

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

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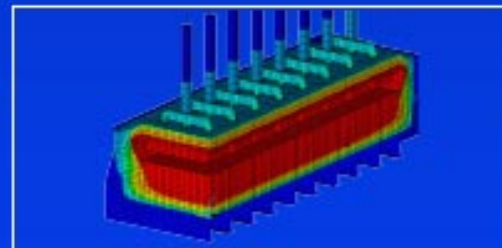
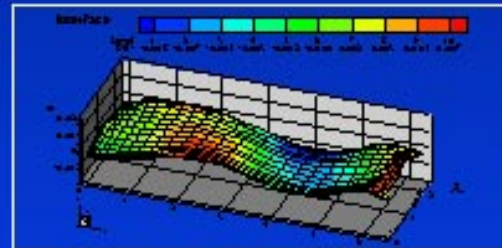
Plan of the Presentation

- **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**

Modeling the Hall-Héroult Cell

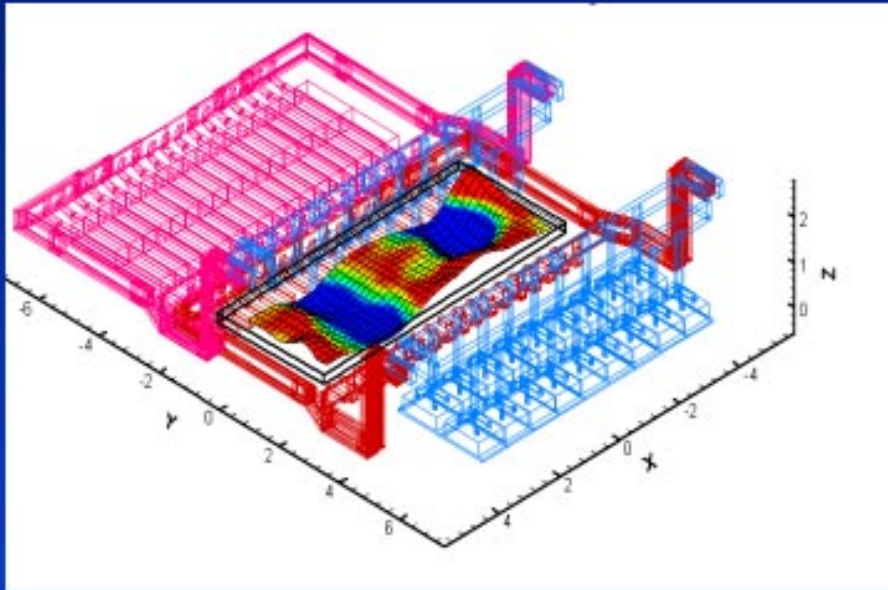
Currently, we can fit Hall-Héroult mathematical models into three broad categories:

- 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.

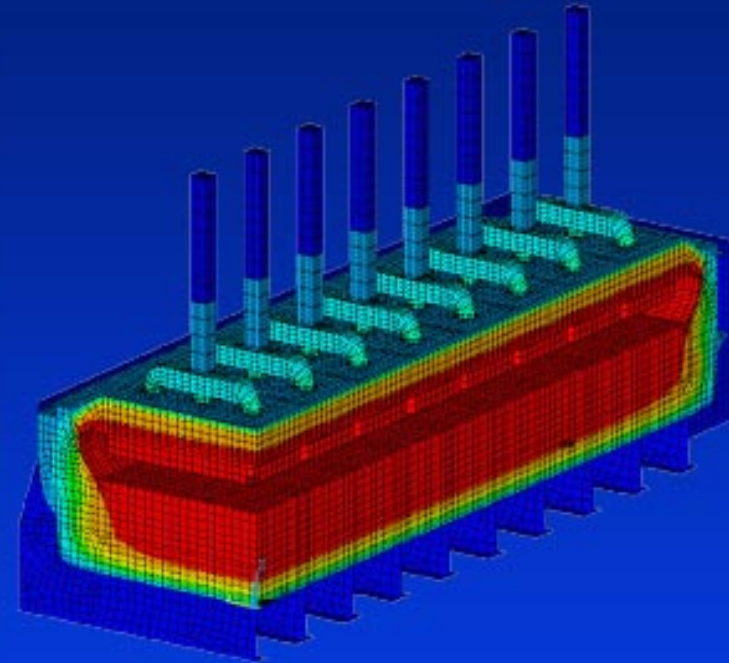


Cell
Design

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

Dyna/MARC 1.7 - [YAW016]

