Demonstration Thermo-Electric and MHD Mathematical Models of a 500 kA Al Electrolysis Cell: Part 2

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Plan of the Presentation

- Introduction
- Dupuis' Thermo-Electric Models
  - Previous works: Lump Parameters+, Full Cell Slice, Full Cell Quarter
  - Full Cell Cathode Thermo-Electric Model
  - Full Half Cell Quarter Thermo-Electric Model
  - Complete Cell Thermo-Electric Model
- Bojarevics' Cell Stability Model
  - Previous works: Simple Shell, Simple Neighbors Representation
  - Complex Shell and detailed Neighbors Representation
- First Interaction Trial Between Models
- Conclusions

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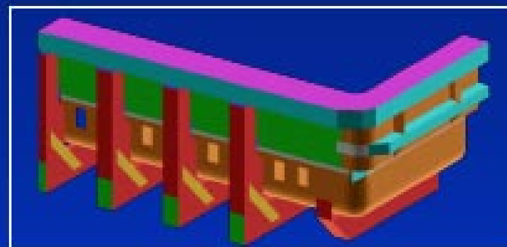
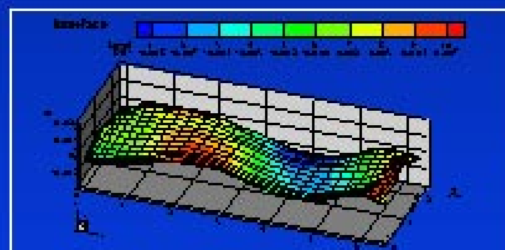
Modeling the Hall-Héroult Cell

Currently, we can fit Hall-Héroult mathematical models into three broad categories:

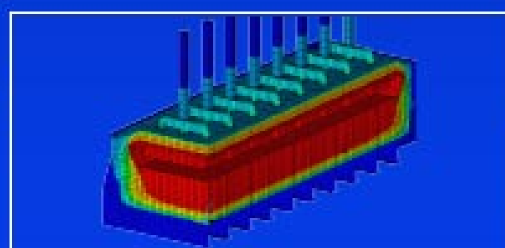
- Stress models which are generally associated with cell shell deformation and cathode heaving issues.



- Magneto-hydro-dynamic (MHD) models which are generally associated with the problem of cell stability.

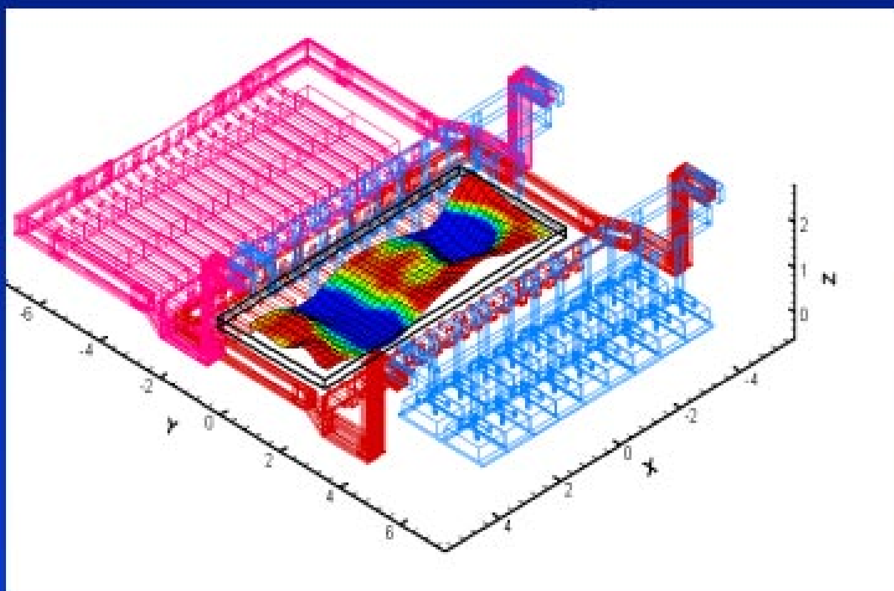


- Thermal-electric models which are generally associated with the problem of cell heat balance.



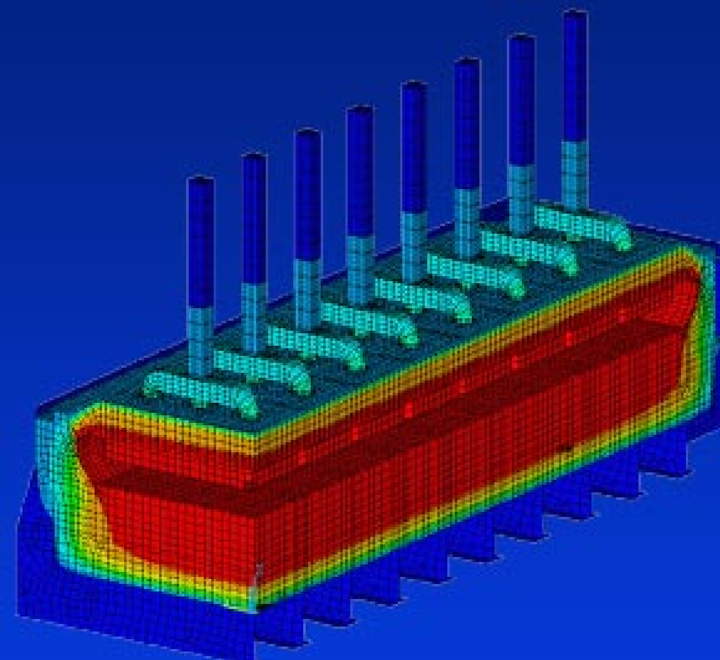
Cell Design

Modeling the Hall-Héroult Cell



MHD model:

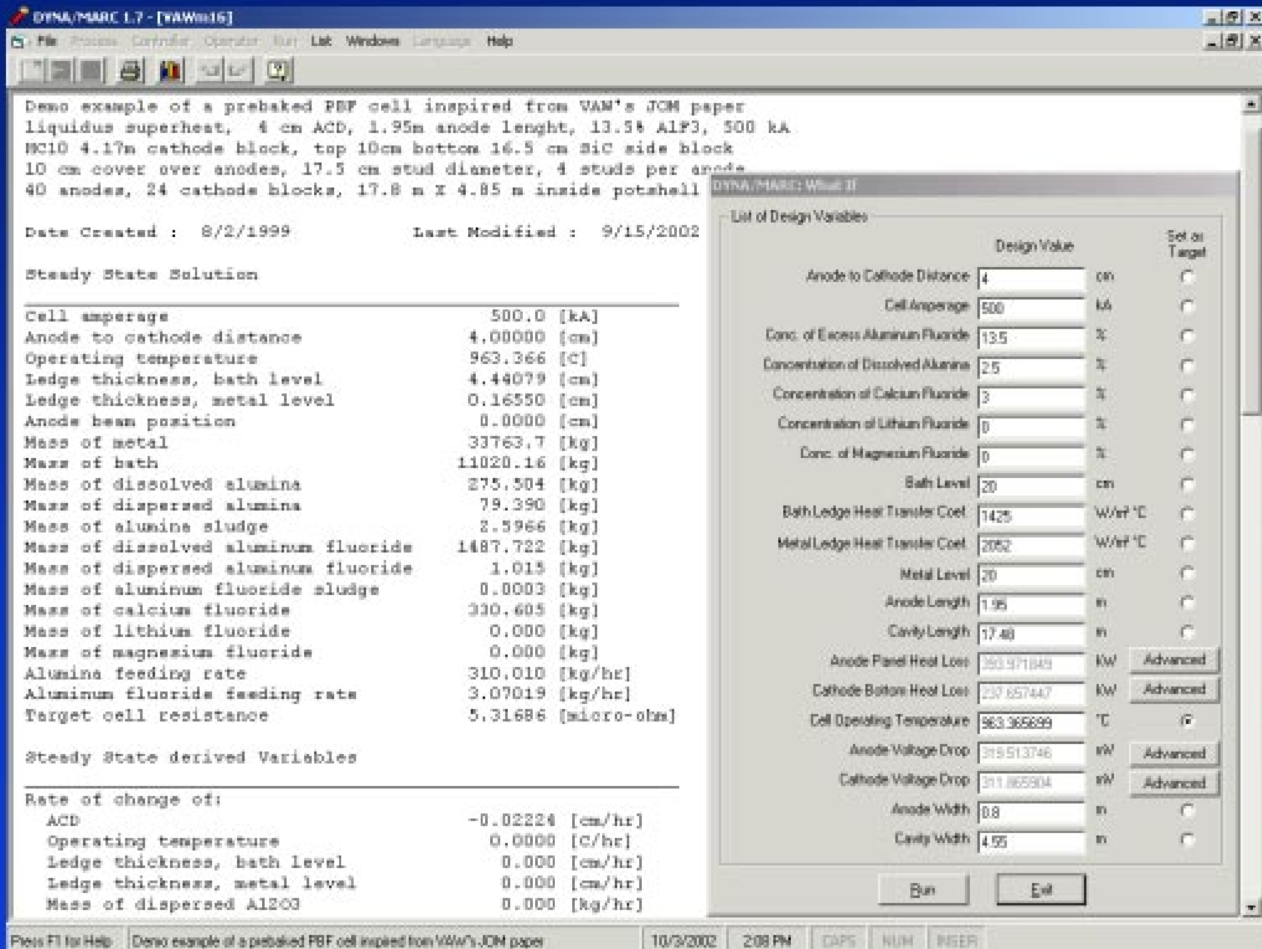
centered around the liquid zone



Thermo-electric model:

no need to include the liquid zone

Thermo-Electric Design of a 500 kA Cell Using a Lump Parameter+ Model



Amperage	500 kA
Nb. of anodes	40
Anode size	1.95 m X 0.8 m
Nb. of anode studs	4 per anode
Anode stud diameter	17.5 cm
Anode cover thickness	10 cm
Nb. of cathode blocks	24
Cathode block length	4.17 m
Type of cathode block	HC10
Type of side block	SiC
Side block thickness	10 cm +
ASD	30 cm
Inside potshell size	17.8 X 4.85 m
ACD	4 cm
Excess AlF_3	13.5 %
Anode drop	320 mV
Cathode drop	312 mV
Anode panel heat loss	394 kW
Cathode bottom heat loss	238 kW
Operating temperature	963.4 °C
Liquidus superheat	9.7 °C
Bath ledge thickness	4.44 cm
Metal ledge thickness	0.17 cm
Current efficiency	95.9 %
Internal heat	1019 kW
Energy consumption	13.39 kWh/kg

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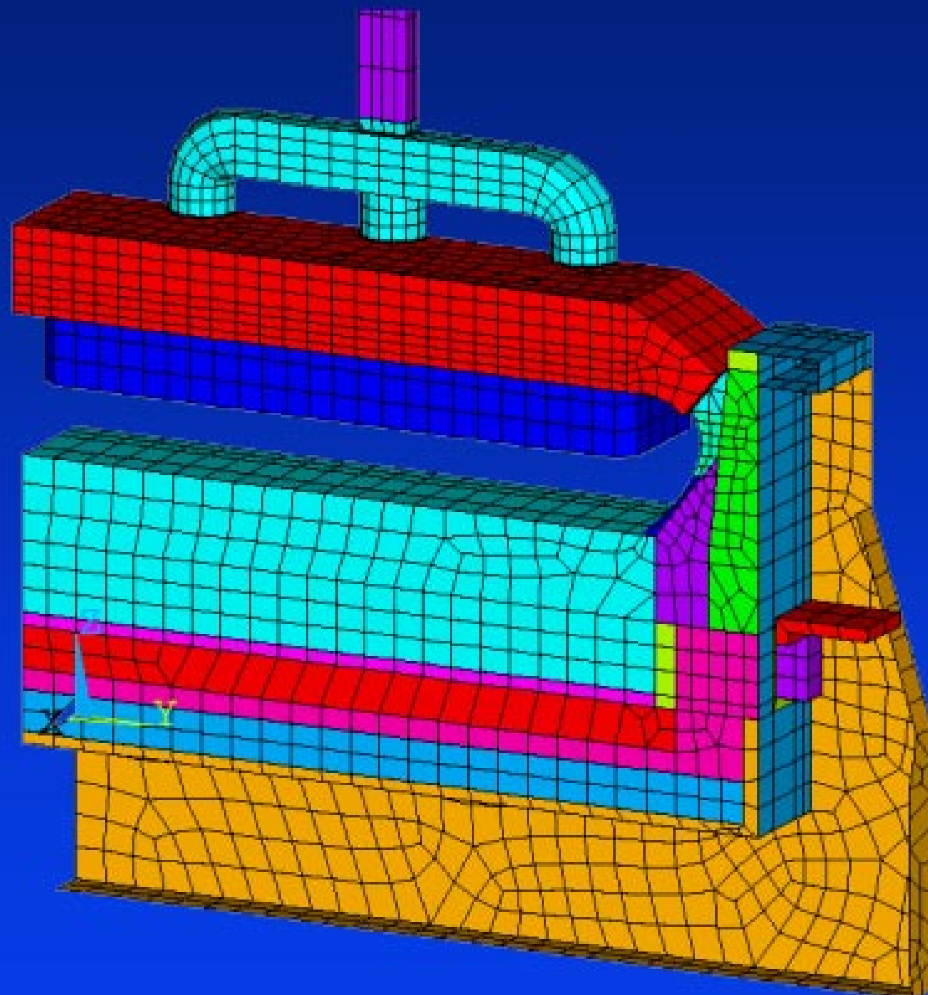
Thermo-Electric Design of a 500 kA Cell Using a 3D Full Cell Side Slice Thermo-Electric Model

500 kA Demonstration Cell Key Characteristics

Inside potshell size:	17.8 m x 4.85 m
Anode size:	1.95 m x 0.8 m
Number of anodes:	40
Anodic current density:	0.80 A/cm^2
Cathode block size:	4.17 m x 0.66 m x 0.48 m
Cathode block type:	HC10
Side block type:	SiC
Number of anodic risers:	6

3D Full Cell Side Slice T-E Model's Key Results

Anode drop:	354 mV
Cathode drop:	314 mV
Anode panel heat loss:	409 kW
Total cathode heat loss:	633 kW
Operating temperature:	963.1 °C
Liquidus superheat:	9.4 °C
Average ledge thickness at bath level:	2.42 cm
Average ledge thickness at metal level:	6.15 cm
Cell internal heat:	1043 kW
Energy consumption:	13.61 kWh/kg



