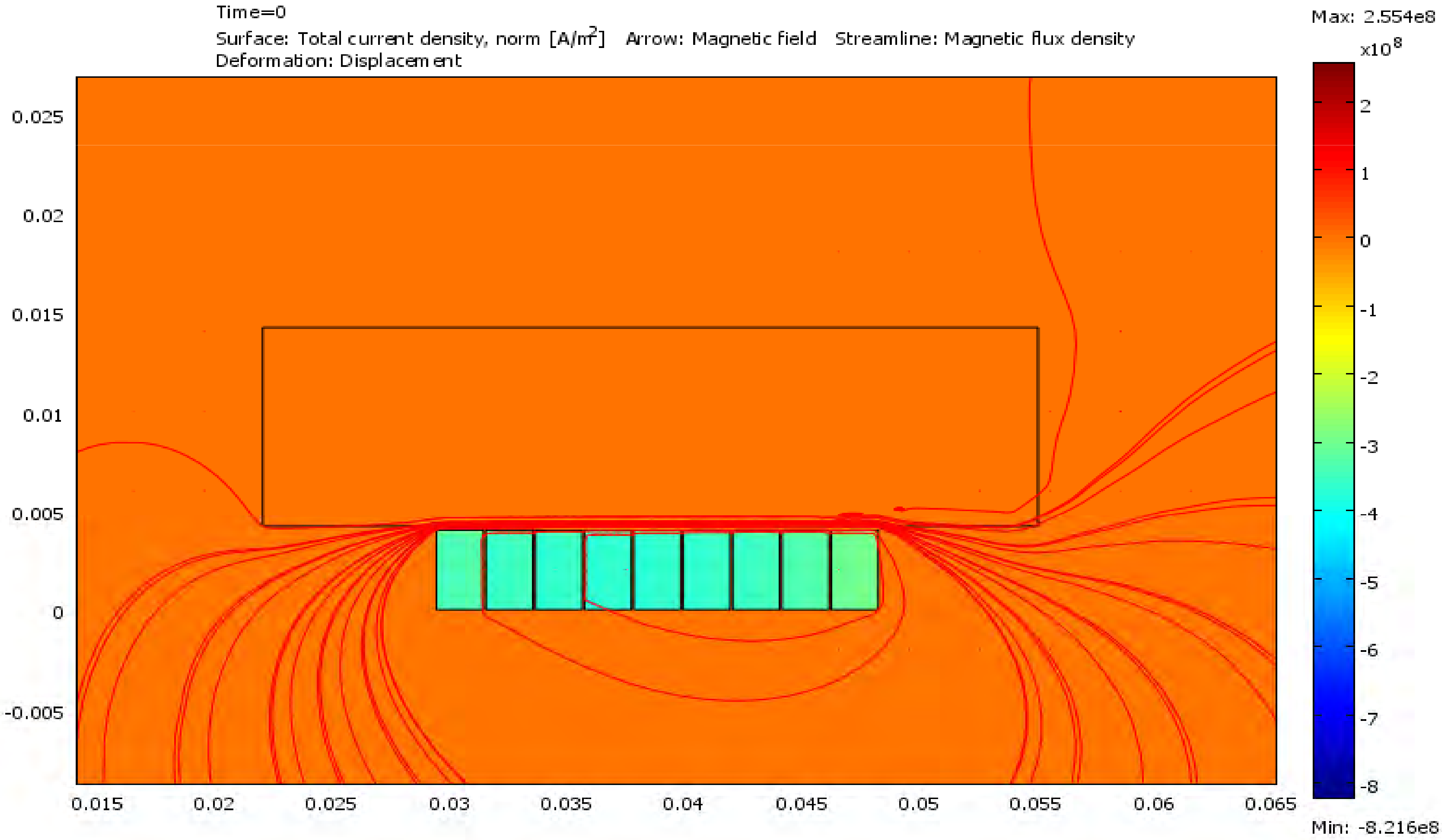




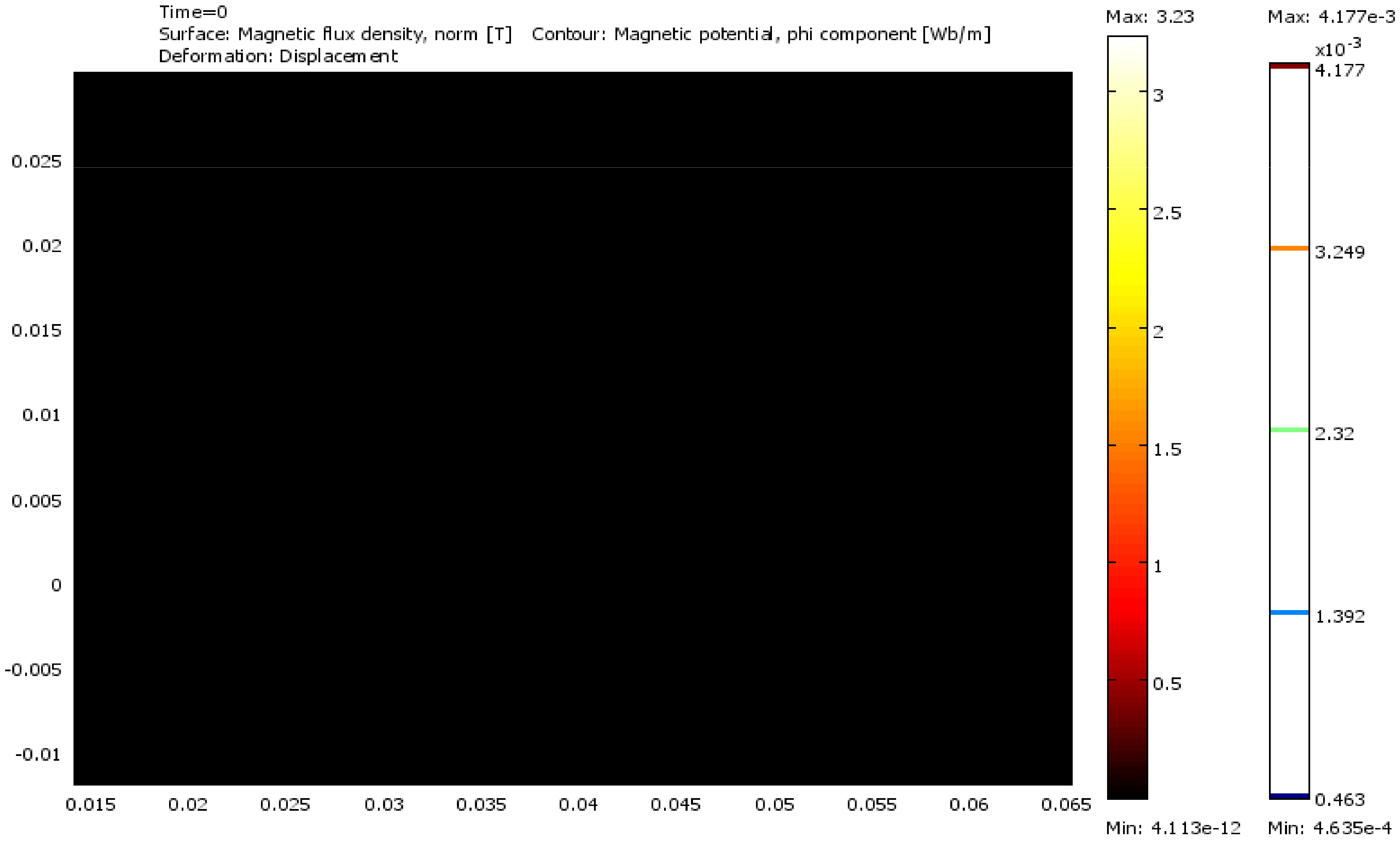