File Process Controller Operator Run List Windows Language Help

Demo example of a prebaked PBF cell inspired from VAN's JOM paper
liquidus superheat, 4 cm ACD, 1.95m anode length, 13.5% AlF₃, 500 kA
HC10 4.17m cathode block, top 10cm bottom 16.5 cm SiC side block
10 cm cover over anodes, 17.5 cm stud diameter, 4 studs per anode
40 anodes, 24 cathode blocks, 17.8 m X 4.85 m inside potshell

Date Created : 8/2/1999 Last Modified : 9/15/2002

Steady State Solution

Parameter	Value	Unit
Cell amperage	500.0	[kA]
Anode to cathode distance	4.00000	[cm]
Operating temperature	963.366	[C]
Ledge thickness, bath level	4.44079	[cm]
Ledge thickness, metal level	0.16550	[cm]
Anode beam position	0.0000	[cm]
Mass of metal	33763.7	[kg]
Mass of bath	11020.16	[kg]
Mass of dissolved alumina	275.504	[kg]
Mass of dispersed alumina	79.390	[kg]
Mass of alumina sludge	2.5966	[kg]
Mass of dissolved aluminum fluoride	1487.722	[kg]
Mass of dispersed aluminum fluoride	1.015	[kg]
Mass of aluminum fluoride sludge	0.0003	[kg]
Mass of calcium fluoride	330.605	[kg]
Mass of lithium fluoride	0.000	[kg]
Mass of magnesium fluoride	0.000	[kg]
Alumina feeding rate	310.010	[kg/hr]
Aluminum fluoride feeding rate	3.07019	[kg/hr]
Target cell resistance	5.31696	[micro-ohm]

Steady State derived Variables

Parameter	Value	Unit
Rate of change of:		
ACD	-0.02224	[cm/hr]
Operating temperature	0.0000	[C/hr]
Ledge thickness, bath level	0.000	[cm/hr]
Ledge thickness, metal level	0.000	[cm/hr]
Mass of dispersed Al ₂ O ₃	0.000	[kg/hr]

List of Design Variables

Design Variable	Design Value	Set as Target
Anode to Cathode Distance	4	<input type="radio"/>
Cell Amperage	500	<input type="radio"/>
Conc. of Excess Aluminum Fluoride	13.5	<input type="radio"/>
Concentration of Dissolved Alumina	2.5	<input type="radio"/>
Concentration of Calcium Fluoride	3	<input type="radio"/>
Concentration of Lithium Fluoride	0	<input type="radio"/>
Conc. of Magnesium Fluoride	0	<input type="radio"/>
Bath Level	20	<input type="radio"/>
Bath Ledge Heat Transfer Coef.	1425	<input type="radio"/>
Metal Ledge Heat Transfer Coef.	2052	<input type="radio"/>
Metal Level	20	<input type="radio"/>
Anode Length	1.95	<input type="radio"/>
Cavity Length	17.40	<input type="radio"/>
Anode Panel Heat Loss	303.971840	<input type="radio"/> Advanced
Cathode Bottom Heat Loss	237.657447	<input type="radio"/> Advanced
Cell Operating Temperature	963.365699	<input checked="" type="radio"/>
Anode Voltage Drop	319.513746	<input type="radio"/> Advanced
Cathode Voltage Drop	311.865934	<input type="radio"/> Advanced
Anode Width	0.8	<input type="radio"/>
Cavity Width	4.95	<input type="radio"/>

Run Exit

Press F1 for Help Demo example of a prebaked PBF cell inspired from VAN's JOM paper 10/3/2002 2:08 PM CAPS NUM INSERT

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
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