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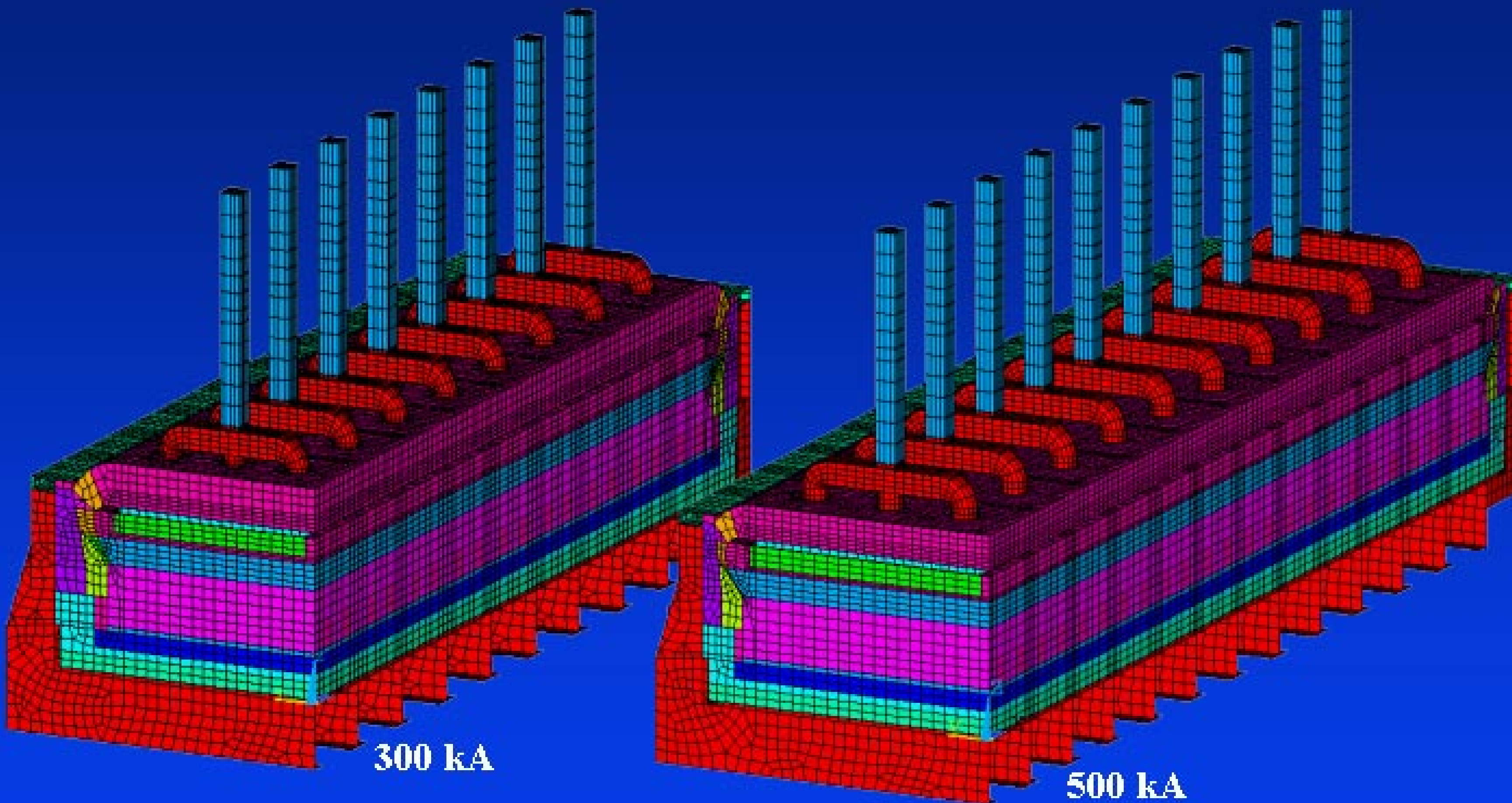
Thermo-Electric Design of a 500 kA Cell Using a Complete Full Cell Quarter Thermo-Electric Model



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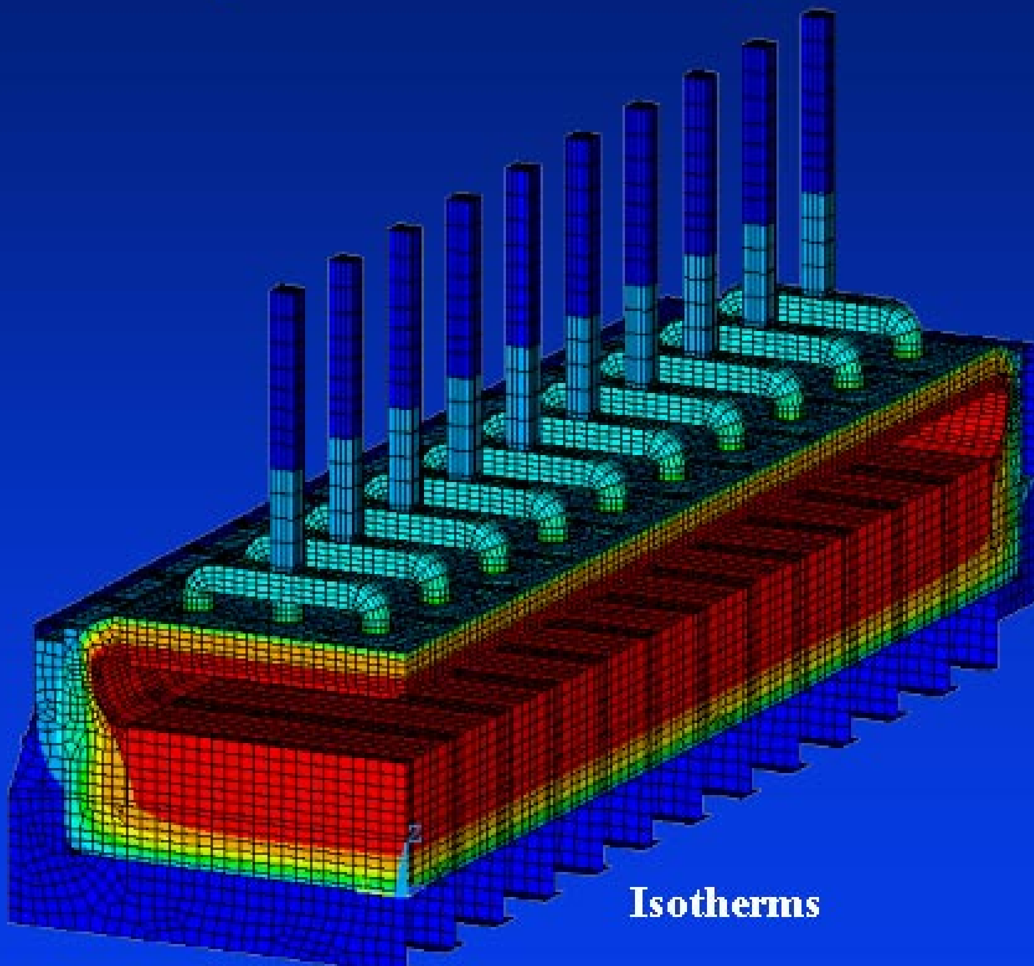
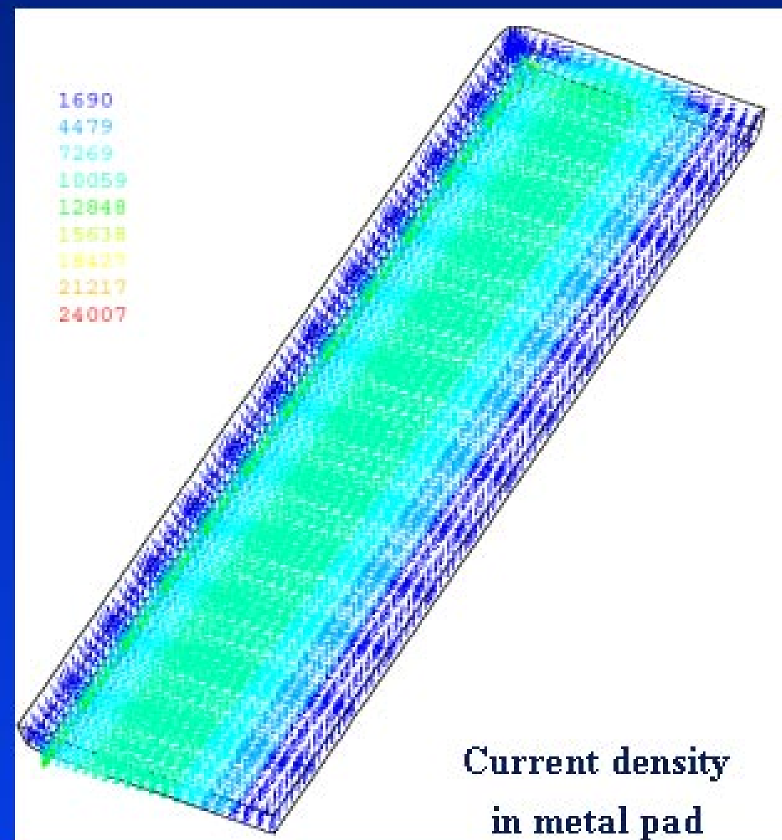


Isotherms



Current density in metal pad

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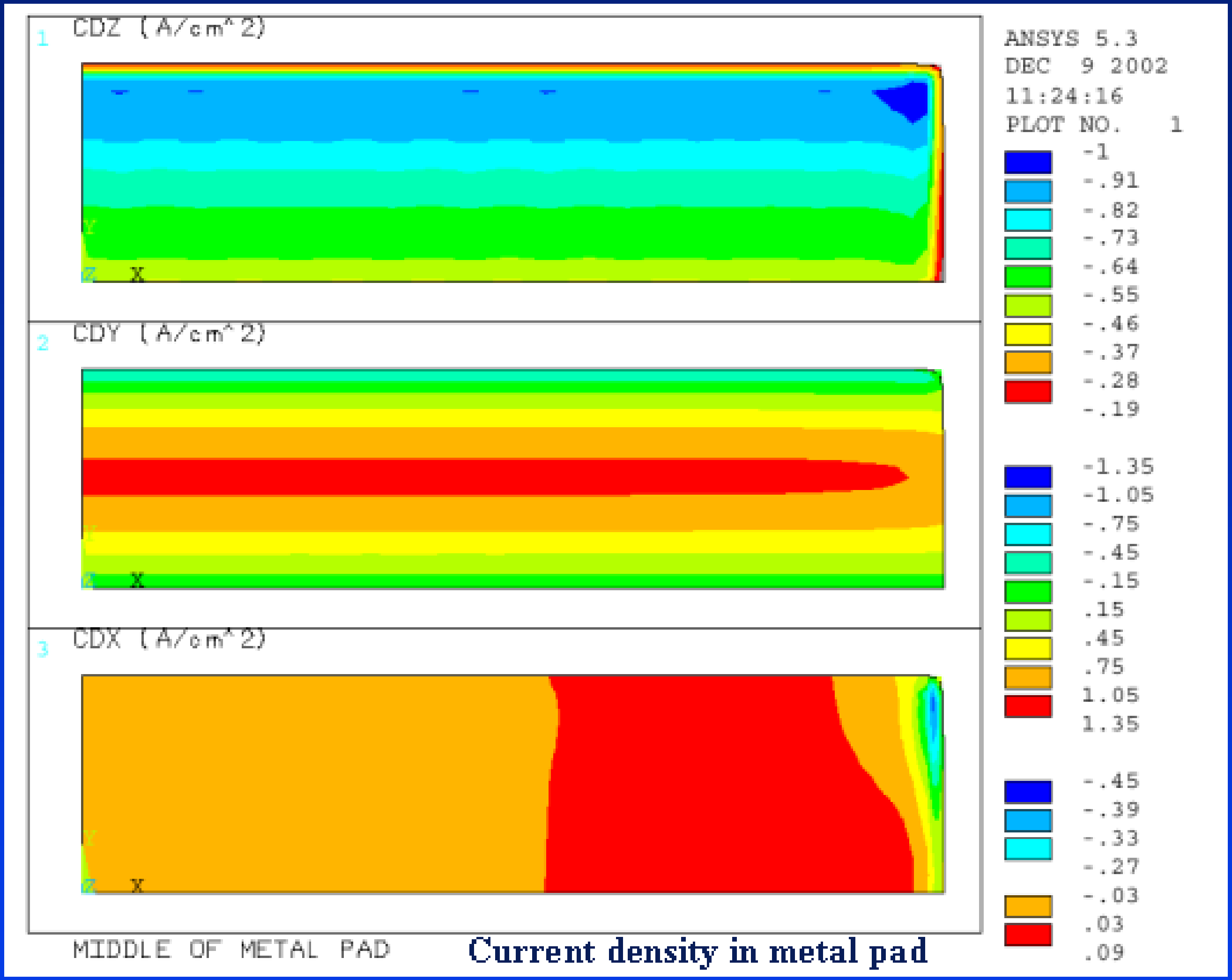
Thermo-Electric Design of a 500 kA Cell Using a Complete Full Cell Quarter Thermo-Electric Model



