COMSOL CONFERENCE EUROPE 2012

# Assessing COMSOL Performances on Typical Electromagnetic (EM) Problems Faced by Turbo-Generator Manufacturers

E. A. BADEA[1], J. OESTERHELD[1], S. FRIEDEL[2], M. OLSSON[2]

[1]Alstom (Switzerland) Ltd – Steam Business – Turbo-Generators
[2]COMSOL AB

Milan, 11th October 2012

COMSOL

we are shaping the future | ALSTOM

Excerpt from the Proceedings of the 2012 COMSOL Conference in Milan

# Agenda

Introduction

Benchmarks

Conclusions

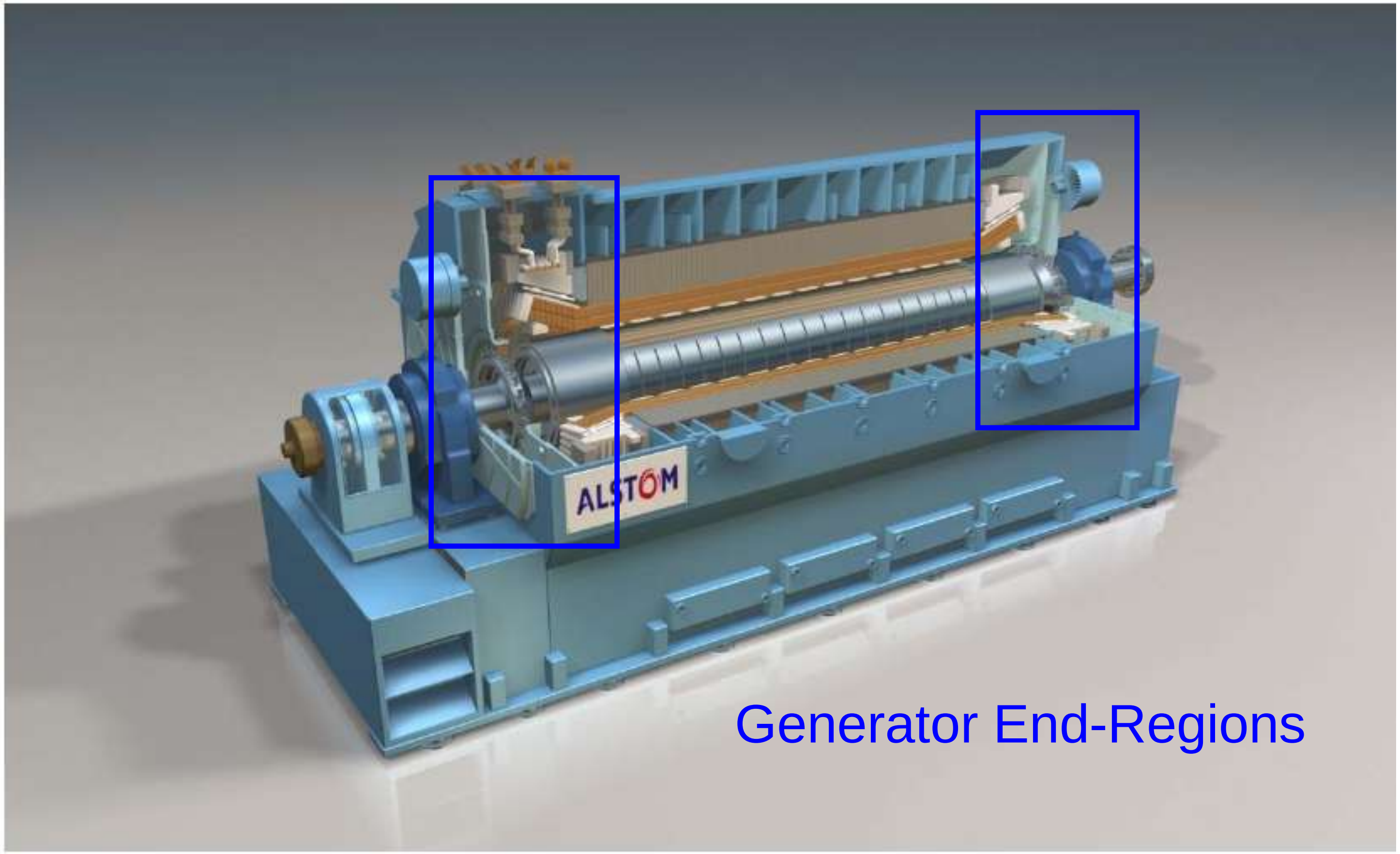
# Introduction

➢ Multi-physics processes are triggered by leakage EM field of stator end winding and its associated effects manifesting at machine frontal end

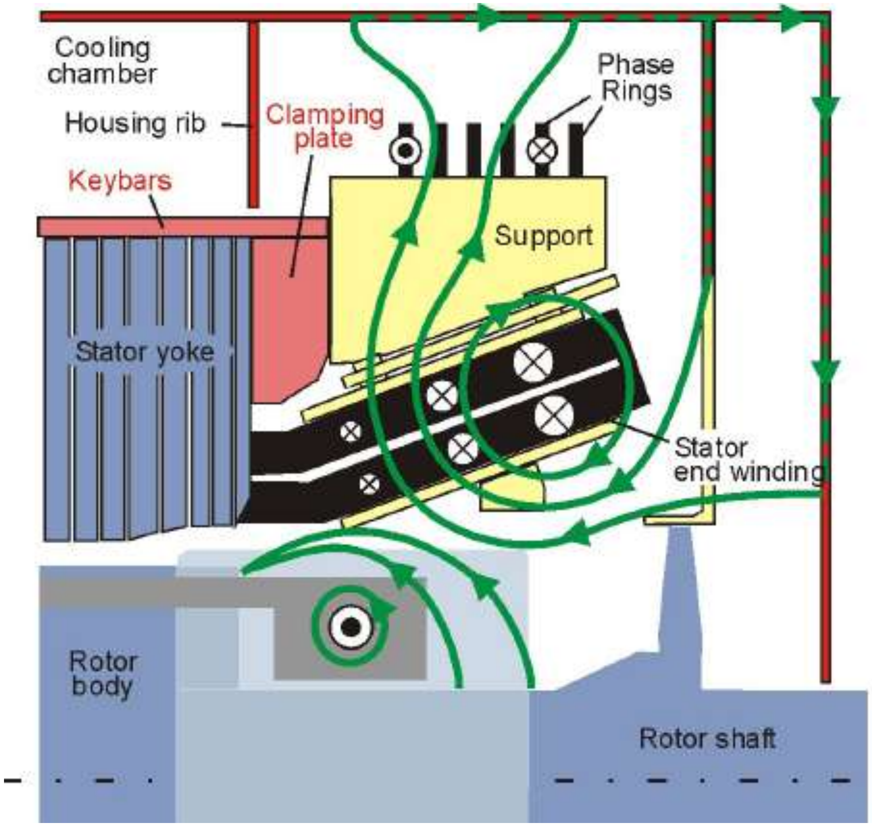
➢ A compilation of coupled phenomena with different EM, thermal, fluid flow and mechanical backgrounds are defining such processes