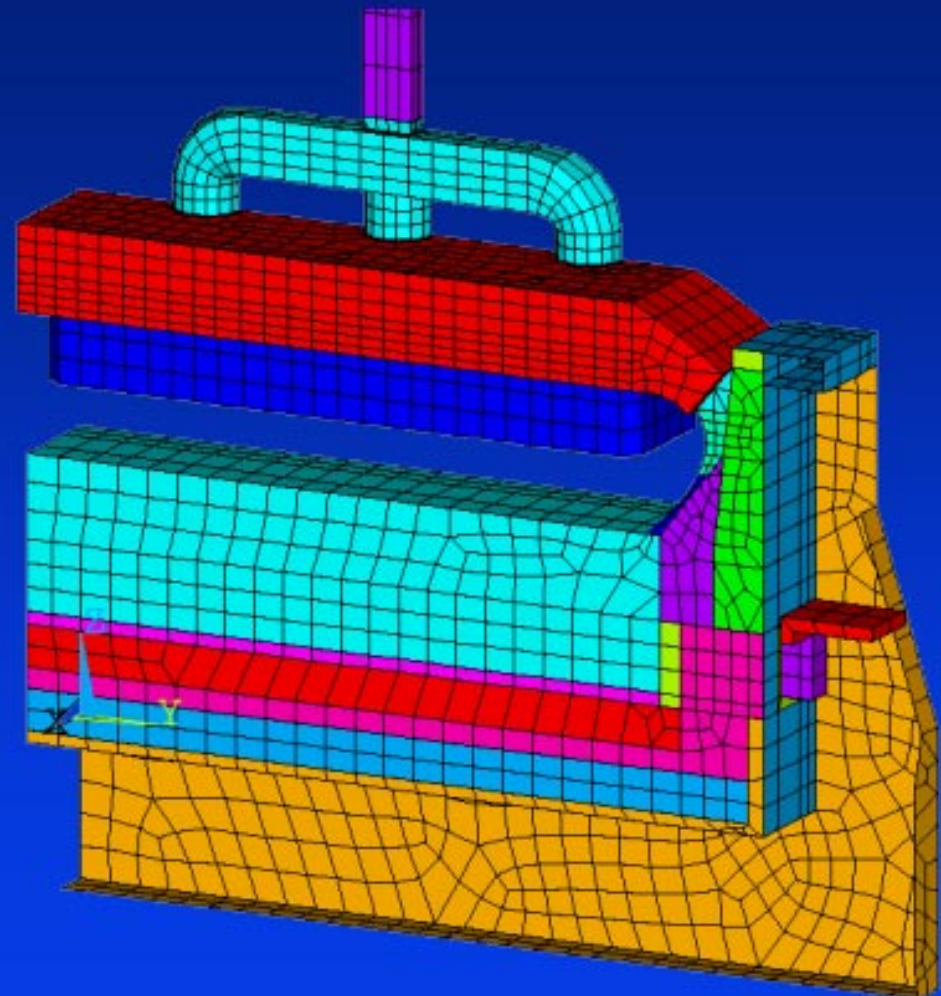
Thermo-Electric Design of a 500 kA Cell Using a 3D Full Cell Side Slice Thermo-Electric Model