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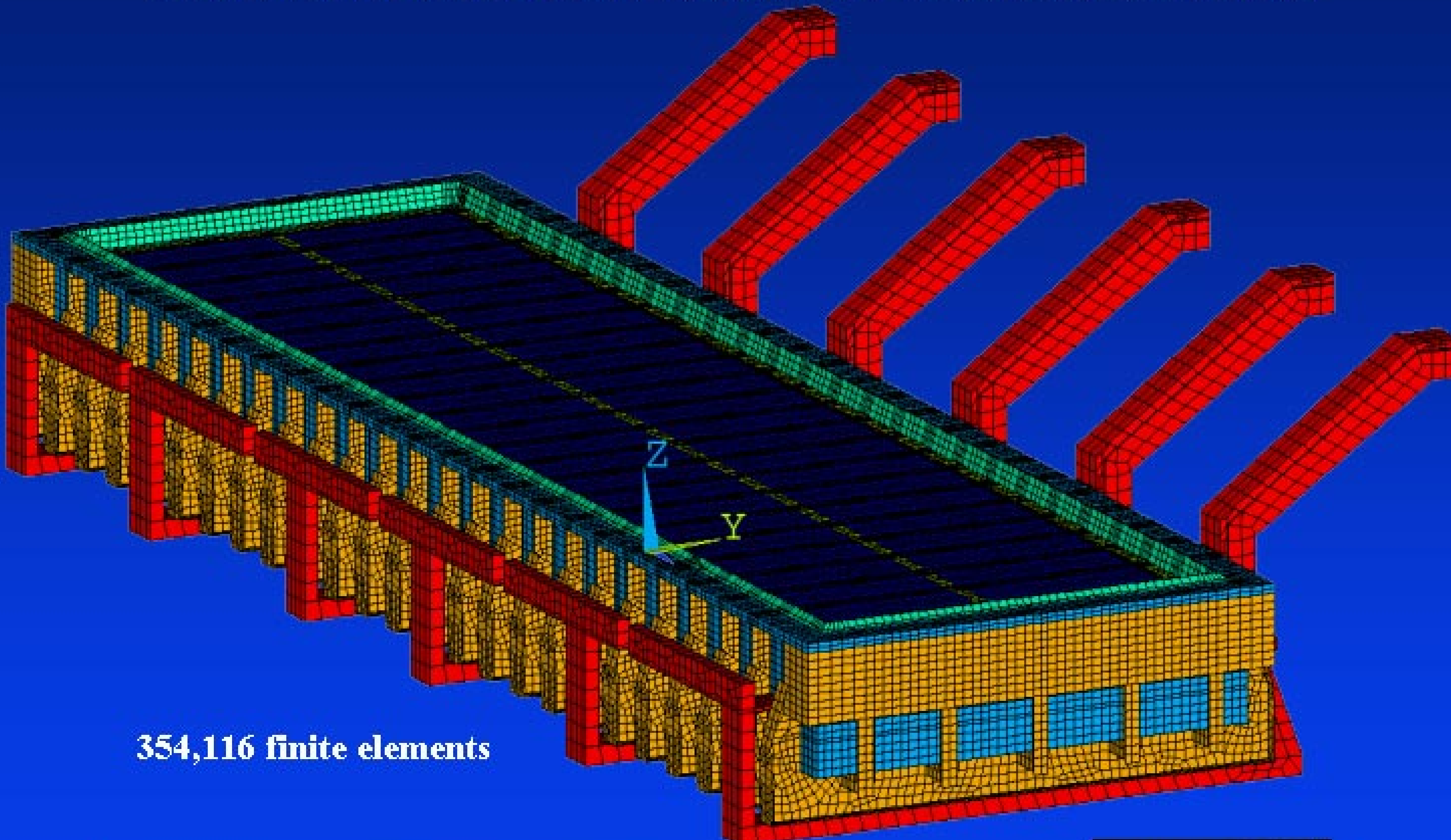
Thermo-Electric Design of a 500 kA Cell Using a Full Cell Cathode Thermo-Electric Model



354,116 finite elements

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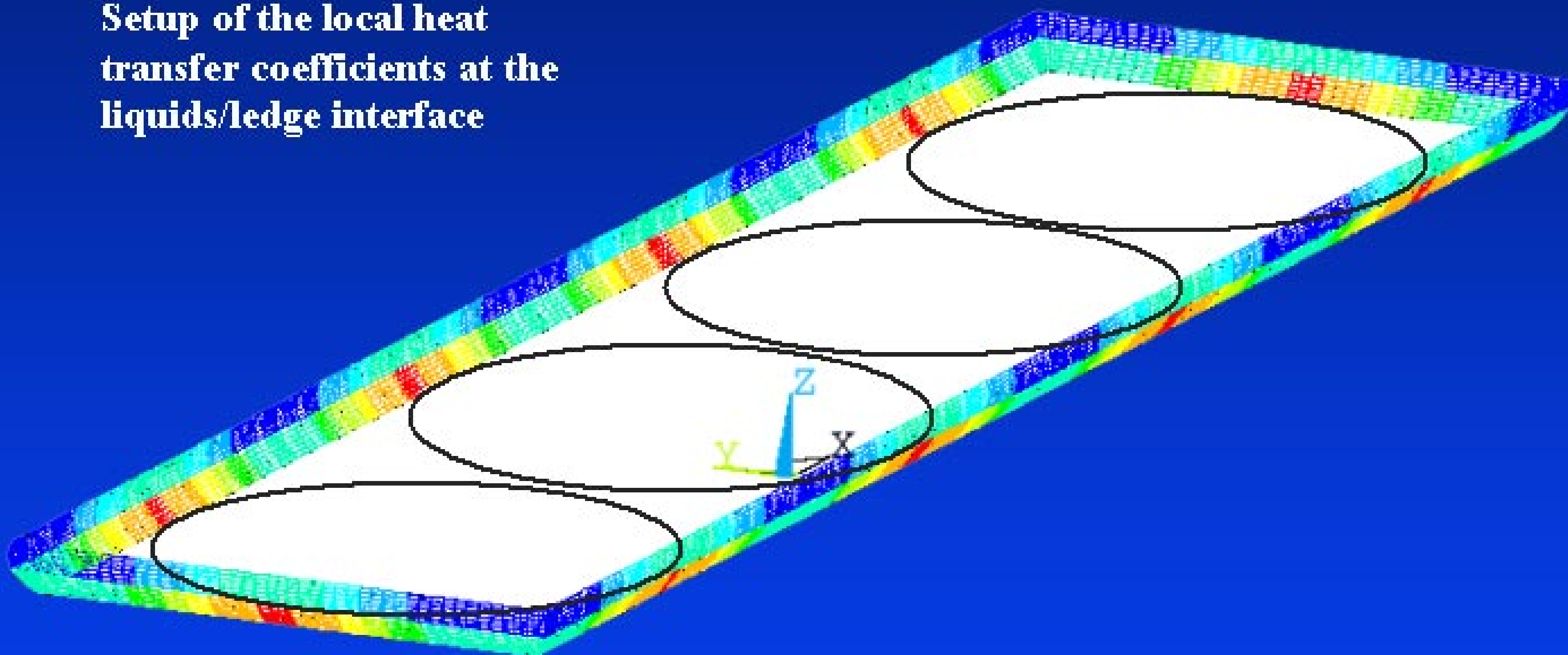
Thermo-Electric Design of a 500 kA Cell Using a Full Cell Cathode Thermo-Electric Model

Setup of the local heat transfer coefficients at the liquids/ledge interface



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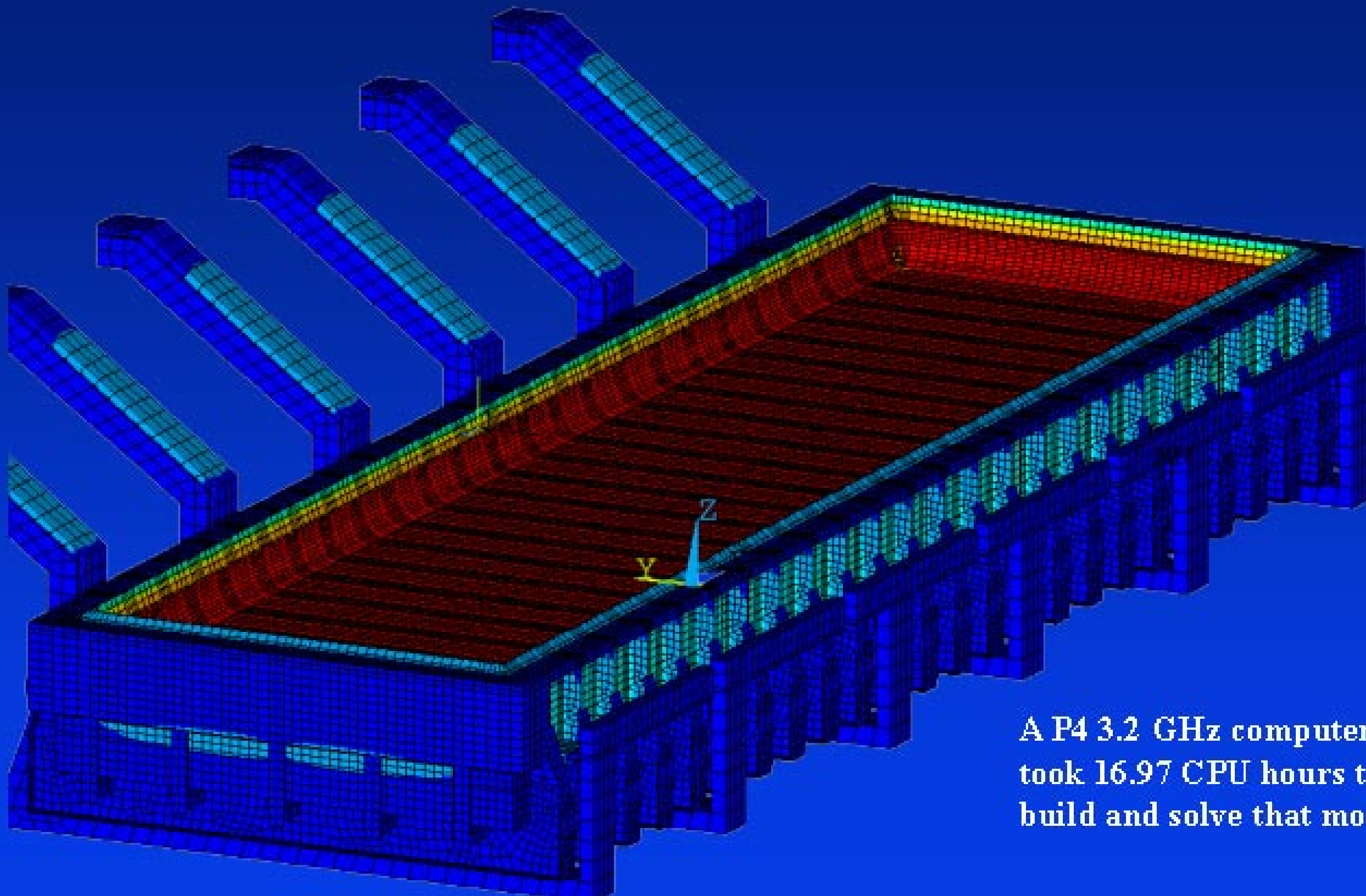
Thermo-Electric Design of a 500 kA Cell Using a Full Cell Cathode Thermo-Electric Model



A P4 3.2 GHz computer took 16.97 CPU hours to build and solve that model

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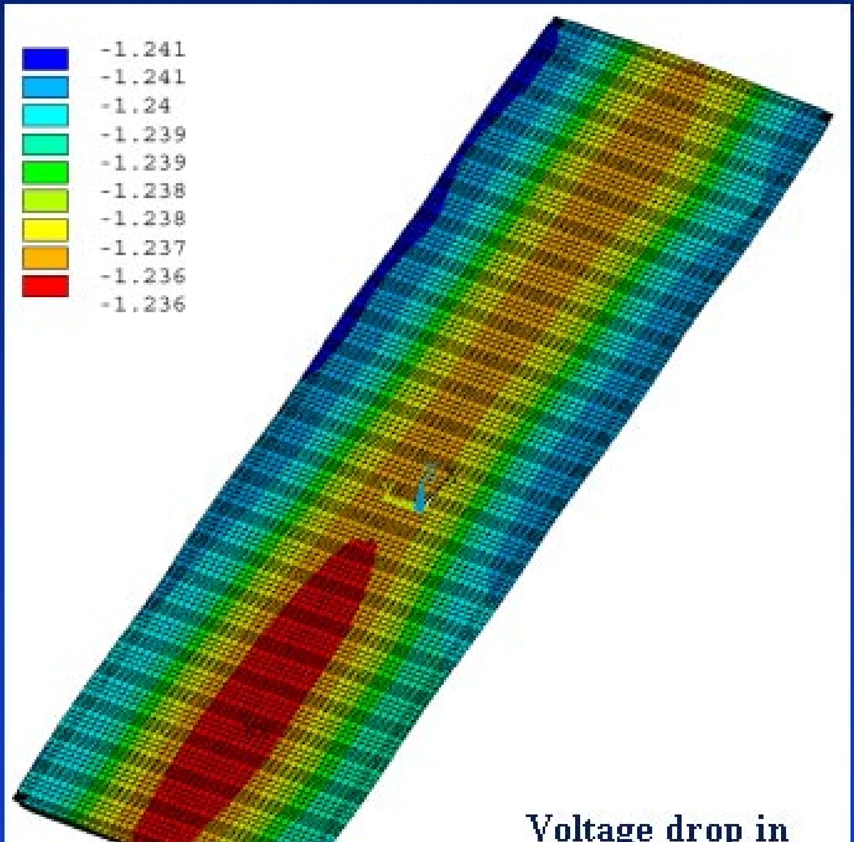
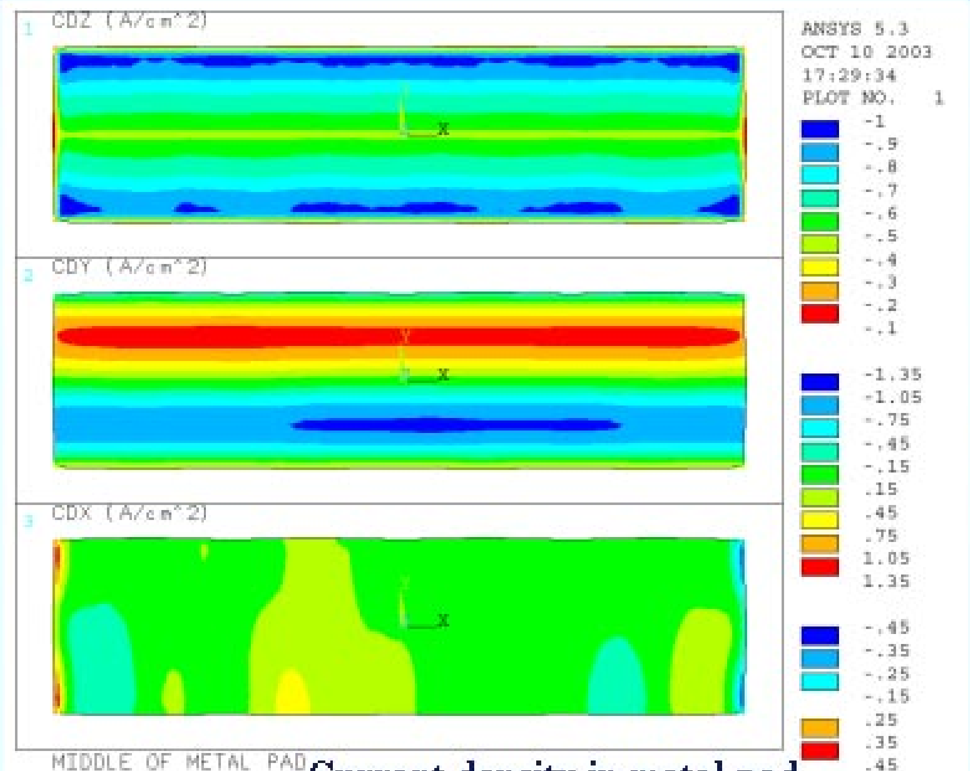
Thermo-Electric Design of a 500 kA Cell Using a Full Cell Cathode Thermo-Electric Model