➢ A few relevant topics for turbo-generator R&D are:

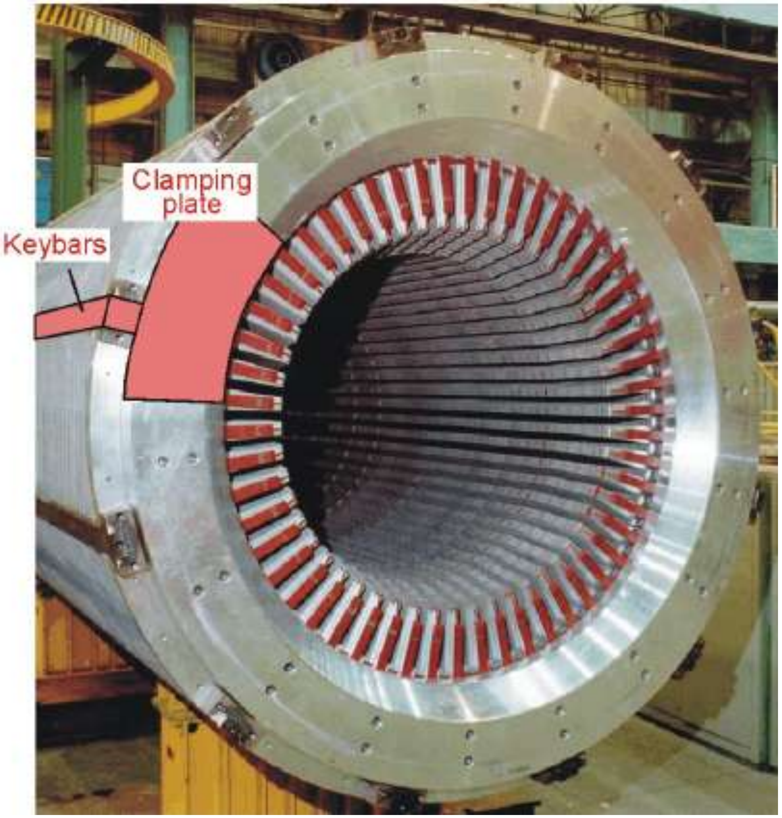
- ***Circulating currents in metallic components***
- ***Local overheating***
- ***EM forces acting on stator end winding***
- ***Inter-laminar insulation fault in stator core***
- ***Insulation design for stator end winding***