TC simulation 1



TC simulation 2

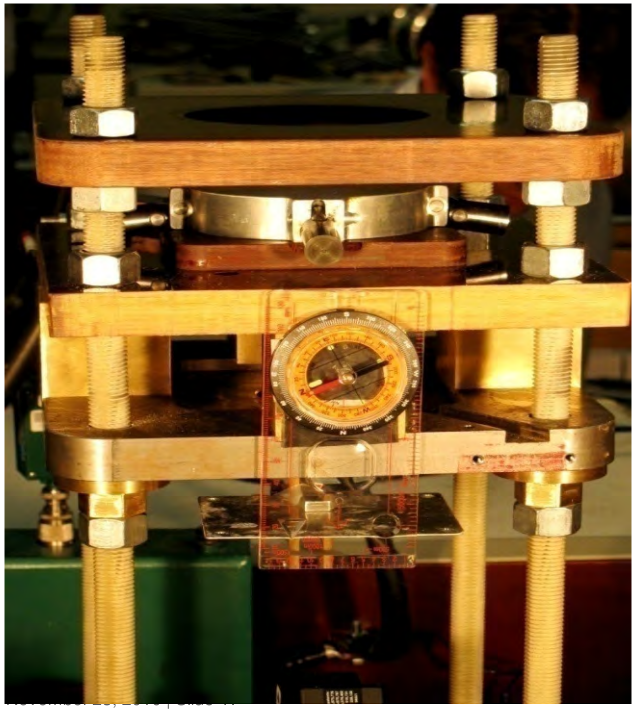