Voltage drop in metal pad: 5 mV



Current density in metal pad

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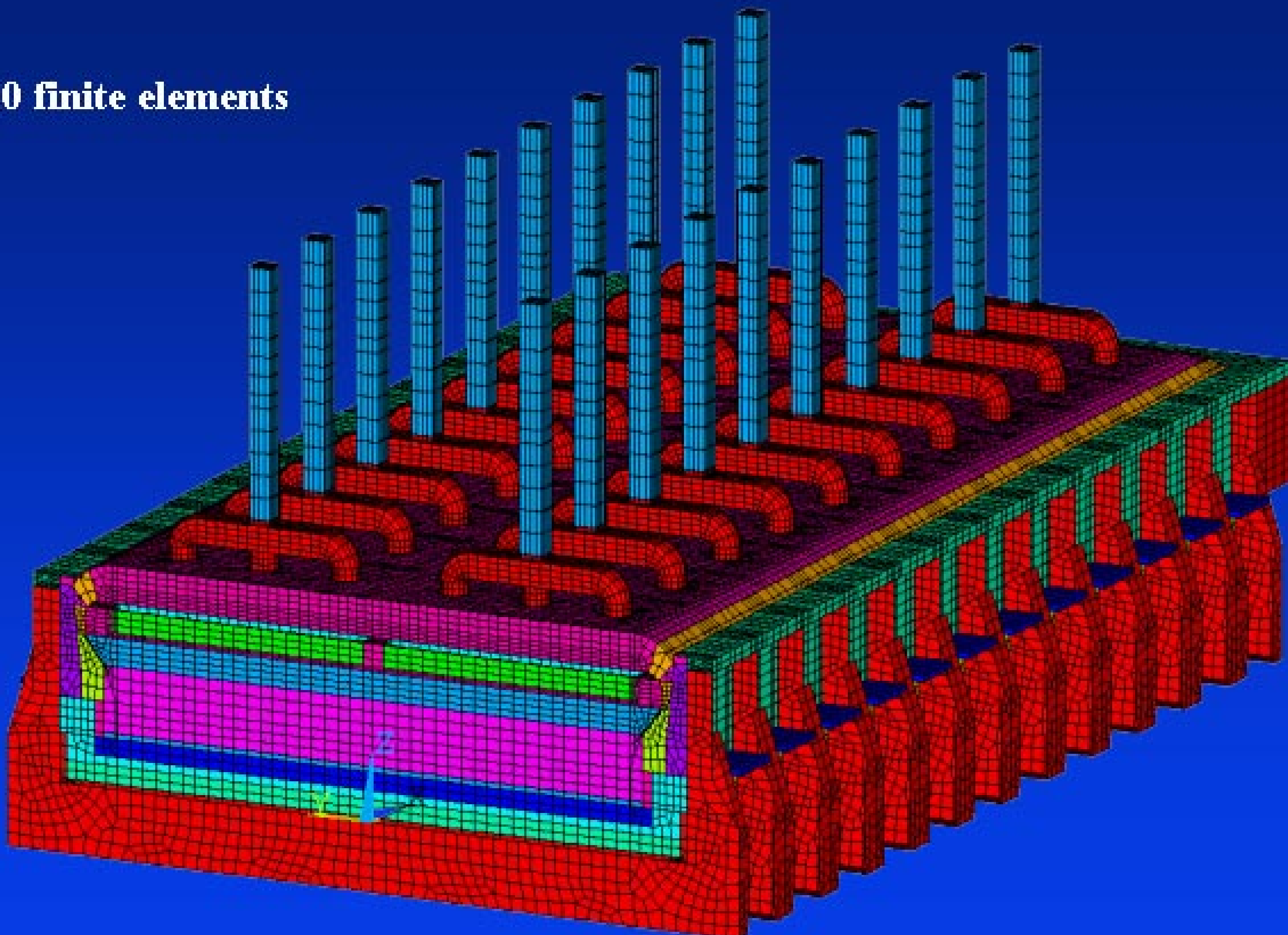
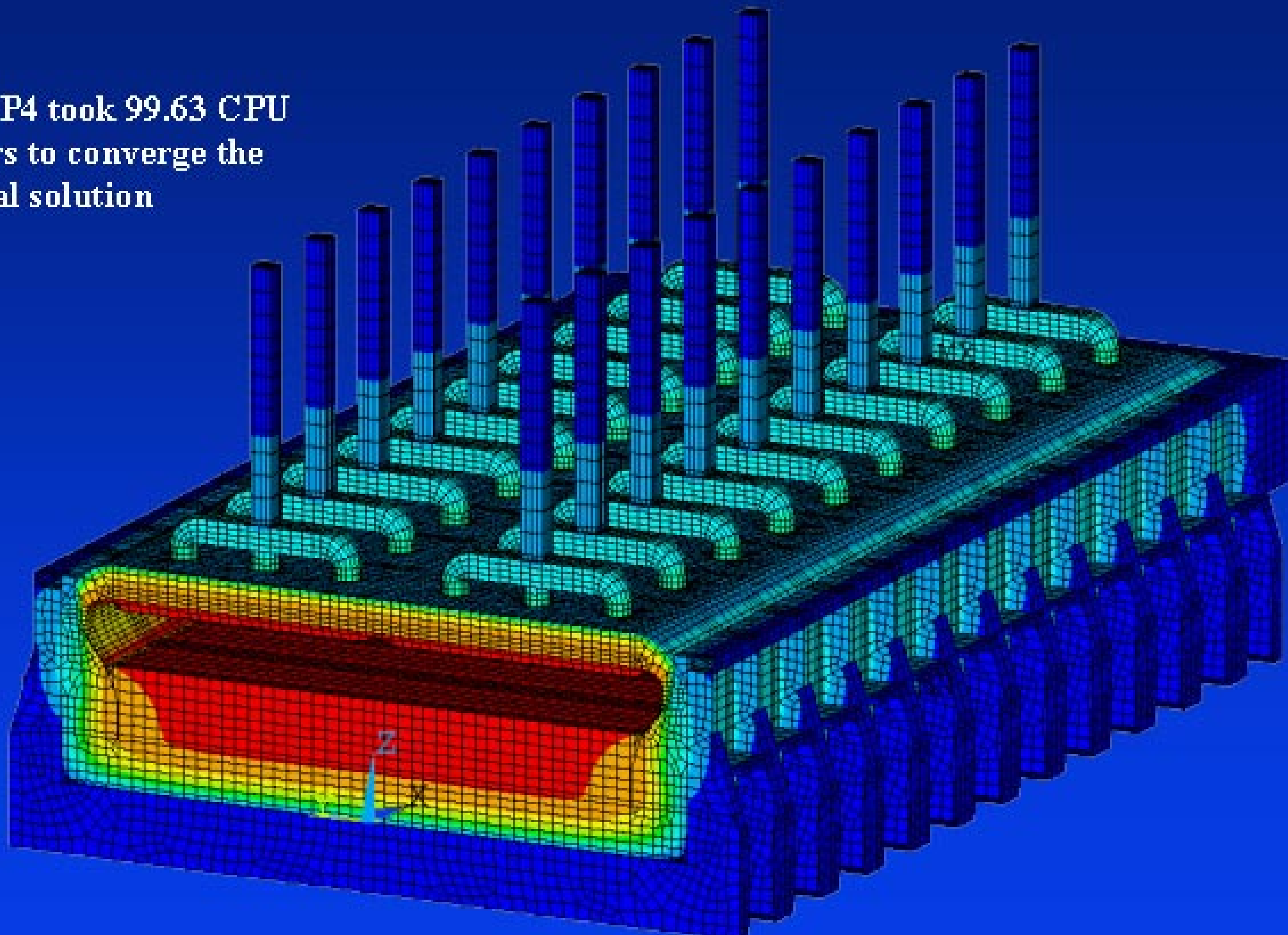
Thermo-Electric Design of a 500 kA Cell Using a Full Half Cell Thermo-Electric Model

290,410 finite elements



Thermo-Electric Design of a 500 kA Cell Using a Full Half Cell Thermo-Electric Model

The P4 took 99.63 CPU hours to converge the initial solution



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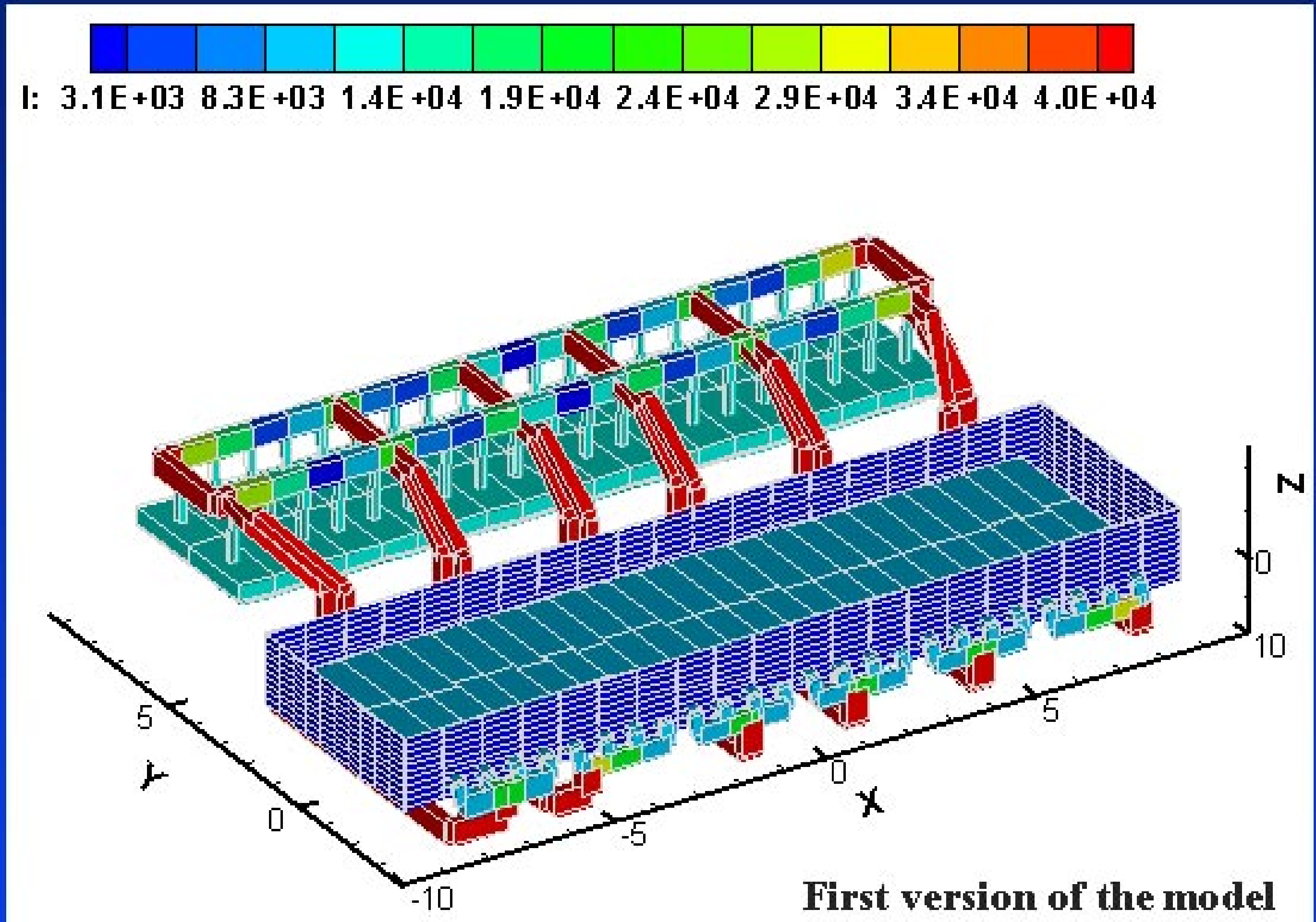
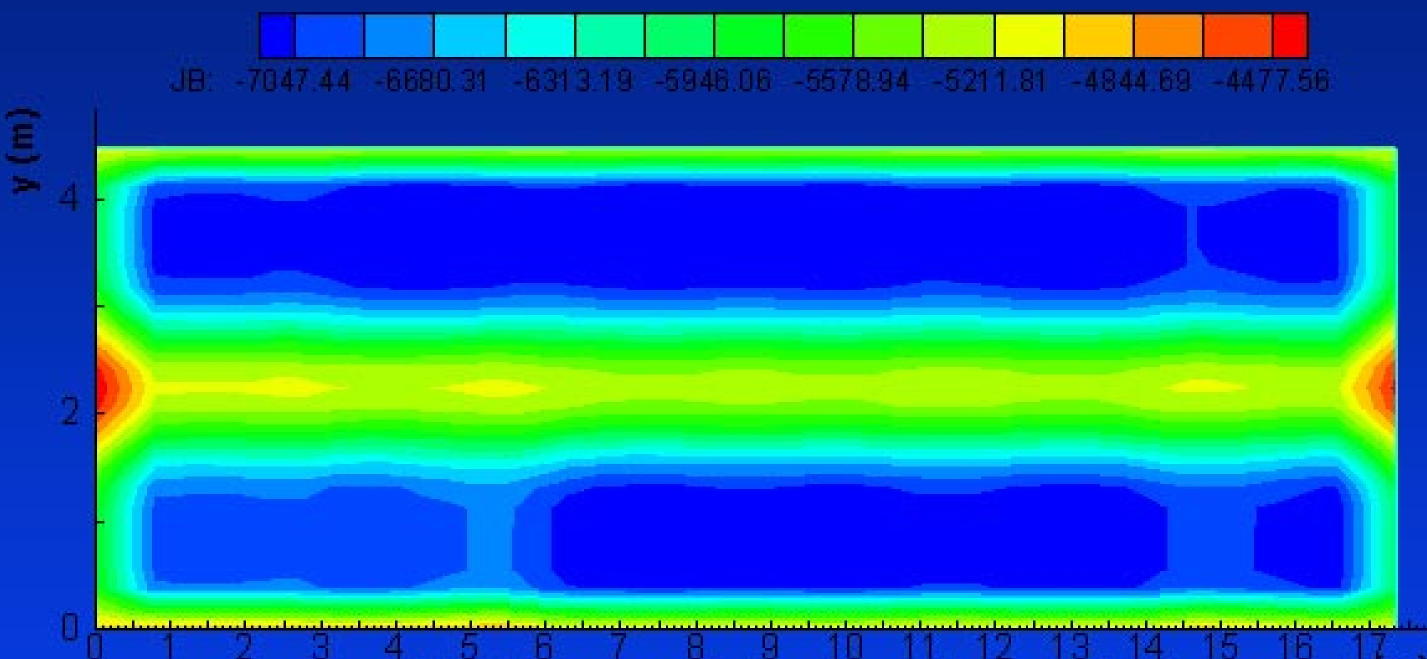
MHD Design of a 500 kA Cell Using Bojarevics' Cell Stability Model