Turbo-Generator



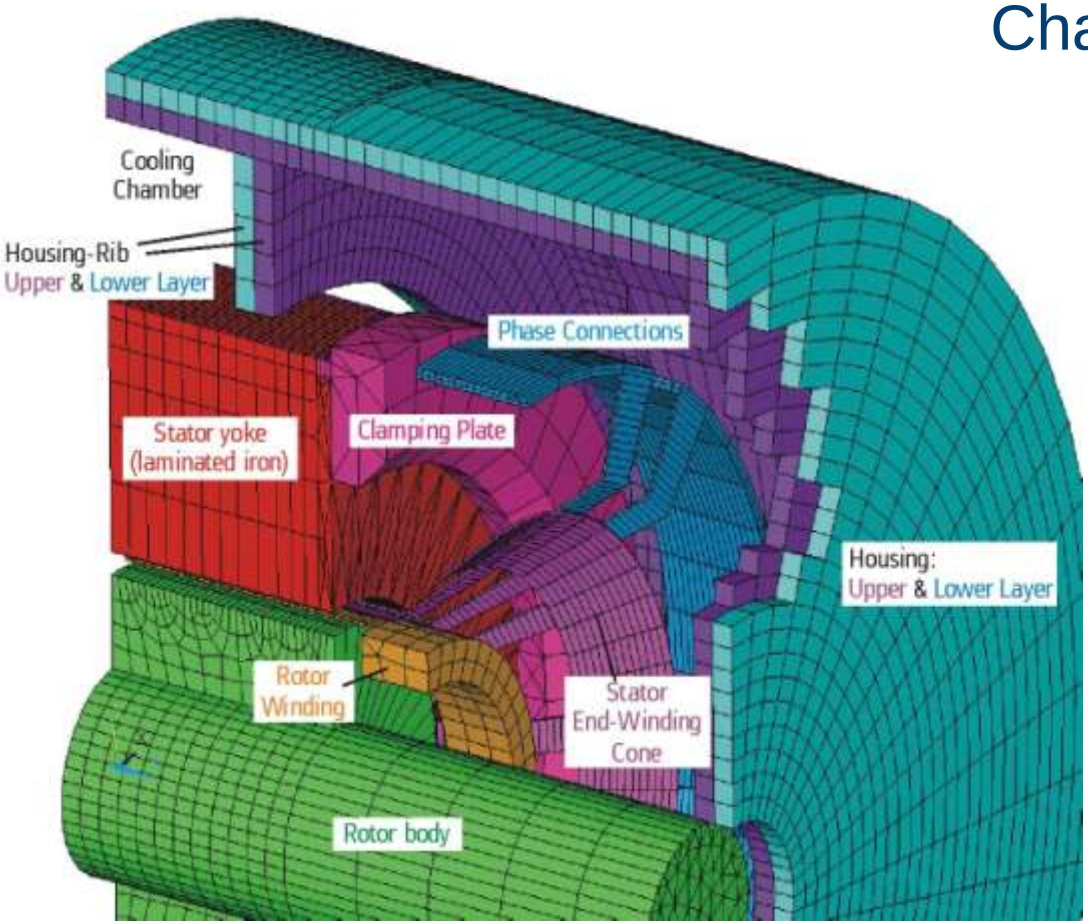

Longitudinal Section




Stator Core in Factory

# End Regions of the Turbo-Generator

# Challenges for FEM Software




- Distributed windings and complicated boundary shapes must be included in the 3D model to accurately predict hidden physics aspects
- Strong contrasts of material properties lead to badly defined problems where massively parallel sparse direct solvers may become imperative to handle the ill-conditioned matrices
- Severe electric and magnetic nonlinearities and small skin-depths require special features (smart transition layers, impedance boundary conditions)

# Benchmarks

- **Benchmark 1:**

  ***Insulation Design (Electrical Stress Grading)***

- **Benchmark 2:**

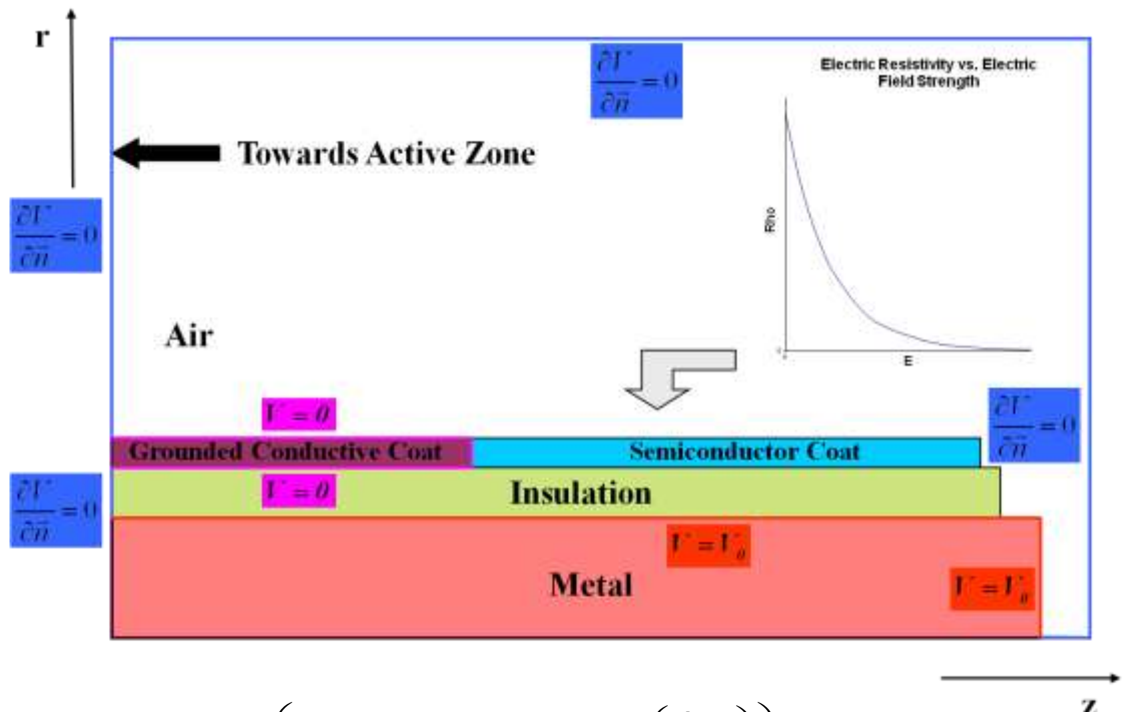
  ***TEAM-7: Asymmetric Conductor with a Hole***

- **Benchmark 3:**

  ***TEAM-21: Ferric Plate Shielded by a Copper Screen***

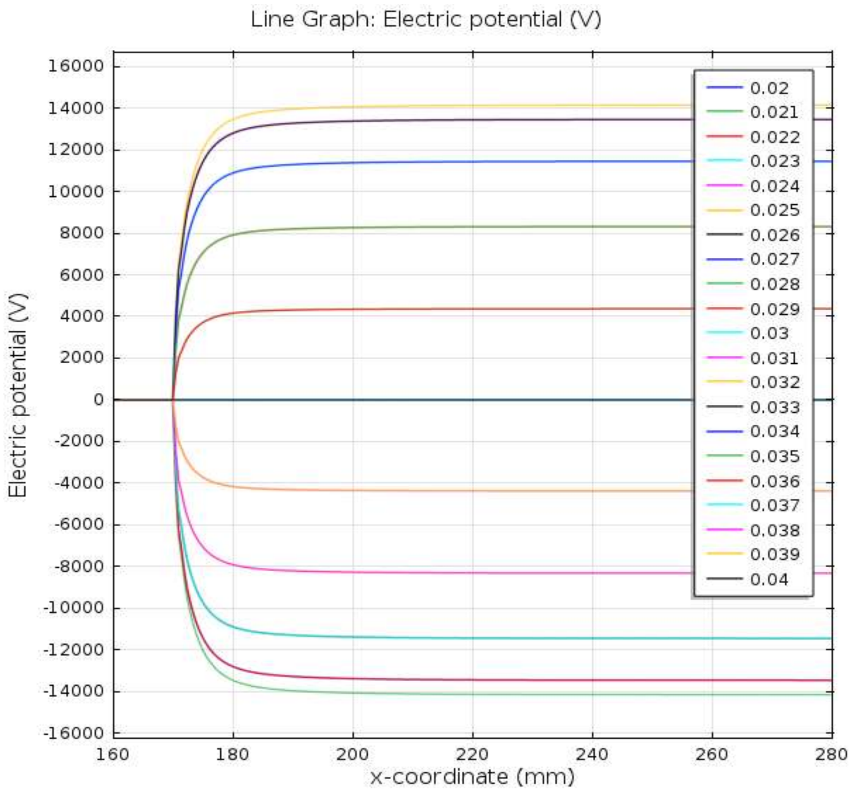
# Benchmark 1: Insulation Design (Electrical Stress Grading)