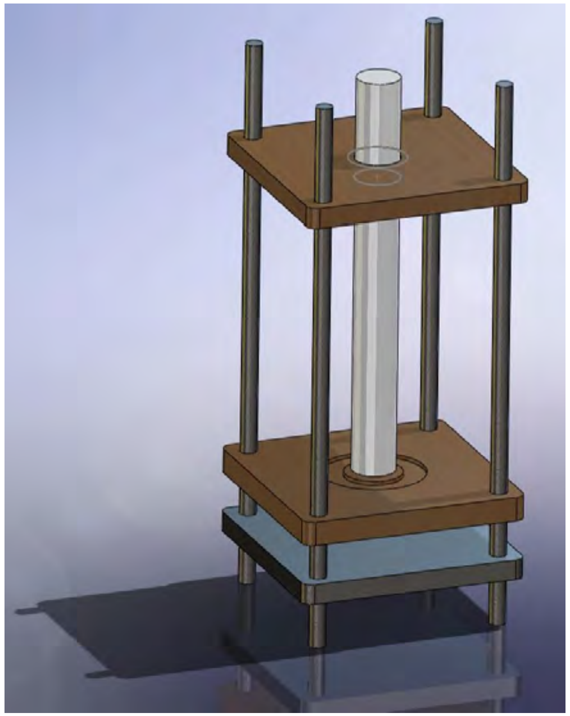
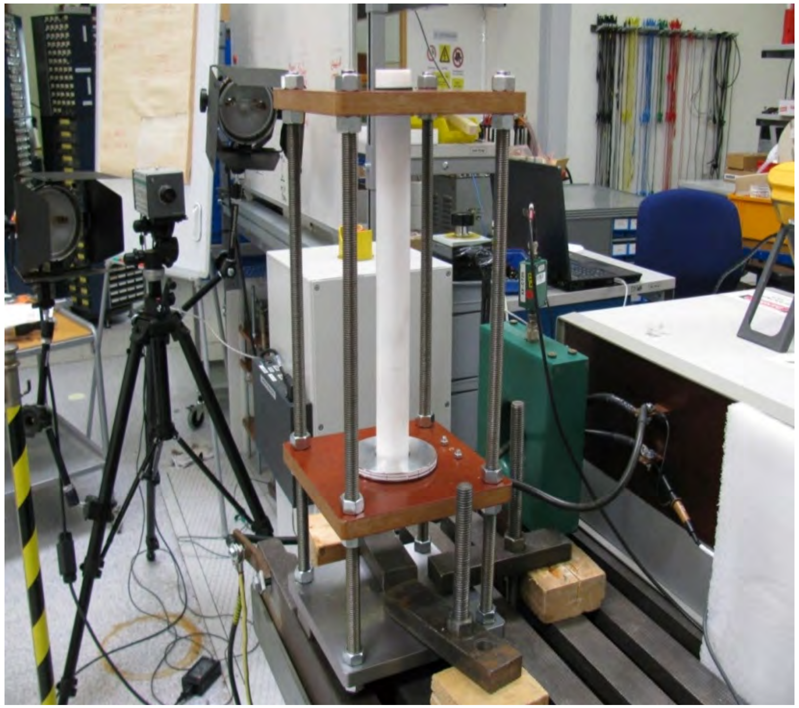