500 kA Demonstration Cell Key Characteristics

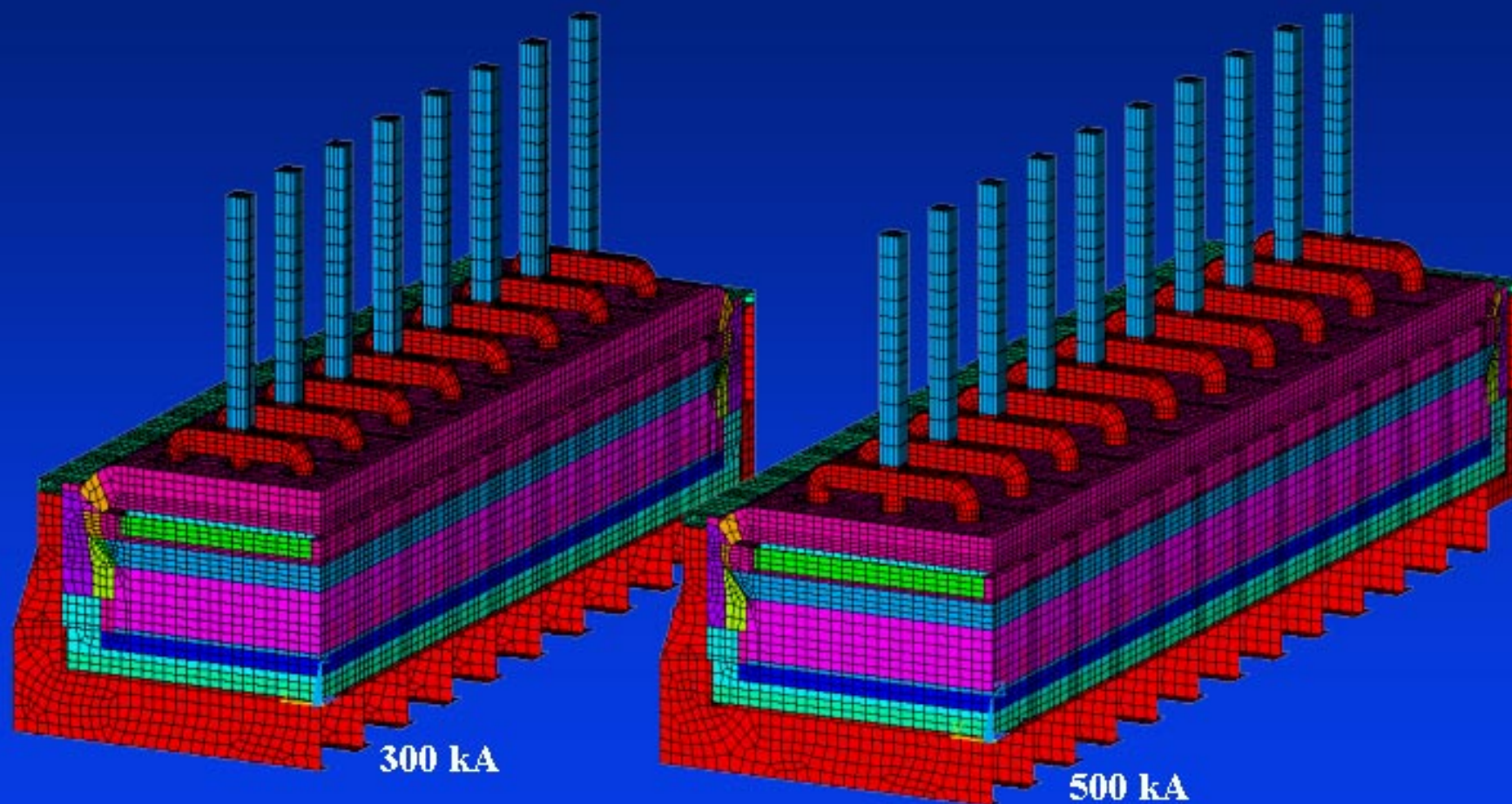
Inside potshell size:	17.8 m x 4.85 m
Anode size:	1.95 m x 0.8 m
Number of anodes:	40
Anodic current density:	0.80 A/cm ²
Cathode block size:	4.17 m x 0.66 m x 0.48 m
Cathode block type:	HC10
Side block type:	SiC
Number of anodic risers:	6