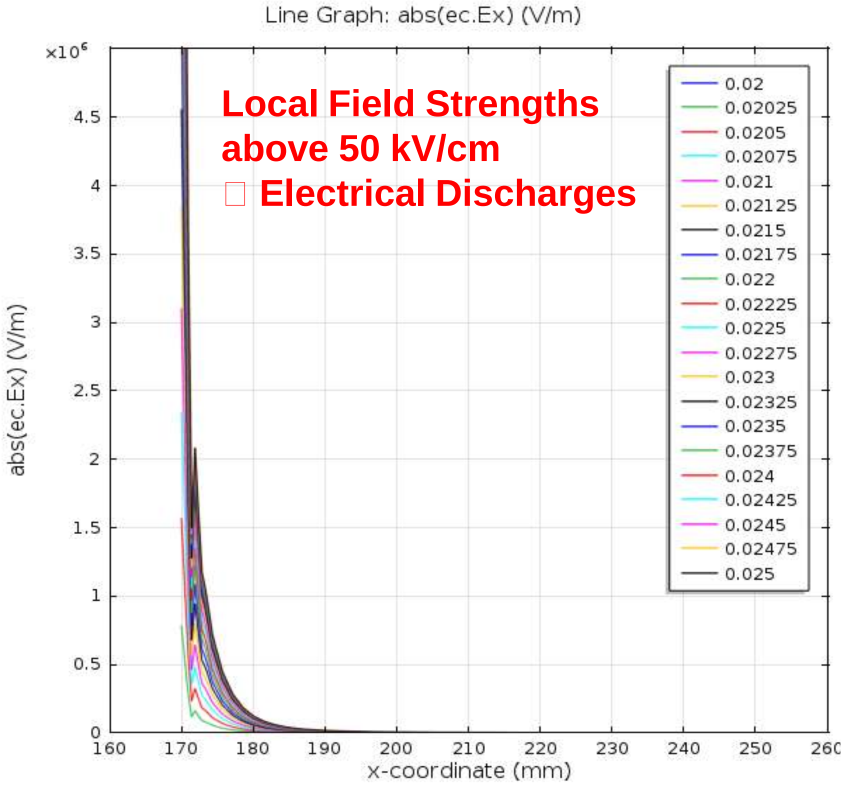
Stator End-Winding




$$\nabla \cdot \left( -\sigma(\vec{E})\nabla V - \varepsilon(\vec{E})\nabla\left(\frac{\partial V}{\partial t}\right)\right) = 0$$