TC simulation 3



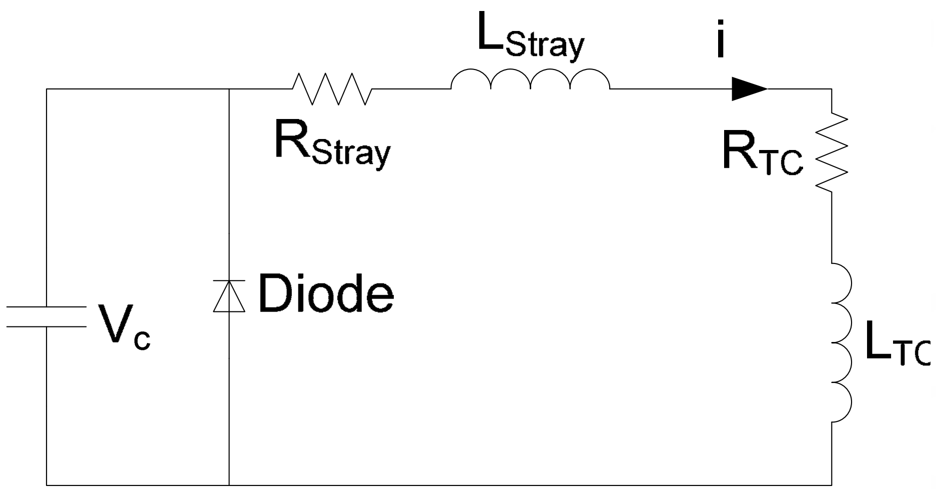
Model verification

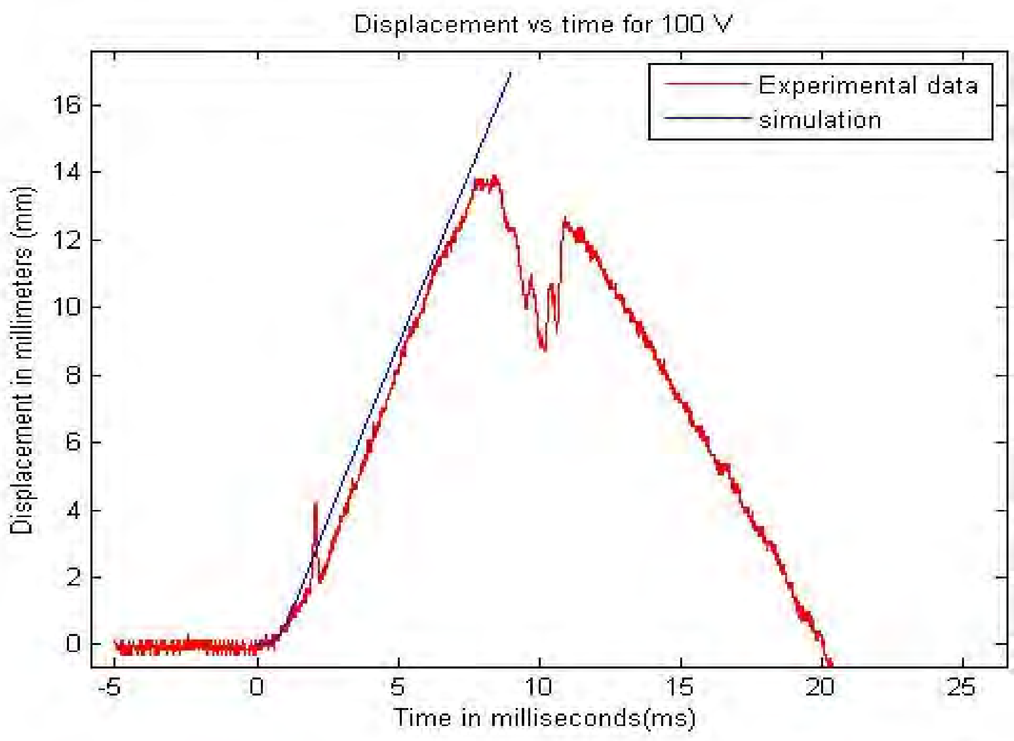
- Experimental verification is carried out to verify the results simulated in COMSOL.
- The results are compared with two experiments:
  - Experiment I was already carried out at ABB
  - Experiment II is the custom built prototype of the TC

Model verification
Exp I

Setup Characteristics	
Capacitor bank	33 mF
Initial voltage	400 V
Al Cross section area	50 mm x 20 mm
Coil conductor cross section area	2 mm x 4 mm
Air gap between coil and Al	1 mm
Number of coil turns	10
Gap between coil turns	0.1 mm
Stray resistance	10 mΩ
Stray inductance	1 µH





Model verification
Exp 2

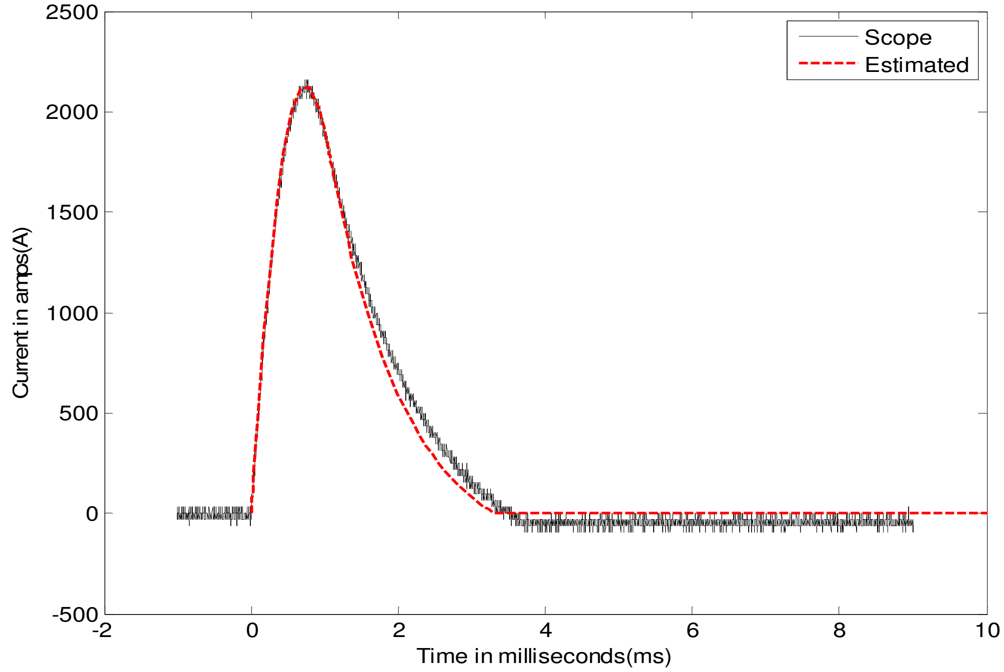
- Three series of tests were carried out:
- Test 1: The 33 mF capacitor bank is discharged in the coil with no aluminum ring on top at three voltage levels: 25, 50, and 100V
  - Aim: Determine the stray impedance
  - **Step 1:** The oscilloscope is used to measure the voltage and current pulse without any influence from the aluminum ring.
  - **Step 2:**The resistance and inductance of the coil are determined by running a COMSOL simulation with no aluminum disk.
  - **Step3:** The stray impedance can be approximated by solving for the following differential equations in MATLAB and comparing with the voltage and current waveforms measured in the lab:

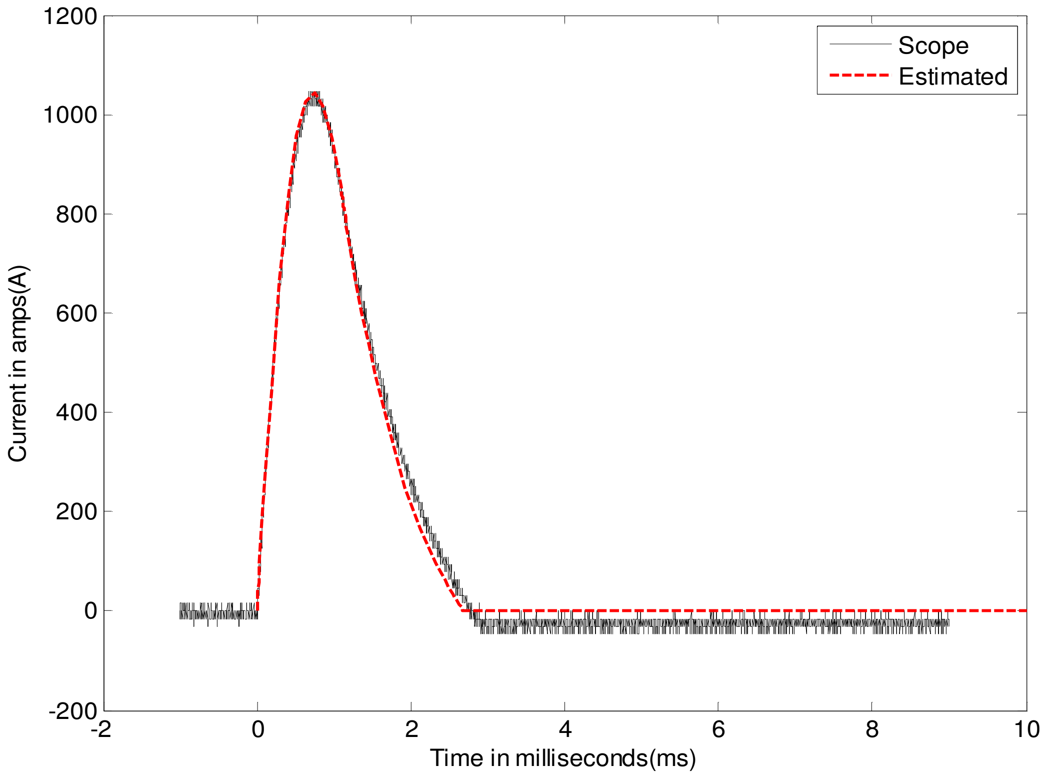
Model verification
Exp 2

$$\frac{dV_C}{dt} = -\frac{i}{C}$$

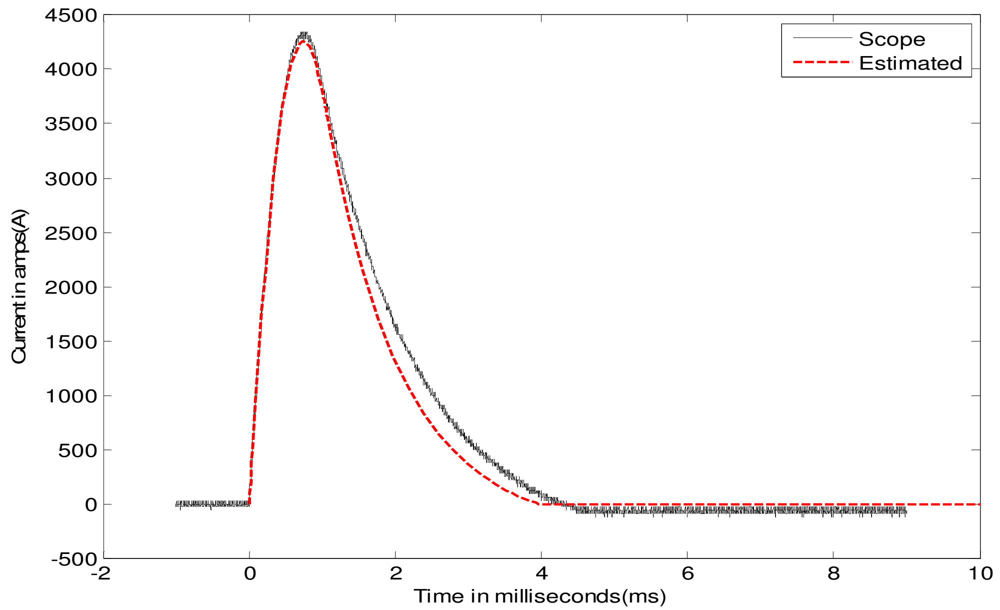
$$\frac{di}{dt} = \frac{1}{L + L_{Stray}}(V_C - R_{Stray}i - R_{TC}i)$$

Current pulse at 50 V