First version of the model

MHD Design of a 500 kA Cell Using Bojarevics' Cell Stability Model



Electric current density at the cell bottom: J_z

First version of the model: current density

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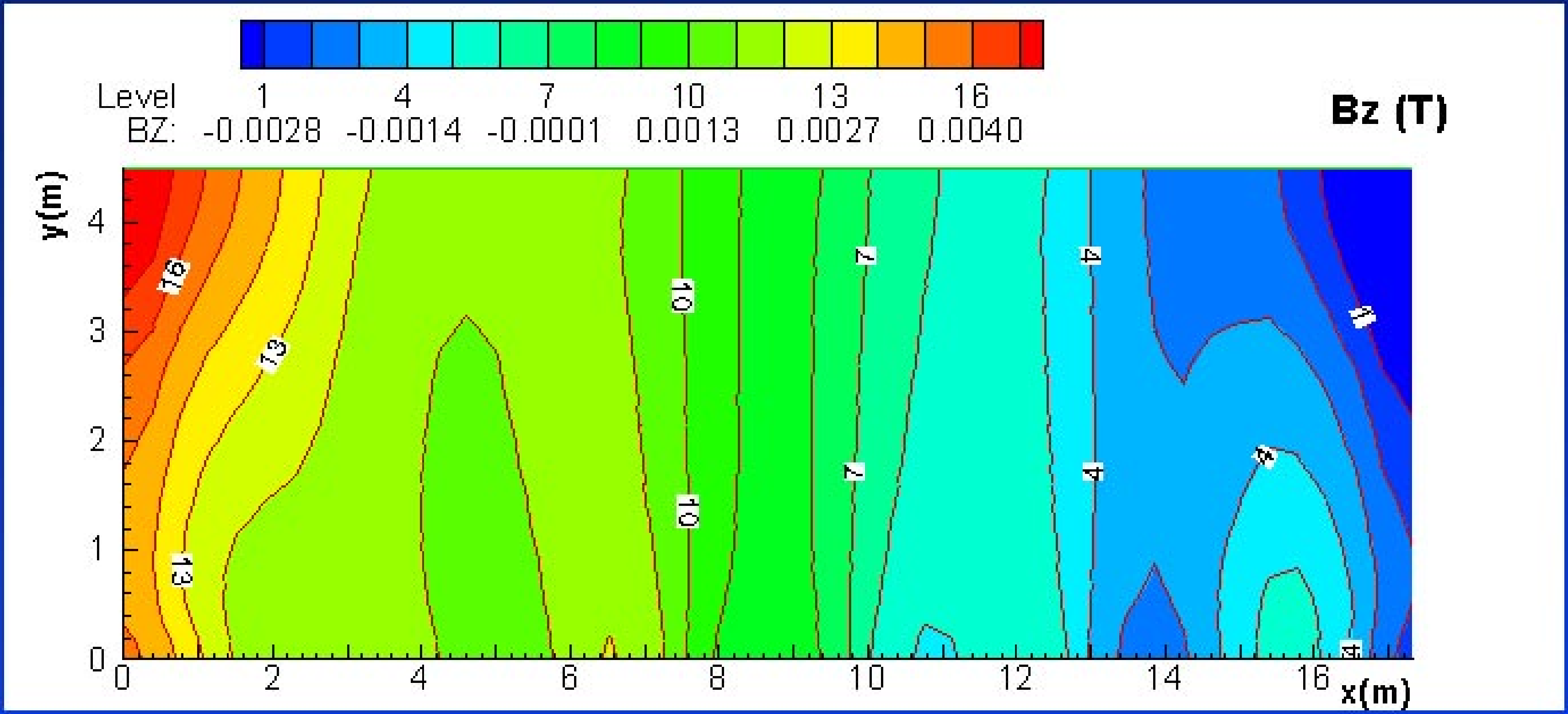
MHD Design of a 500 kA Cell Using Bojarevics' Cell Stability Model



First version of the model: magnetic field including shell shielding effect

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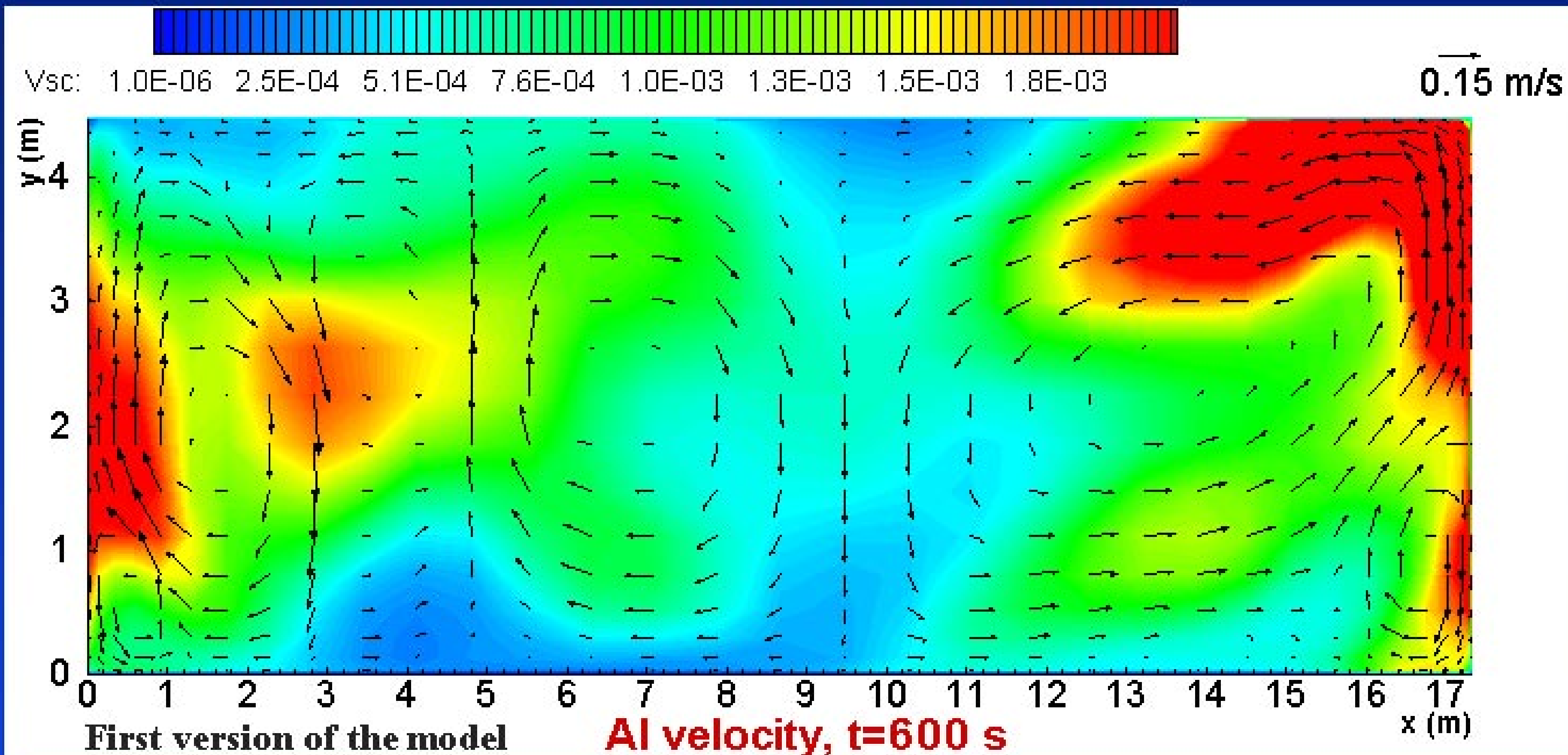
MHD Design of a 500 kA Cell Using Bojarevics' Cell Stability Model



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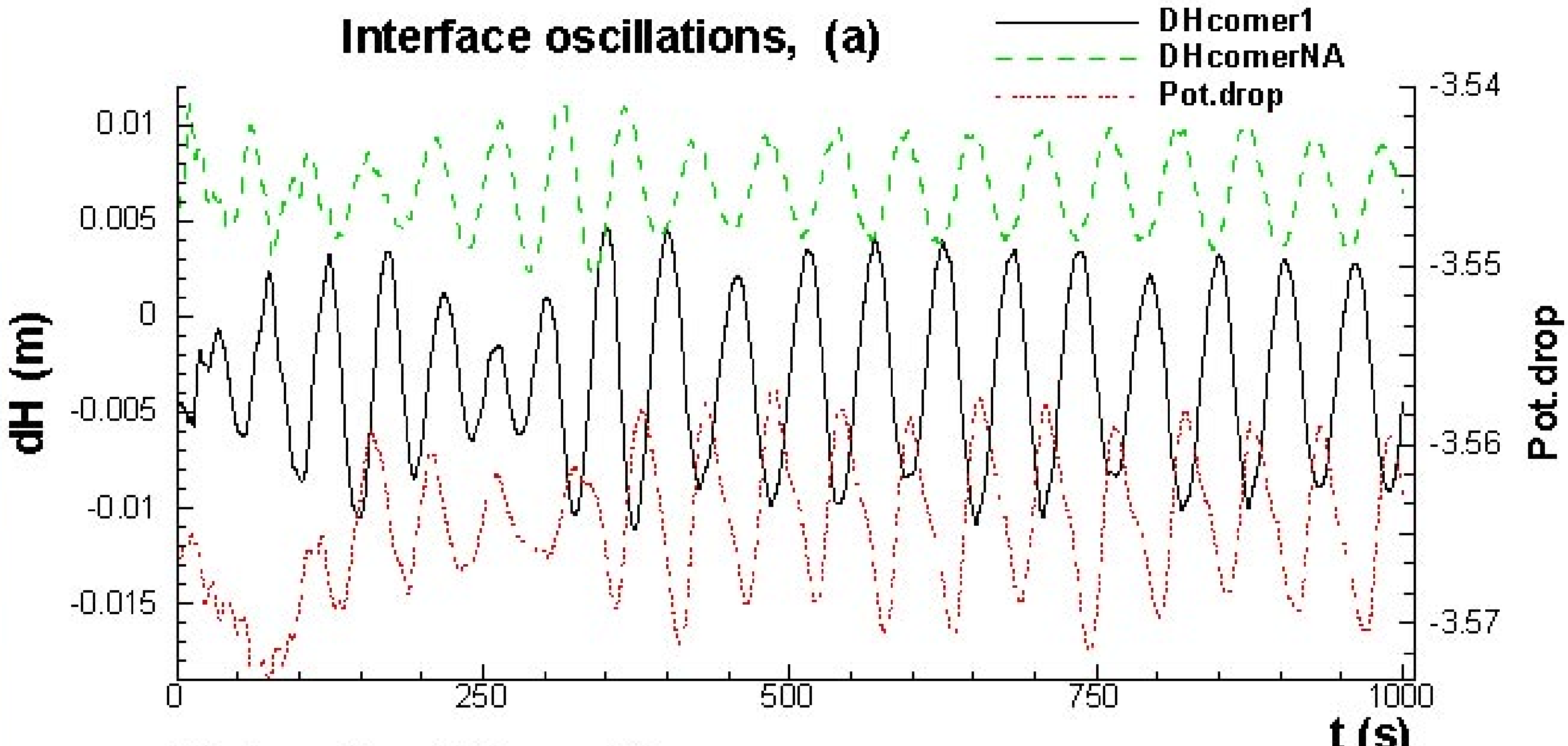
MHD Design of a 500 kA Cell Using Bojarevics' Cell Stability Model