# Benchmark 1: Insulation Design (Electrical Stress Grading)

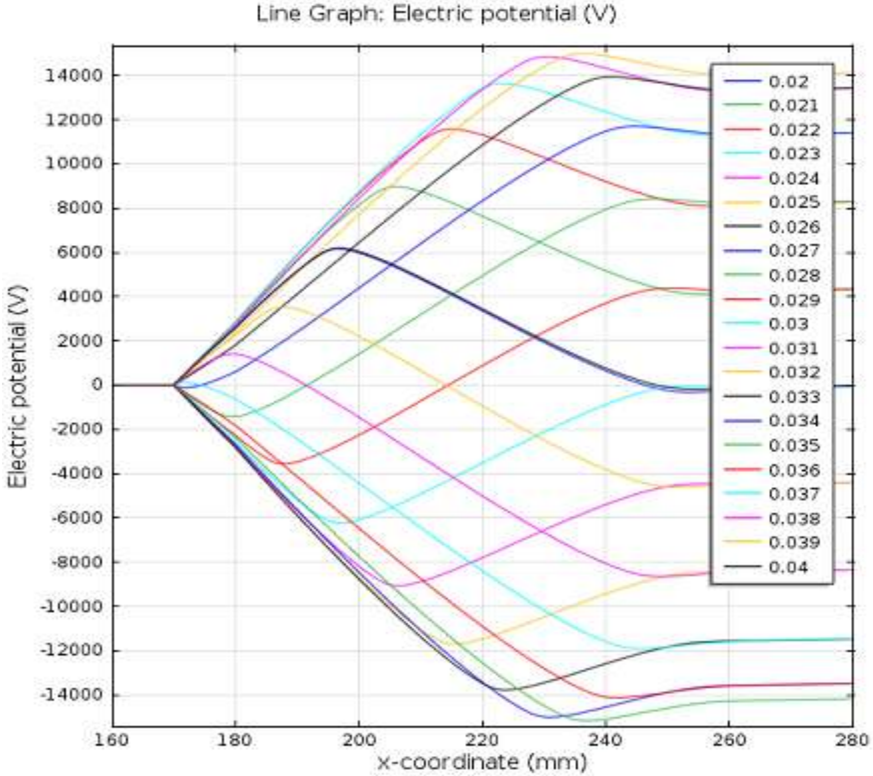


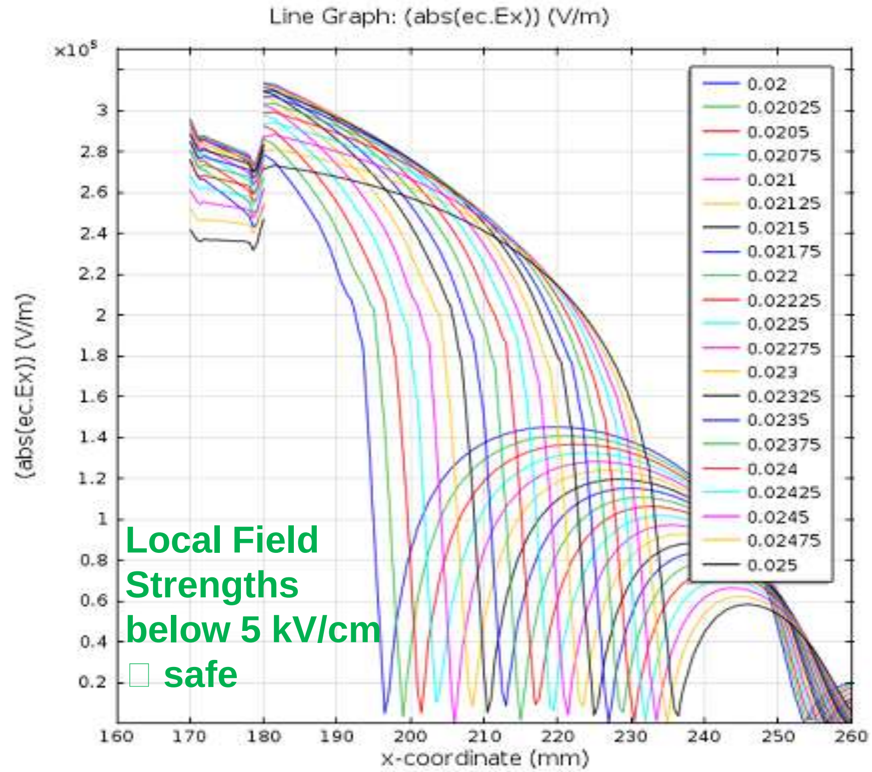




## Stator Bar End Region: No Stress Grading

*Surface Potential and Electric Field Strength Distribution*

# Benchmark 1: Insulation Design (Electrical Stress Grading)

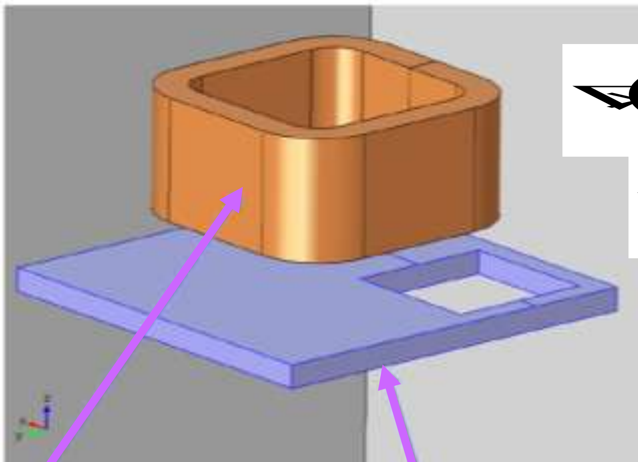



## Stator Bar End Region: With Stress Grading

*Surface Potential and Electric Field Strength Distribution*

# Benchmark 2: TEAM-7 Asymmetric Conductor with a Hole

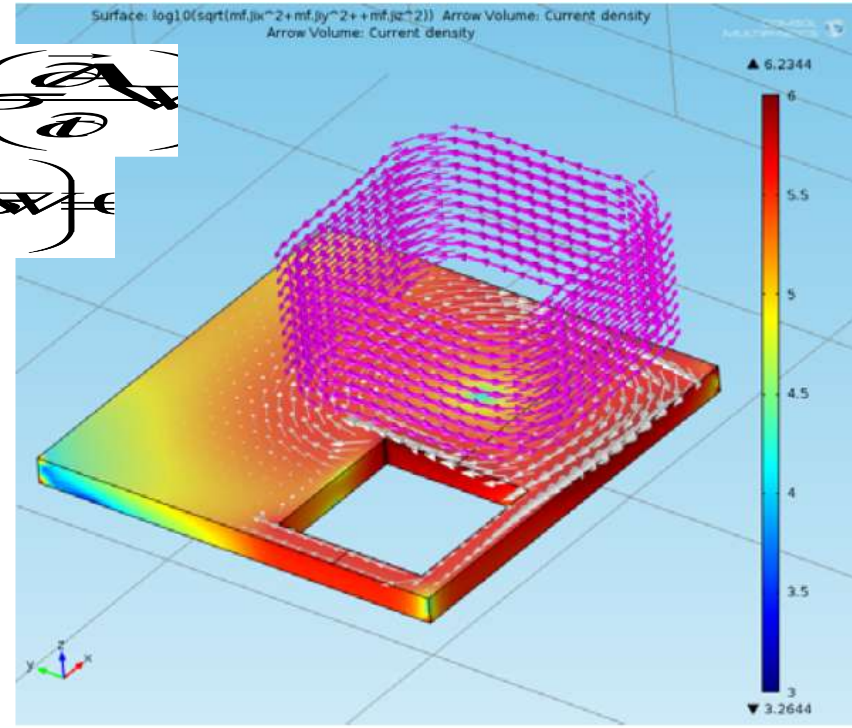


$$\nabla\times\left(\nu\nabla\times\vec{A}\right) - \vec{J}_s + \sigma\left(\frac{\partial\vec{A}}{\partial t} + \nabla V\right) = 0$$

$$\nabla\cdot\left(-\sigma\frac{\partial\vec{A}}{\partial t} - \sigma\nabla V\right) = 0$$

- 2747 turns of 1 A *at 50 Hz and 200 Hz*
- *Induction neglected*
- *Modelled with 3D coil domain (new in COMSOL 4.3)*