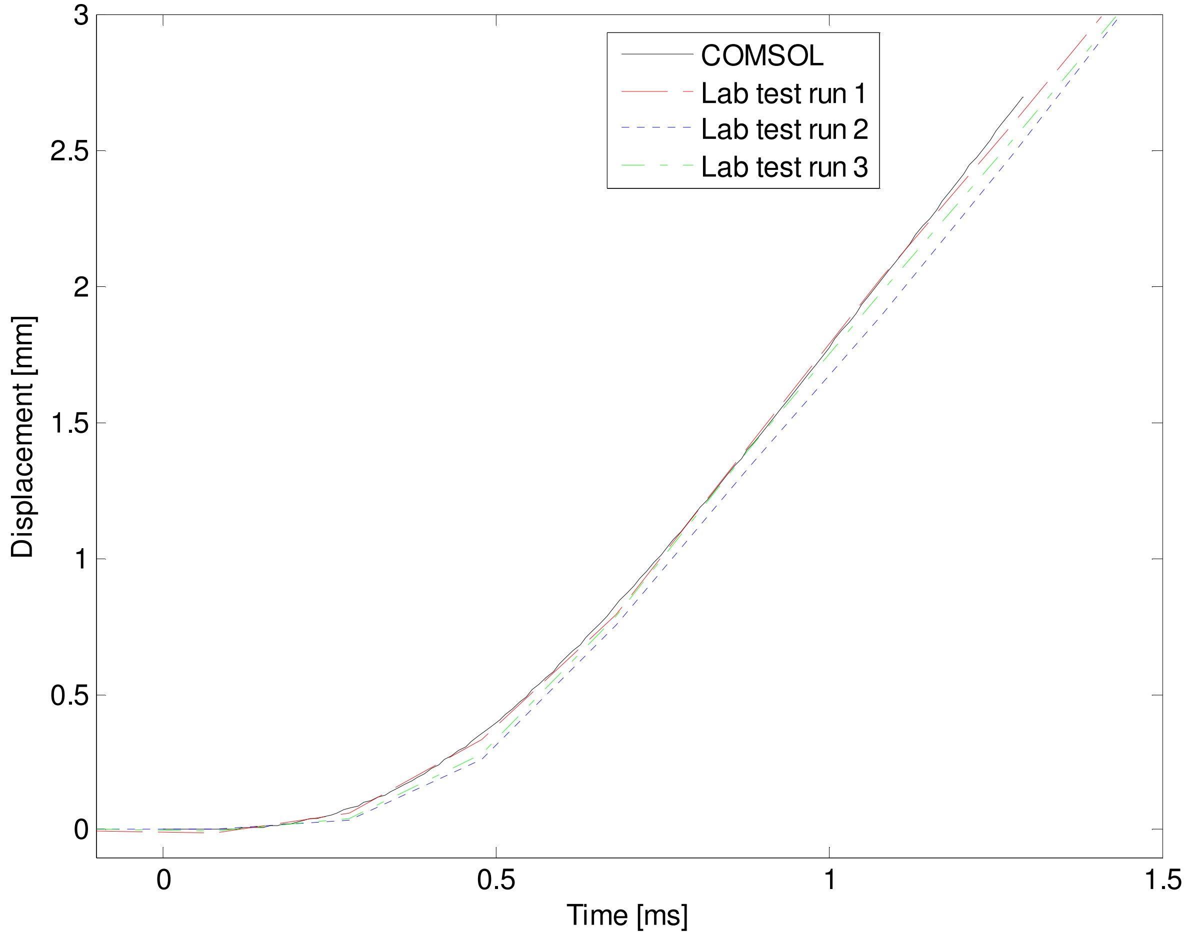
Current pulse at 25 V



Current pulse at 100 V

Model verification
Exp 2

- Test 2: A Teflon cylinder is used to guide the aluminum ring.
- Test 3: The guide is removed to record the displacement of the aluminum disk without friction.