First version of the model

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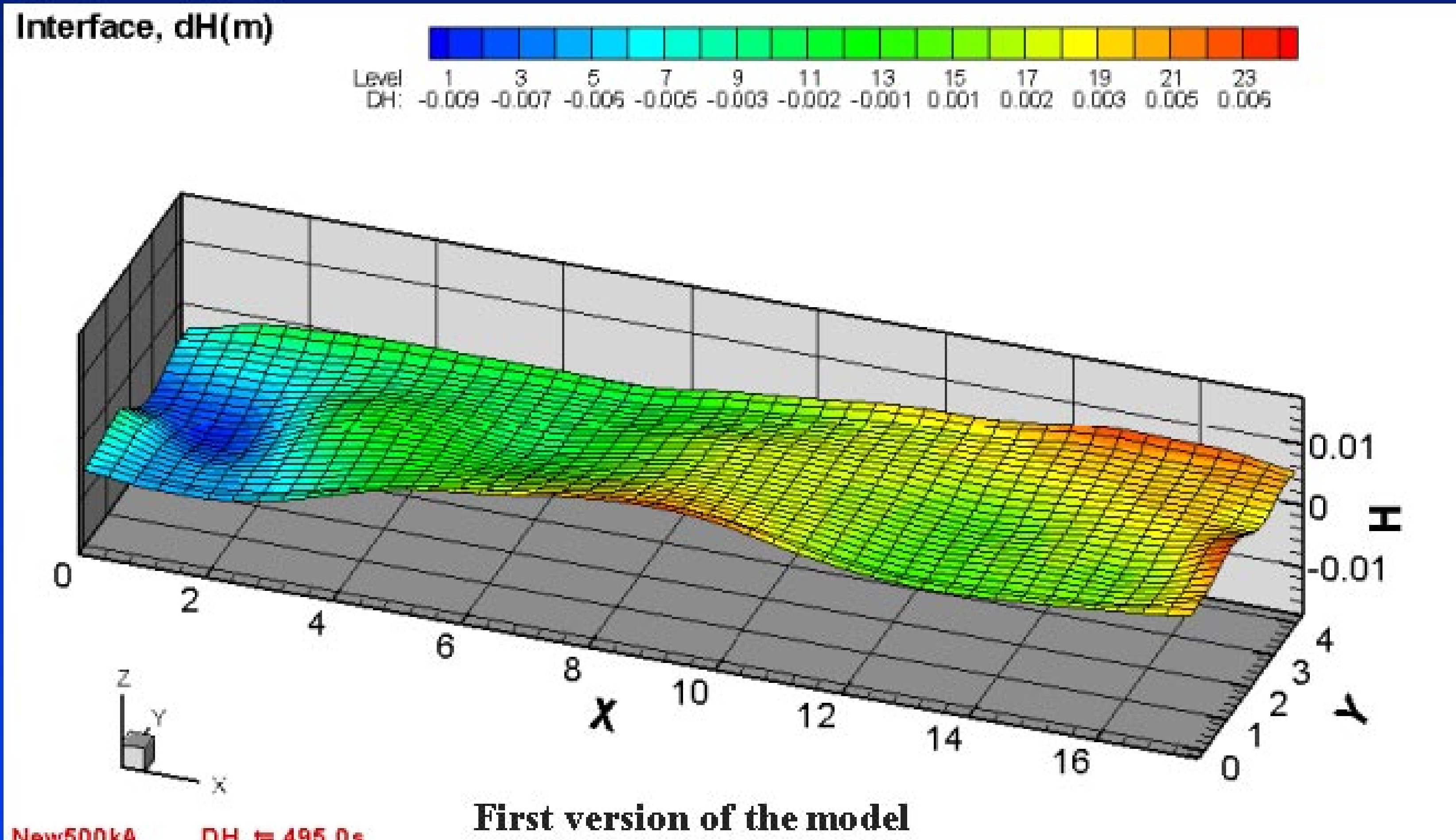
MHD Design of a 500 kA Cell Using Bojarevics' Cell Stability Model



First version of the model

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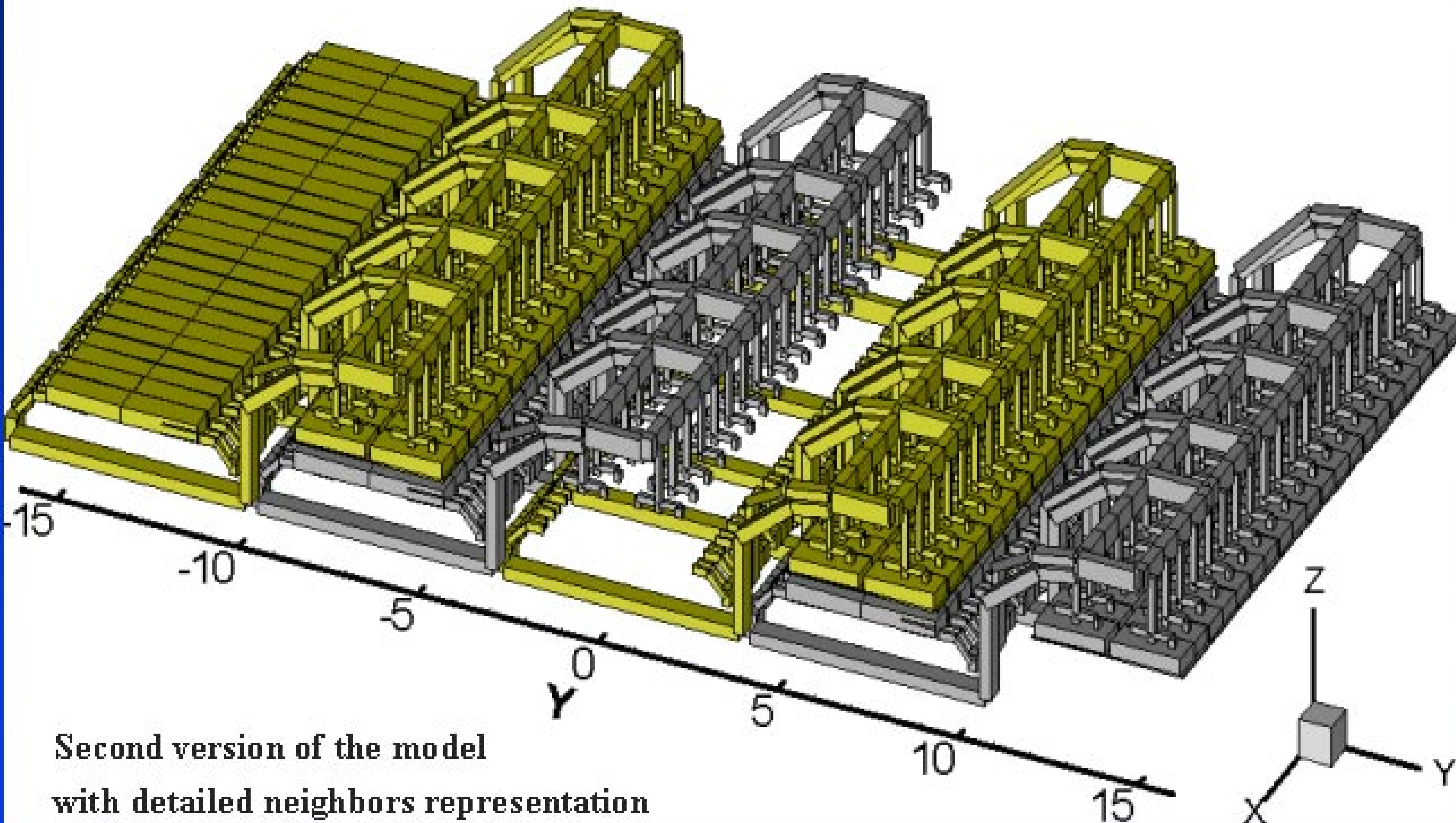
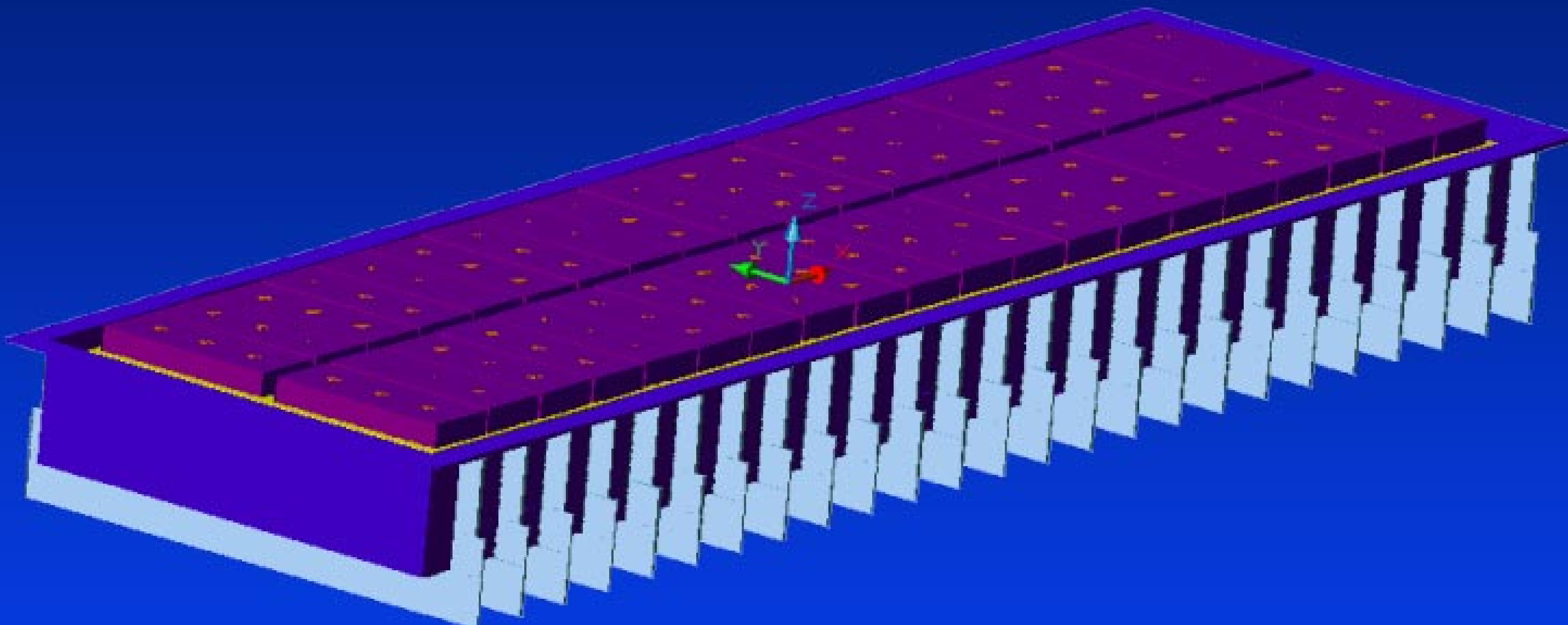


Second version of the model
with detailed neighbors representation

MHD Design of a 500 kA Cell Using Bojarevics' Cell Stability Model



Second version of the model with detailed shell representation

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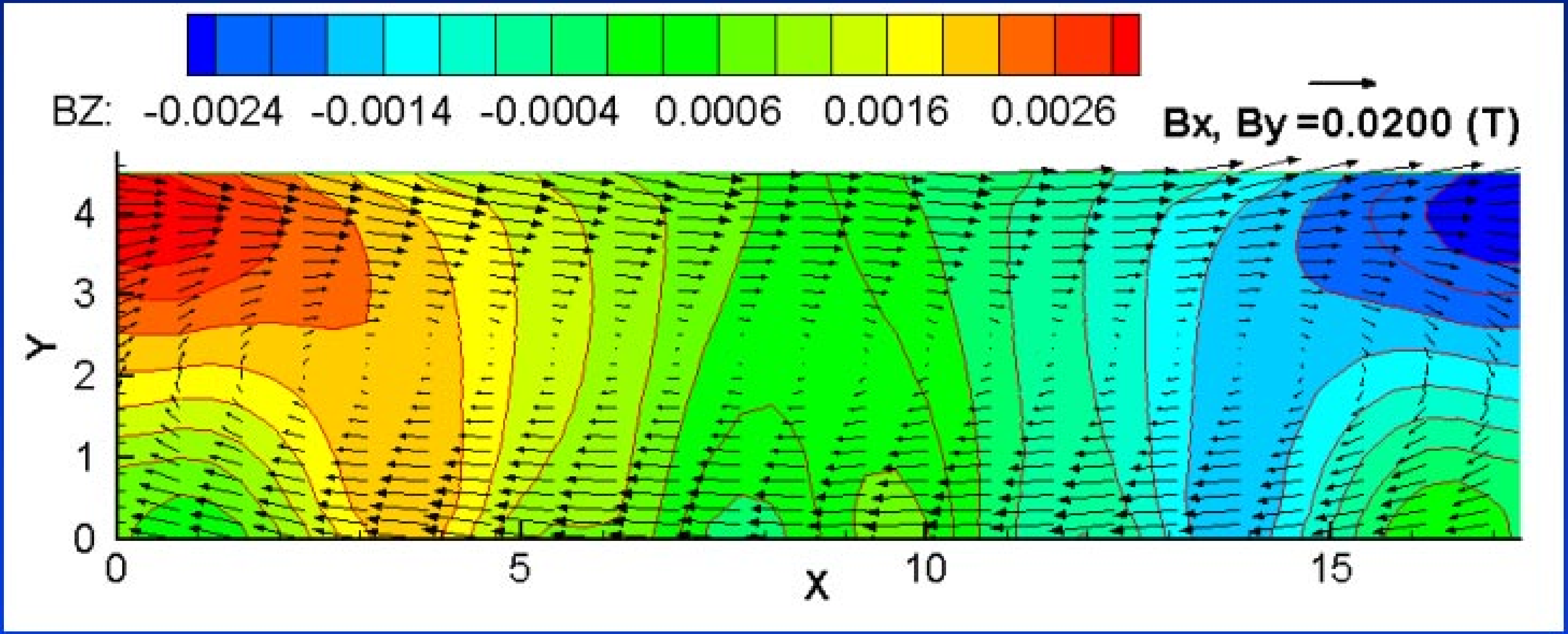
MHD Design of a 500 kA Cell Using Bojarevics' Cell Stability Model