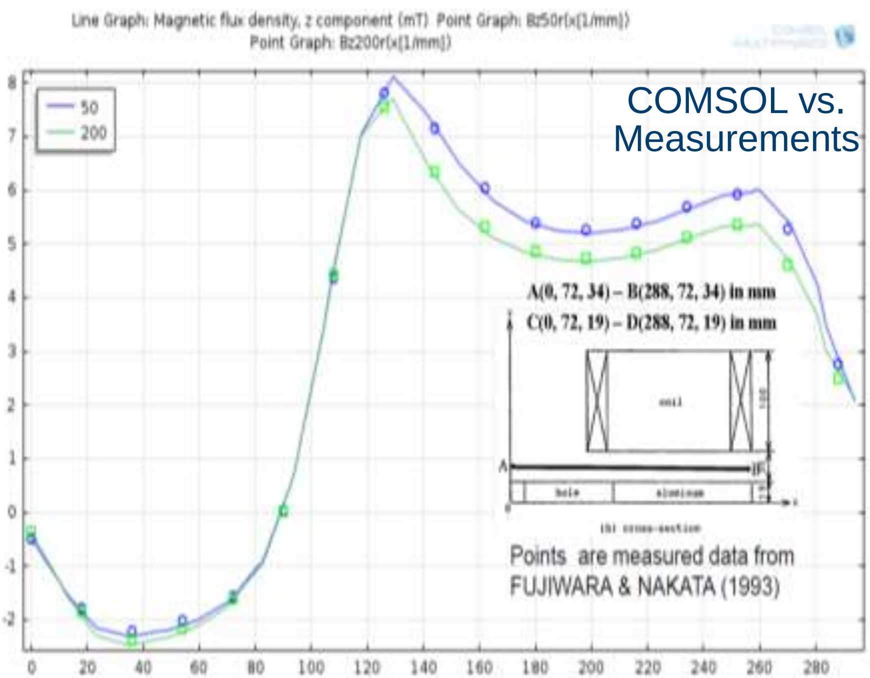
- Aluminium shield 19 mm thick



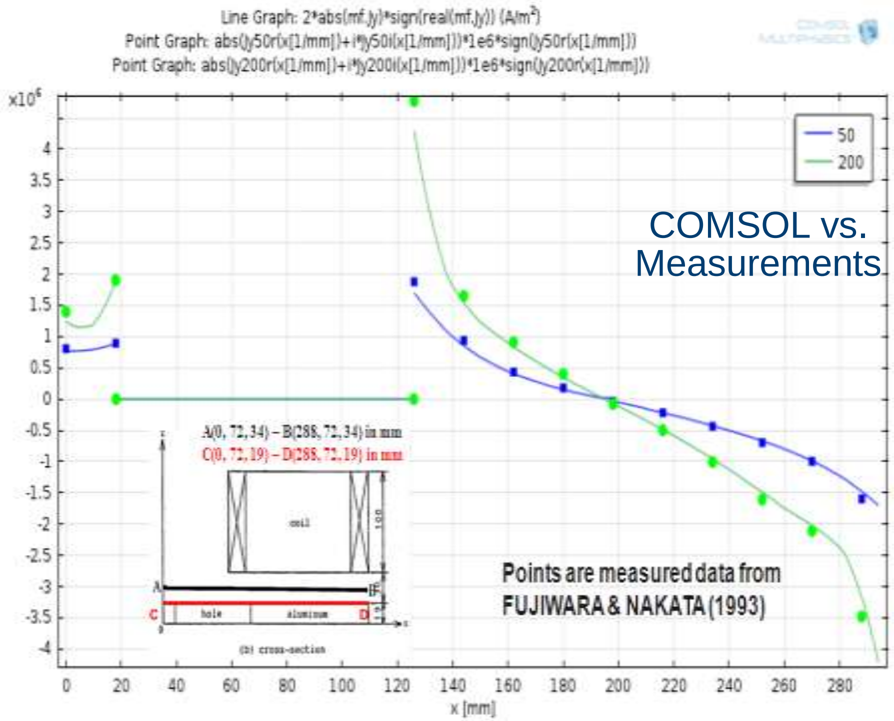

Impressed (magenta) and induced (grey) currents at *50 Hz*

## TEAM-7:
## Geometry and Materials

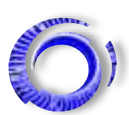
# Benchmark 2: TEAM-7 Asymmetric Conductor with a Hole




Magnetic Induction along path ***AB*** at *50 Hz* and *200 Hz*

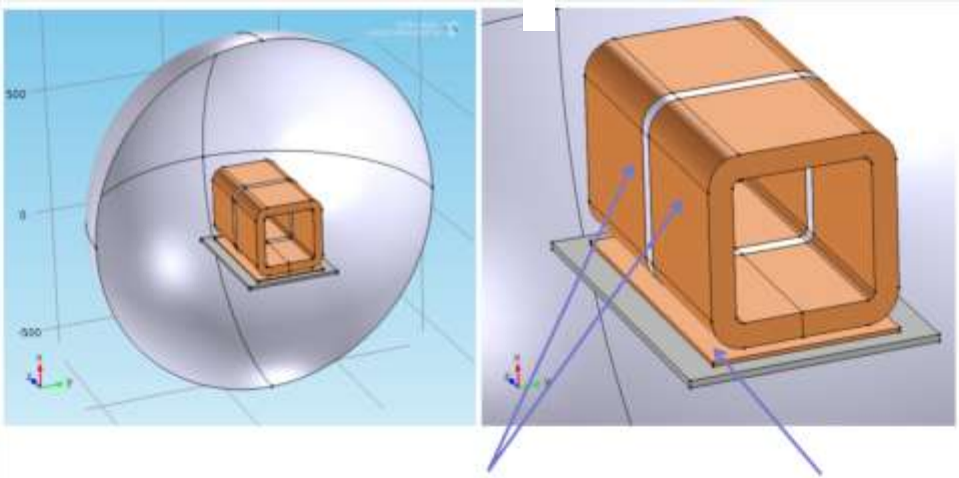



Eddy Current Density along path ***CD*** at *50 Hz* and *200 Hz*



TEAM-7:
Comparison of Results

# Benchmark 3: TEAM-21 Ferric Plate Shielded by a Copper Screen



Dimensions according to [5]

Two oppositely wounded coils fed by an AC current of 50 Hz with a peak value of 4242.64 A (3000 A * sqrt(2)) induction neglected

6 mm Cu shield
10 mm nonlinear Fe shield

- Copper:

**Material Contents**

| Property | Name | Value | Unit |
|---|---|---|---|
| ✓ Relative permittivity | epsilonr | 1 | 1 |
| ✓ Relative permeability | mur | 1 | 1 |
| ✓ Electrical conductivity | sigma | 5e7 | S/m |