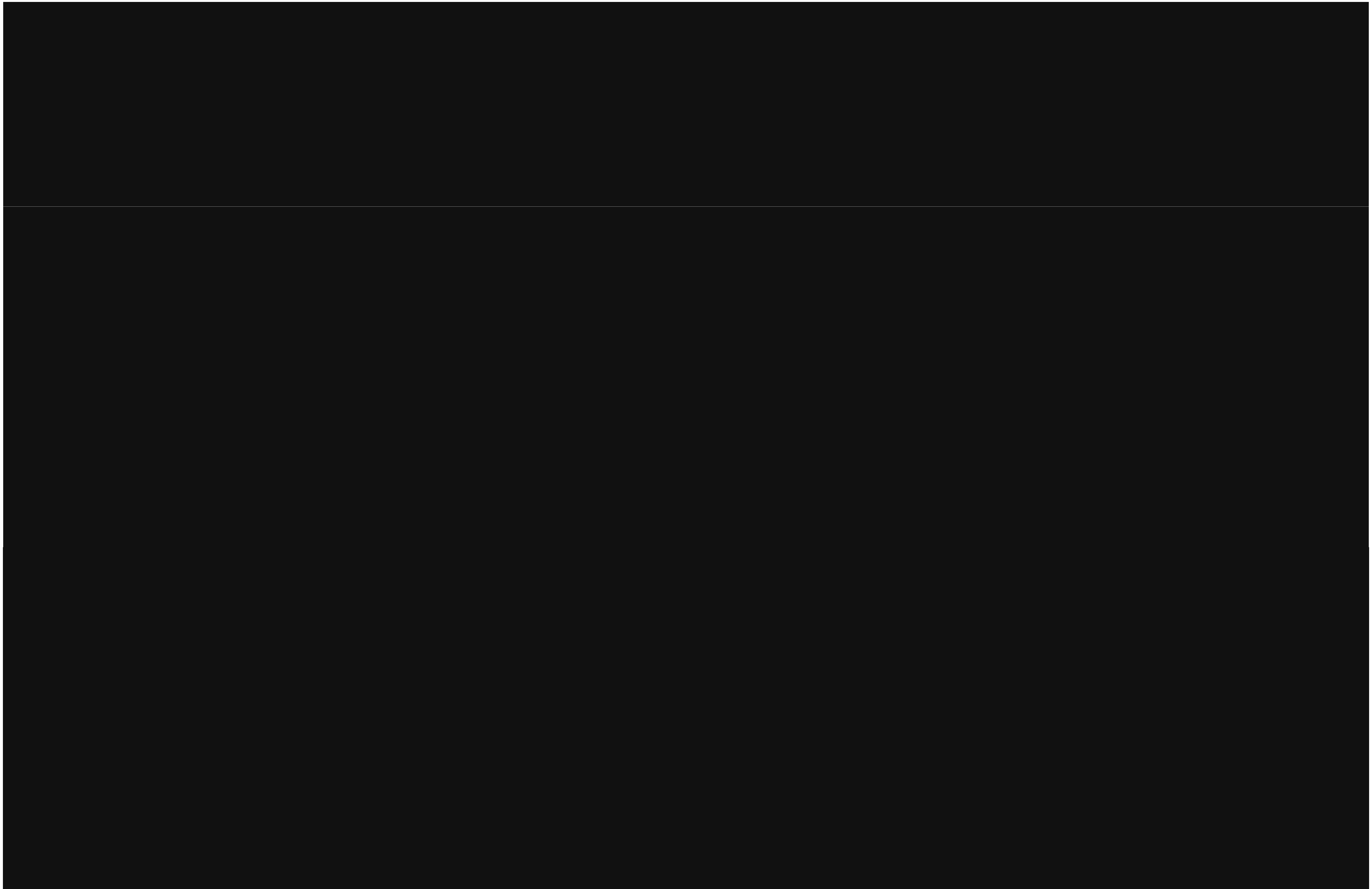
Model verification
Exp 2

- The sources of error are:
  - The coil is modeled as concentric rings in COMSOL and not as a spiral
  - Air resistance is neglected
  - The impedance of the coil is not 100% accurate
  - The stray impedance is not constant
  - The discharged voltage from the capacitor bank is not 100% exact
  - **Conclusions**:
    - No need for a guide since the aluminum follows a straight trajectory.
    - The model predicts the exerted forces on the aluminum disk with high accuracy.