Second version of the model: magnetic field including shell shielding effect

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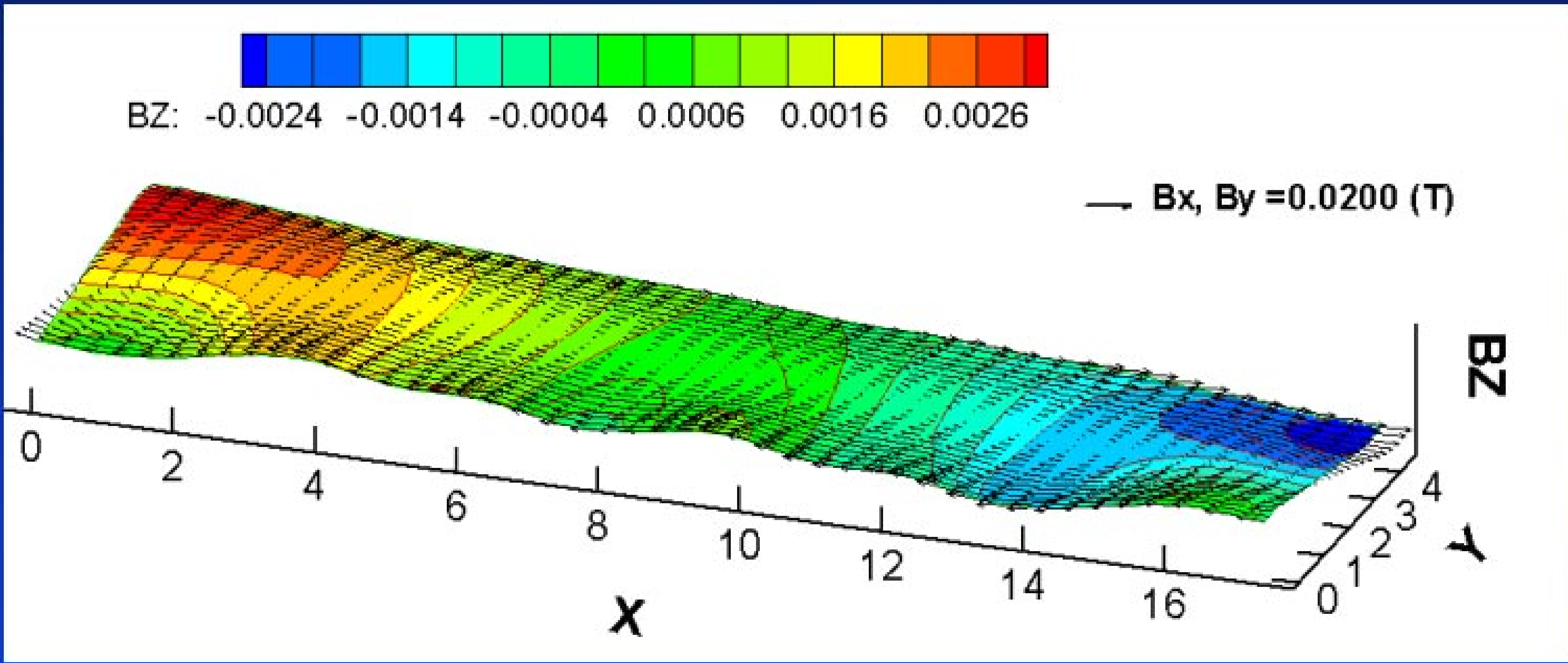
MHD Design of a 500 kA Cell Using Bojarevics' Cell Stability Model



Second version of the model: magnetic field including shell shielding effect

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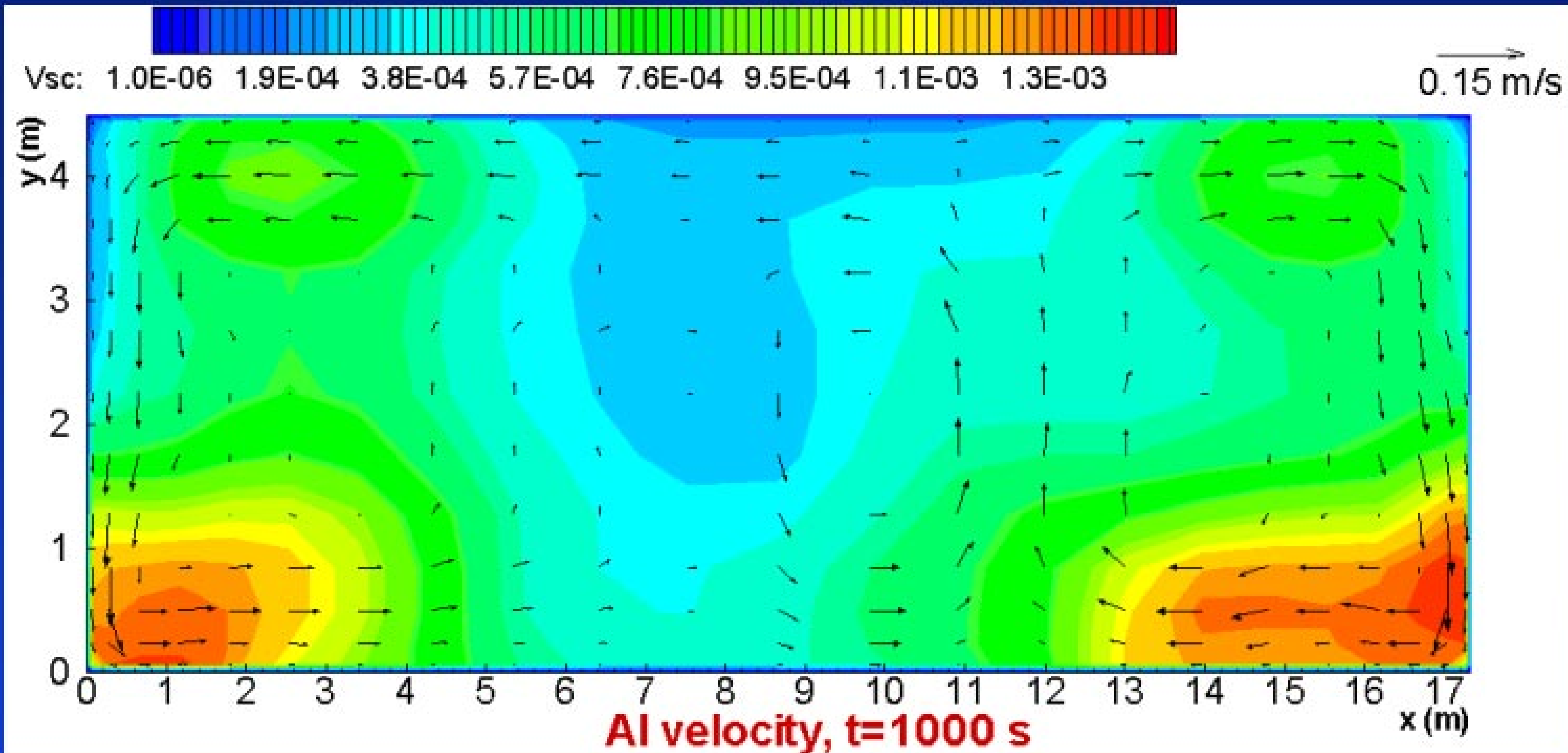
MHD Design of a 500 kA Cell Using Bojarevics' Cell Stability Model



Second version of the model: velocity in the metal pad

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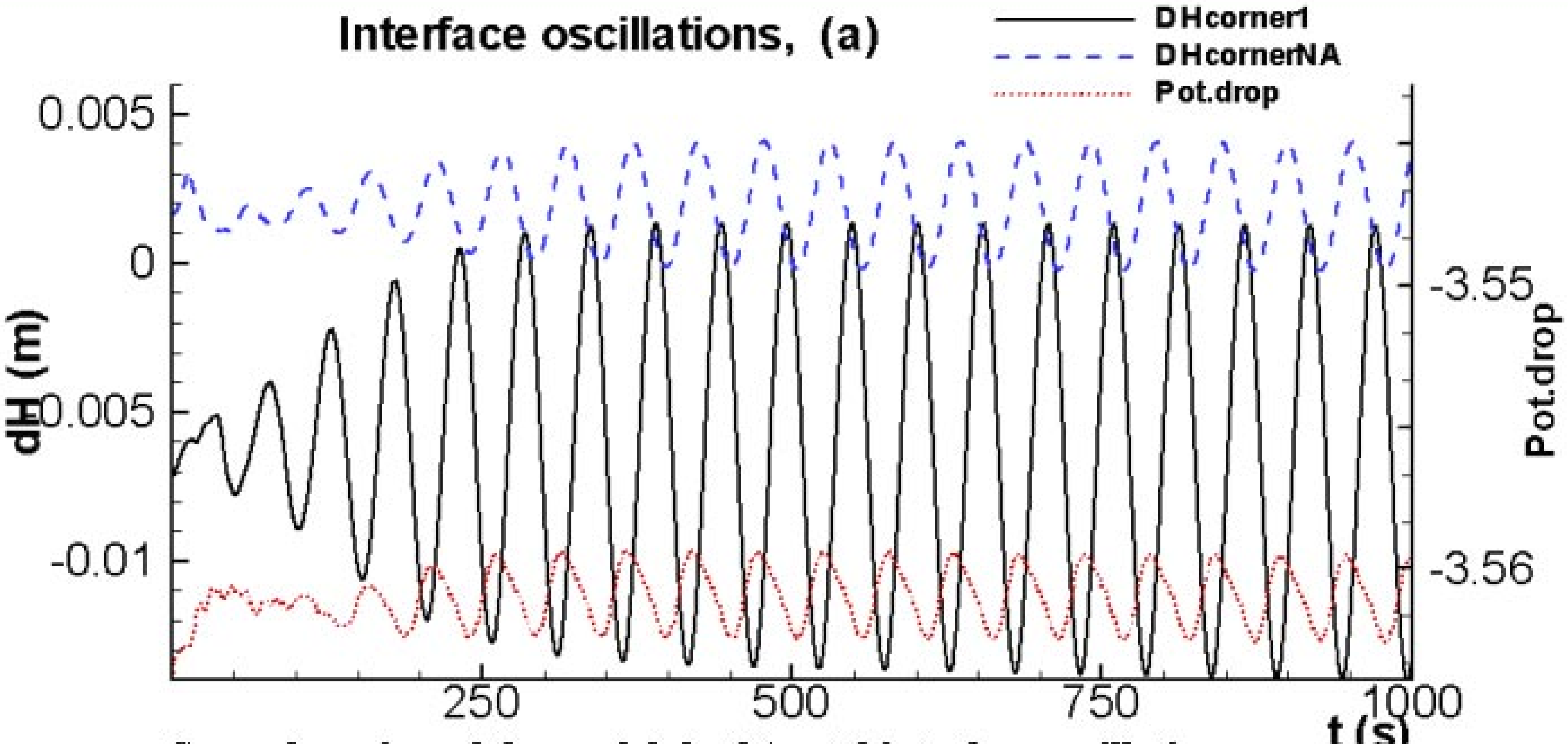
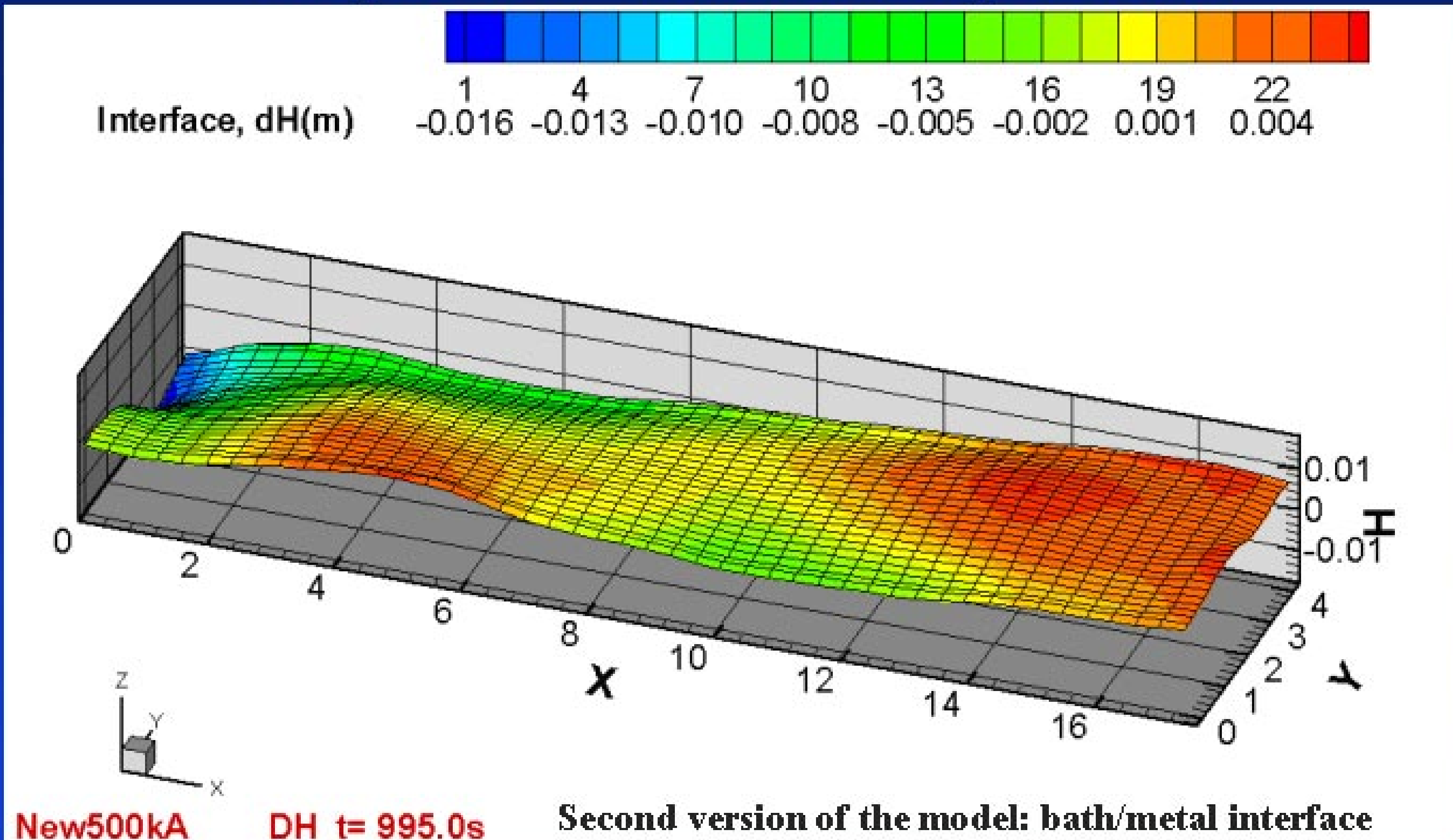
MHD Design of a 500 kA Cell Using Bojarevics' Cell Stability Model