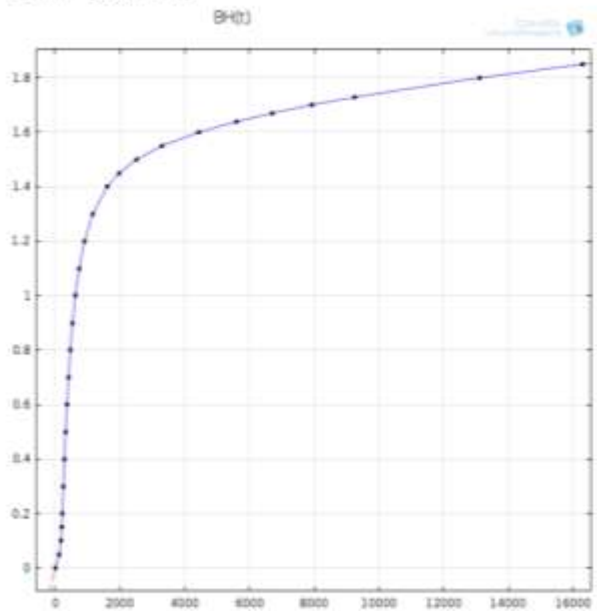
- Nonlinear Iron

| Property | Name | Value | Unit |
|---|---|---|---|
| ✓ Electrical conductivity | sigma | 6.484e6[S/m] | S/m |
| ✓ Relative permittivity | epsilonr | 1 | 1 |
| ✓ normH | normH | sqrt(H1^2+H2^2+H3^2) | A/m |
| ✓ Magnetic field norm | normH | HB(normB[1/T])[A/m] | A/m |
| Magnetic flux density ... | normB | BH(normH[m/A])[T] | T |
| normB | normB | sqrt(B1^2+B2^2+B3^2) | T |

## TEAM-21:
## Geometry and Materials

# Benchmark 3: TEAM-21 Ferric Plate Shielded by a Copper Screen

## B-H curve

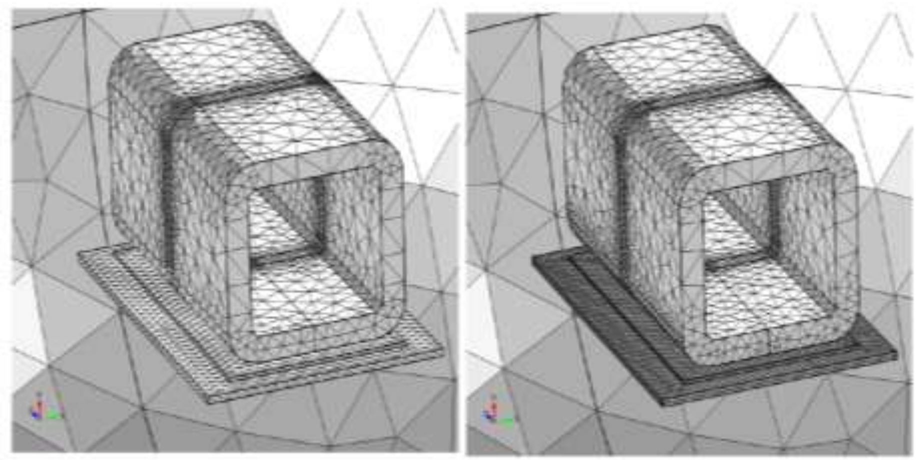



| B [T] | H [A/m] |
|---|---|
| 0 | 0 |
| 0.049 | 115 |
| 0.101 | 171 |
| 0.15 | 196 |
| 0.2 | 214 |
| 0.299 | 245 |
| 0.399 | 279 |
| 0.499 | 316 |
| 0.601 | 359 |
| 0.7 | 405 |
| 0.801 | 461 |
| 0.899 | 528 |
| 1.001 | 616 |
| 1.099 | 732 |
| 1.2 | 898 |
| 1.3 | 1154 |
| 1.401 | 1606 |
| 1.449 | 1965 |
| 1.5 | 2506 |
| 1.55 | 3291 |
| 1.6 | 4430 |
| 1.639 | 5599 |
| 1.67 | 6698 |
| 1.701 | 7926 |
| 1.729 | 9251 |
| 1.8 | 13106 |
| 1.85 | 16290 |
| 1.9 | 19942 |

Magnetization Curve
for Ferric Plate

COMSOL

## Mesh



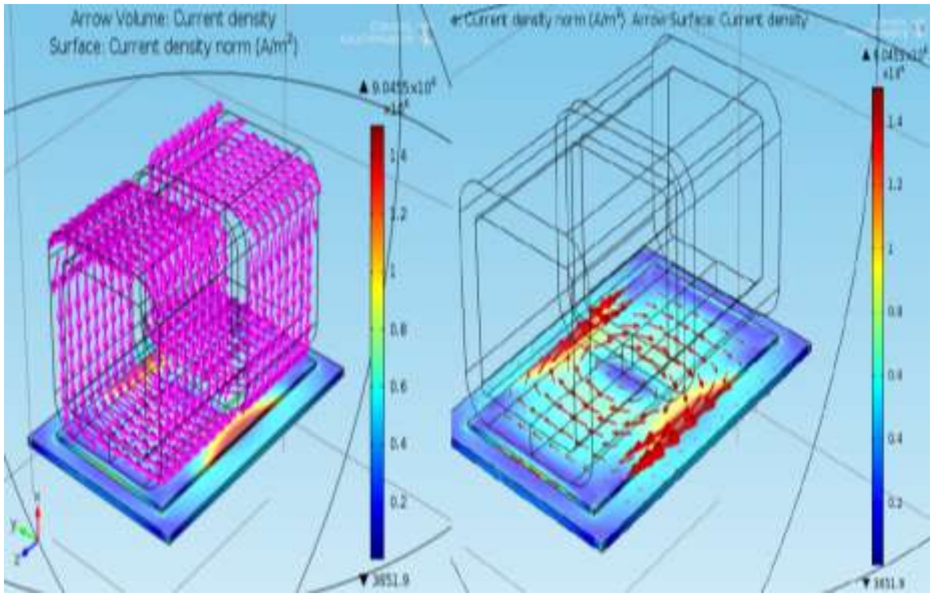
- Two variants with maximum mesh size in the shielding layers ms
- A) ms=15 mm, 99'000 Tets, 652 kDOFs
- B) ms=7 mm, 283'730 Tets, 1.83 MDOFs