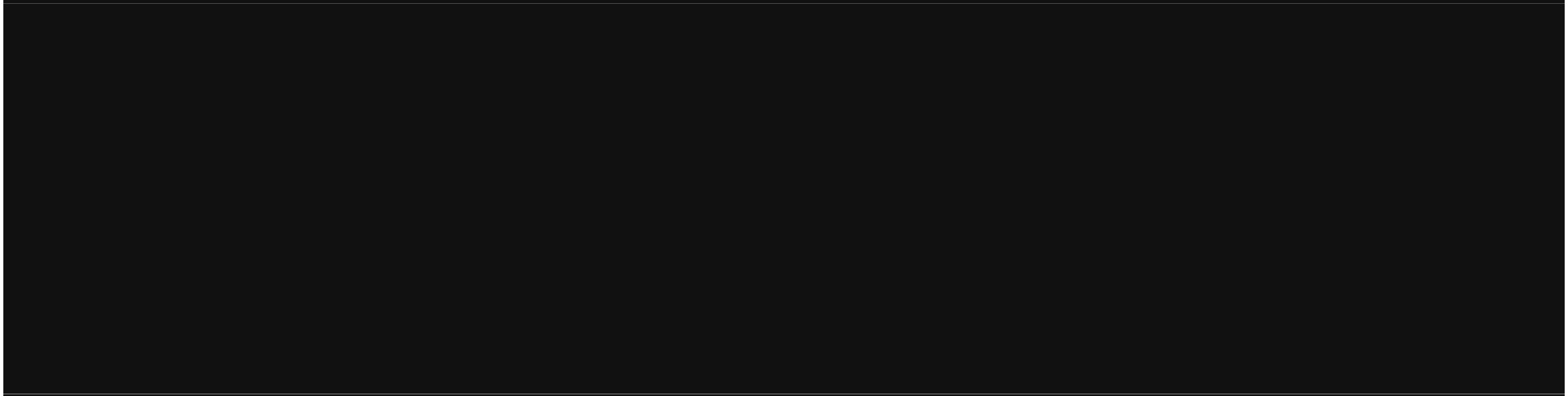
Conclusions

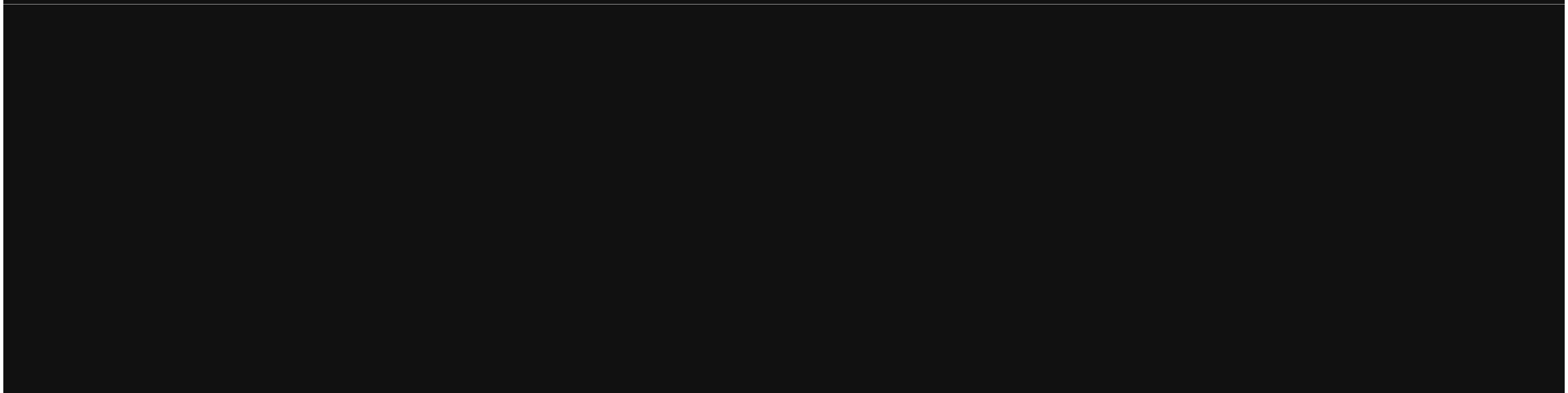
- Static and stationary models serve as a good start to study the behavior and characteristics of a TC at different frequencies
- A single equivalent frequency in a stationary model is not sufficient
- This experimentally validated multiphysics finite element transient model can be used to design a TC to meet the needed requirements

Movies- TC 50 V No guide, No bottom damper



Movies- TC 150 V with guide and bottom damper





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