Second version of the model: bath/metal interface oscillations

MHD Design of a 500 kA Cell Using Bojarevics' Cell Stability Model



Second version of the model: bath/metal interface

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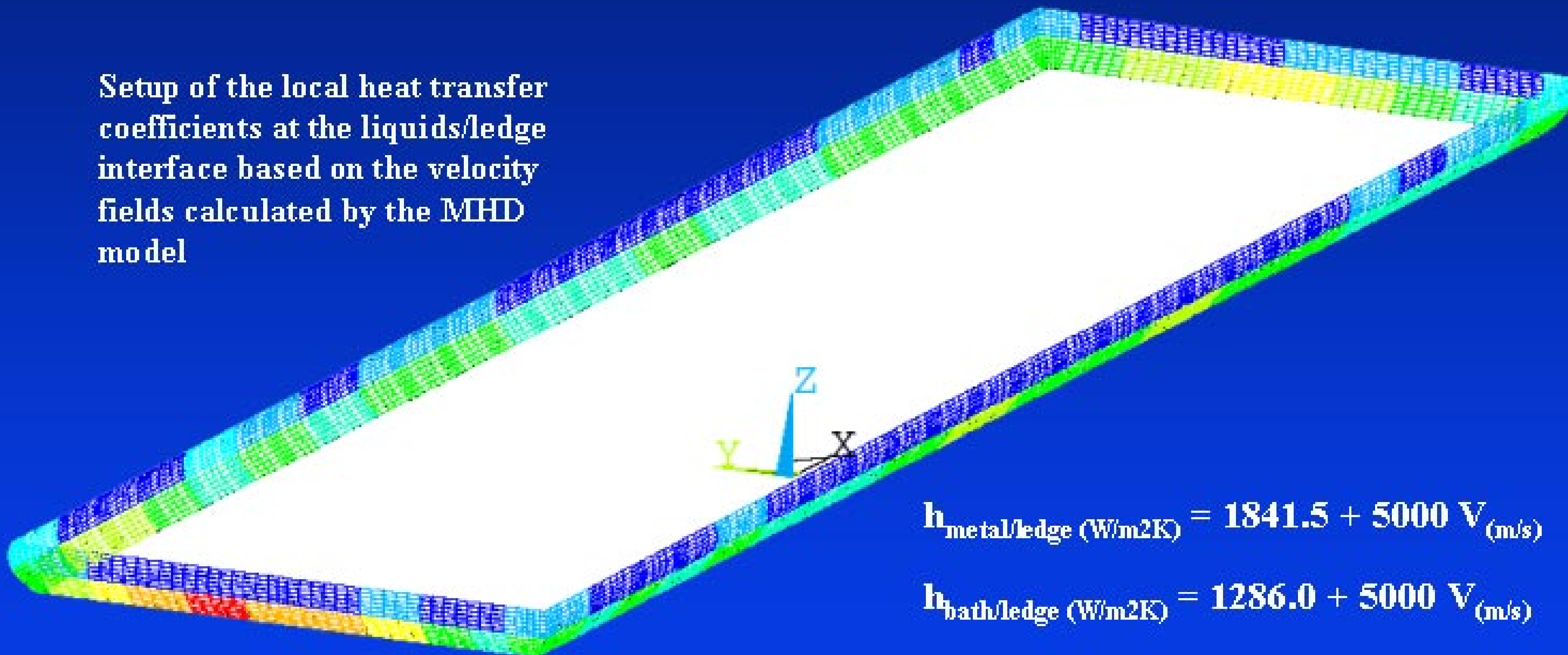
Thermo-Electric Design of a 500 kA Cell Using a Full Cell Cathode Thermo-Electric Model First Interaction Trial Between Models

Setup of the local heat transfer coefficients at the liquids/ledge interface based on the velocity fields calculated by the MHD model



$$h_{metal/ledge\ (W/m2K)} = 1841.5 + 5000\ V_{(m/s)}$$

$$h_{bath/ledge\ (W/m2K)} = 1286.0 + 5000\ V_{(m/s)}$$

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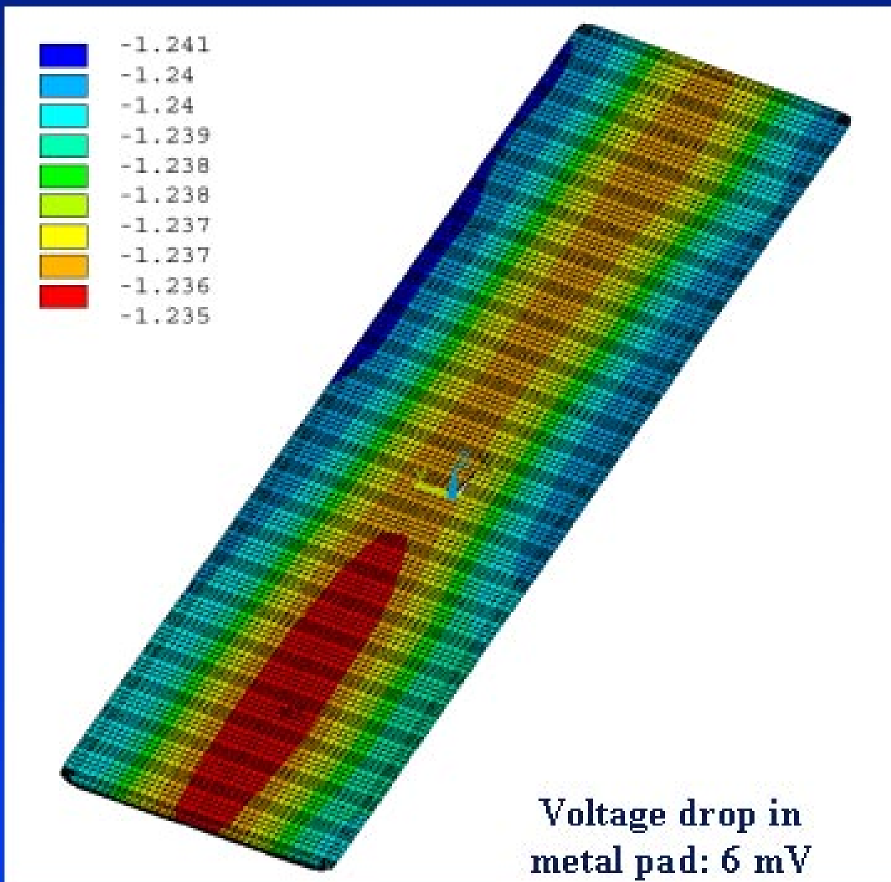
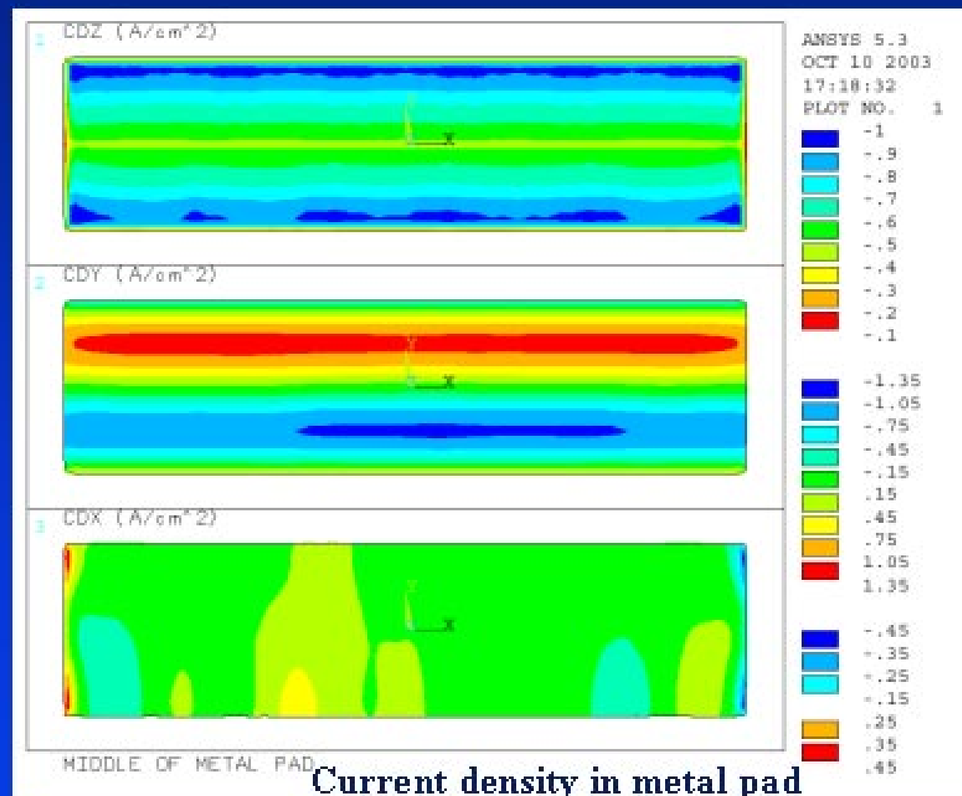
Thermo-Electric Design of a 500 kA Cell Using a Full Cell Cathode Thermo-Electric Model First Interaction Trial Between Models



Voltage drop in metal pad: 6 mV



Current density in metal pad

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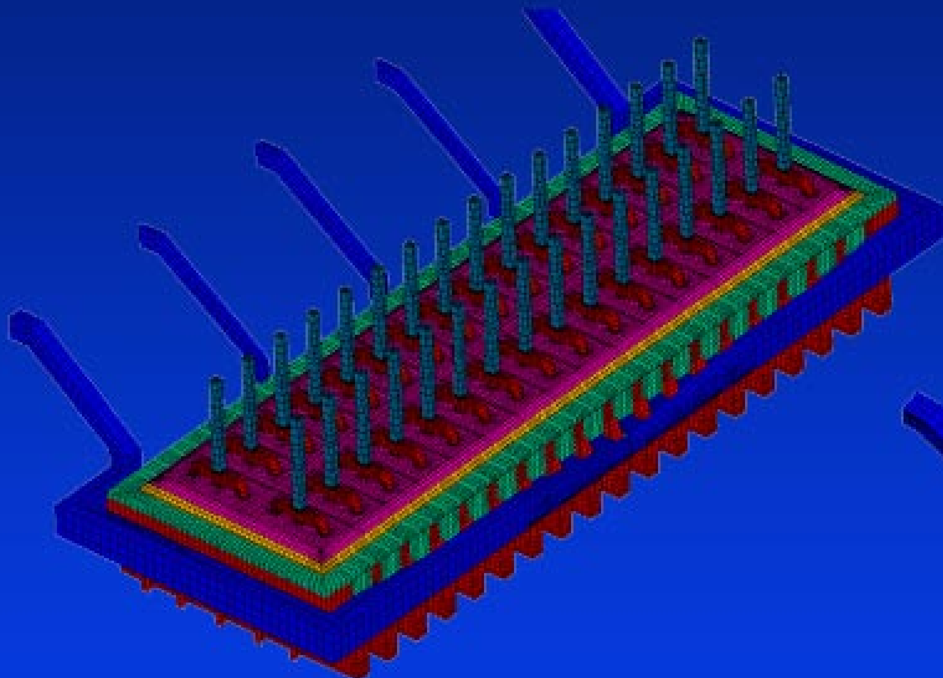
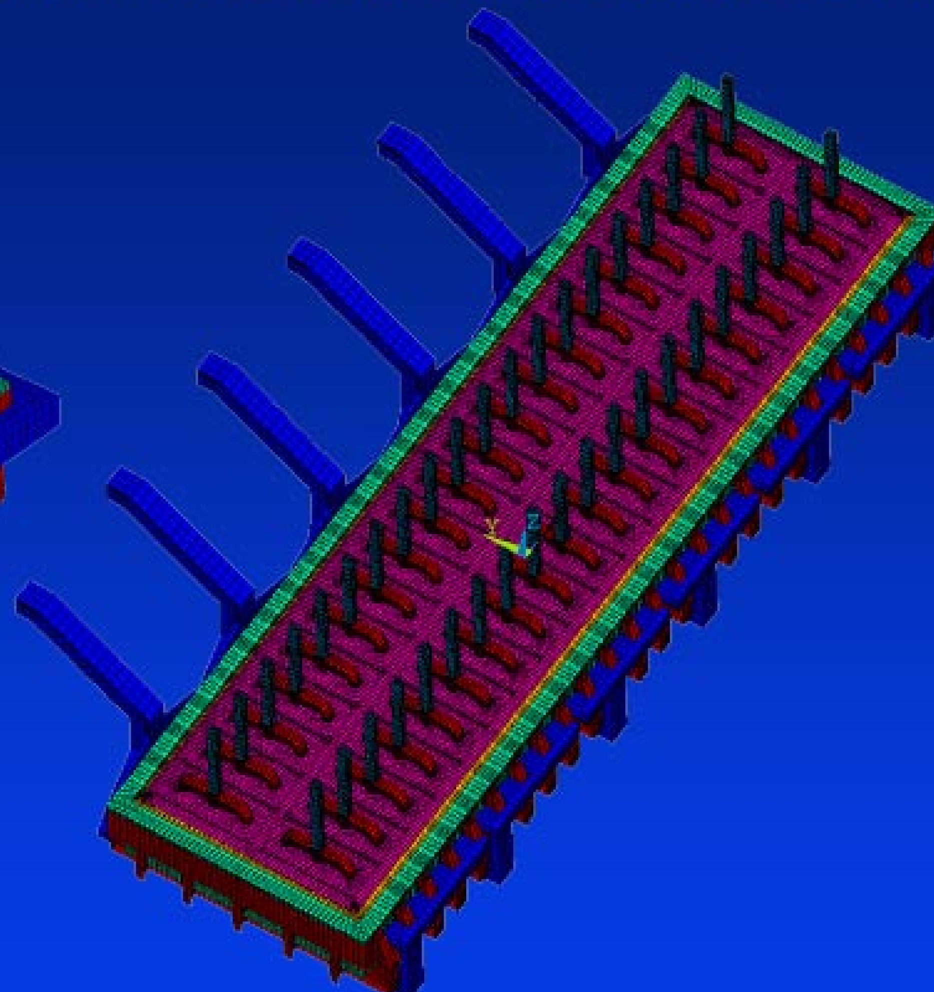
Full Cell + External Busbar Thermo-Electric Model



The 300 kA model has 423,296 elements



The 500 kA model has 585,016 elements

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Conclusions

- State of the art 3D thermo-electric and MHD models have been successfully used to produce a demonstration design of a 500 kA Al electrolysis cell.
- The MHD model has been improved to better represent the shielding effect of the potshell.
- A 3D full cell cathode and external bus-bar thermo-electric model was developed and successfully used in interaction with the MHD model to converge the ledge profile all along the cell perimeter. The ledge profile convergence calculations took 32 CPU hours on a P4 3.2 GHz computer.
- A 3D full cell and external bus-bar thermo-electric model could not be used to do the same.

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