Mesh

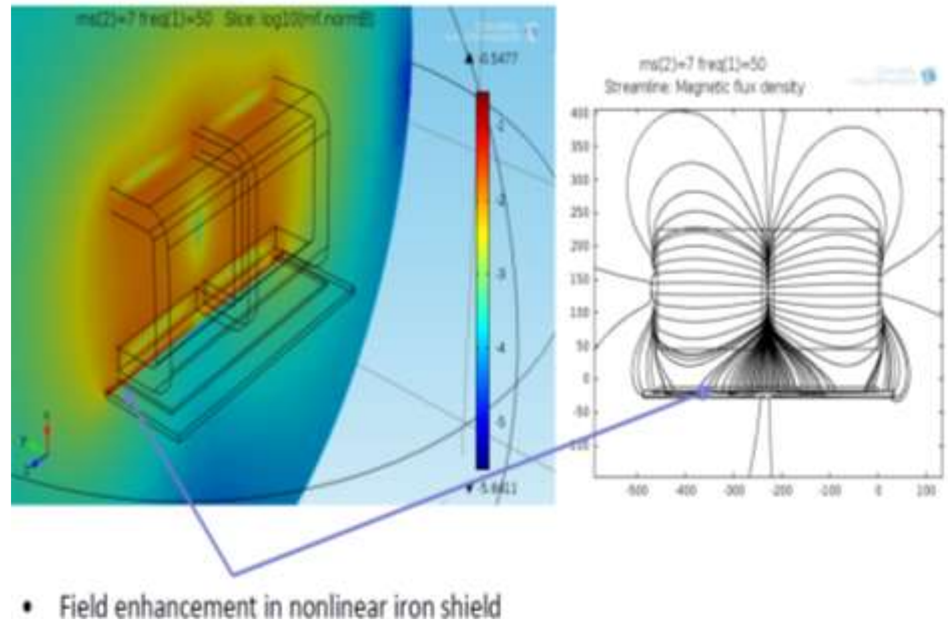
COMSOL

## TEAM-21:
## Materials and Mesh

# **Benchmark 3:** TEAM-21 Ferric Plate Shielded by a Copper Screen



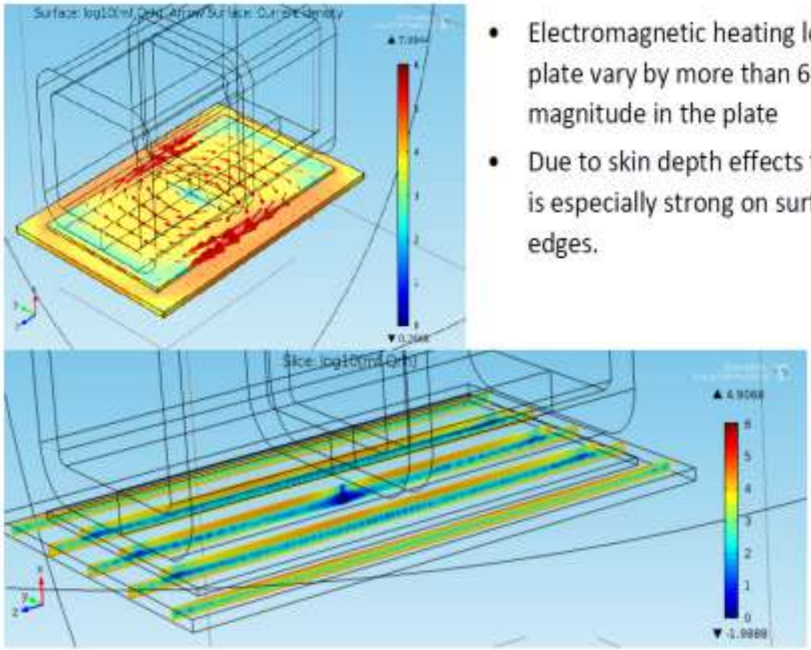

Source and Induced Current Density




Magnetic Induction in Iron Plate (Log Scale) at y=0

TEAM-21:
Qualitative Results

# Benchmark 3: TEAM-21 Ferric Plate Shielded by a Copper Screen



- Electromagnetic heating losses in the plate vary by more than 6 orders of magnitude in the plate
- Due to skin depth effects the heating is especially strong on surfaces and edges.

Power Losses in Iron Plate (Log Scale)

## Integrated Losses (W)

| | freq | Cu Plate | Iron Plate | Total |
|---|---|---|---|---|
| COMSOL | ms=15 | 11.20 | 8.89 | 20.09 |
| COMSOL | ms=7 | 11.38 | 6.19 | 17.57 |
| Chen et. Al. 2006 | | 10.85 | 5.37 | 16.22 |
| Measured | | | | 15.24 |

- The total calculated power losses differ by about 15% from measurements
- While copper losses do not change with the mesh size, the iron losses do improve when a refined mesh is used
- The discrepancy can be explained by the linear approach used by the harmonic solver (no higher harmonics are considered)

TEAM-21:
Comparison of Results

# Summary

- Three different benchmarks were selected to validate COMSOL results against measurements
- These test problems were chosen according to relevant topics of interest for turbo-generator manufacturers
- Special features such as thin transition layers, impedance boundary conditions, or the default algorithms handling electrical and magnetic nonlinearities for both time and frequency domain solvers, were carefully investigated
- Preliminary numerical results were encouraging and indicated that COMSOL is capable of solving such problems, which are daily business for turbo-generator R&D

COMSOL CONFERENCE EUROPE 2012

# Thank you for your attention.

**www.alstom.com**

COMSOL

We are shaping the future | ALSTOM