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

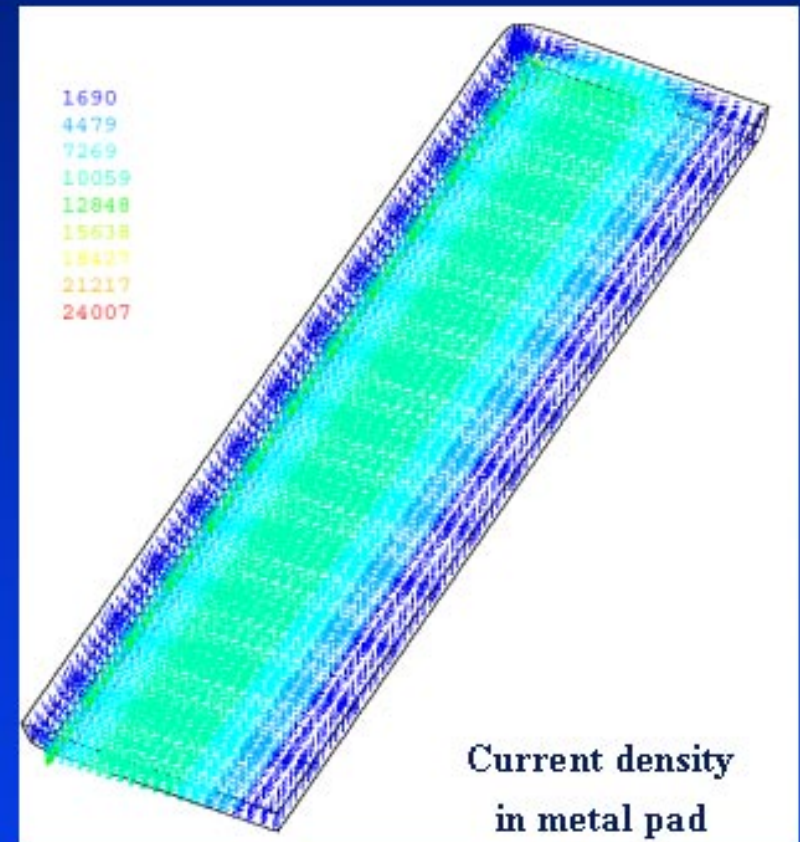
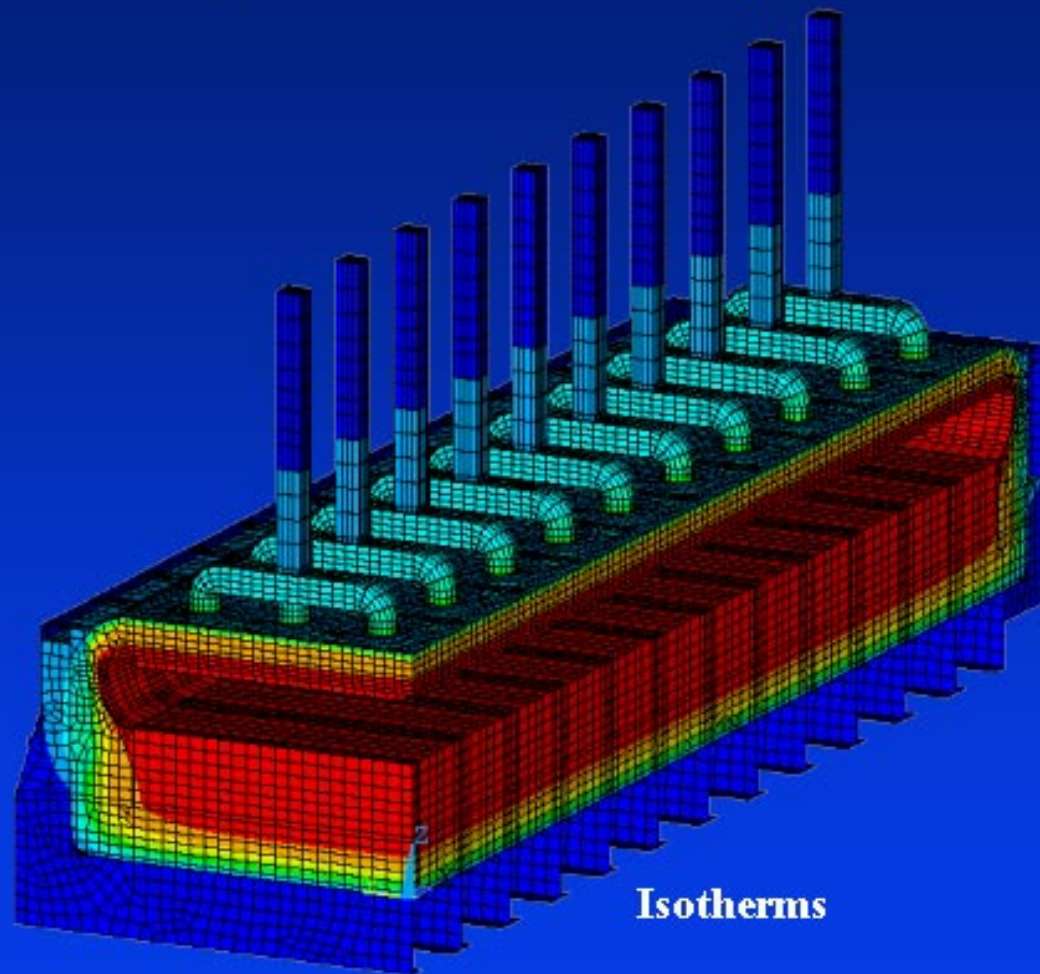
Anode drop:	354 mV
Cathode drop:	314 mV
Anode panel heat loss:	409 kW
Total cathode heat loss:	633 kW
Operating temperature:	963.1 °C
Liquidus superheat:	9.4 °C
Average ledge thickness at bath level:	2.42 cm
Average ledge thickness at metal level:	6.15 cm
Cell internal heat:	1043 kW
Energy consumption: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



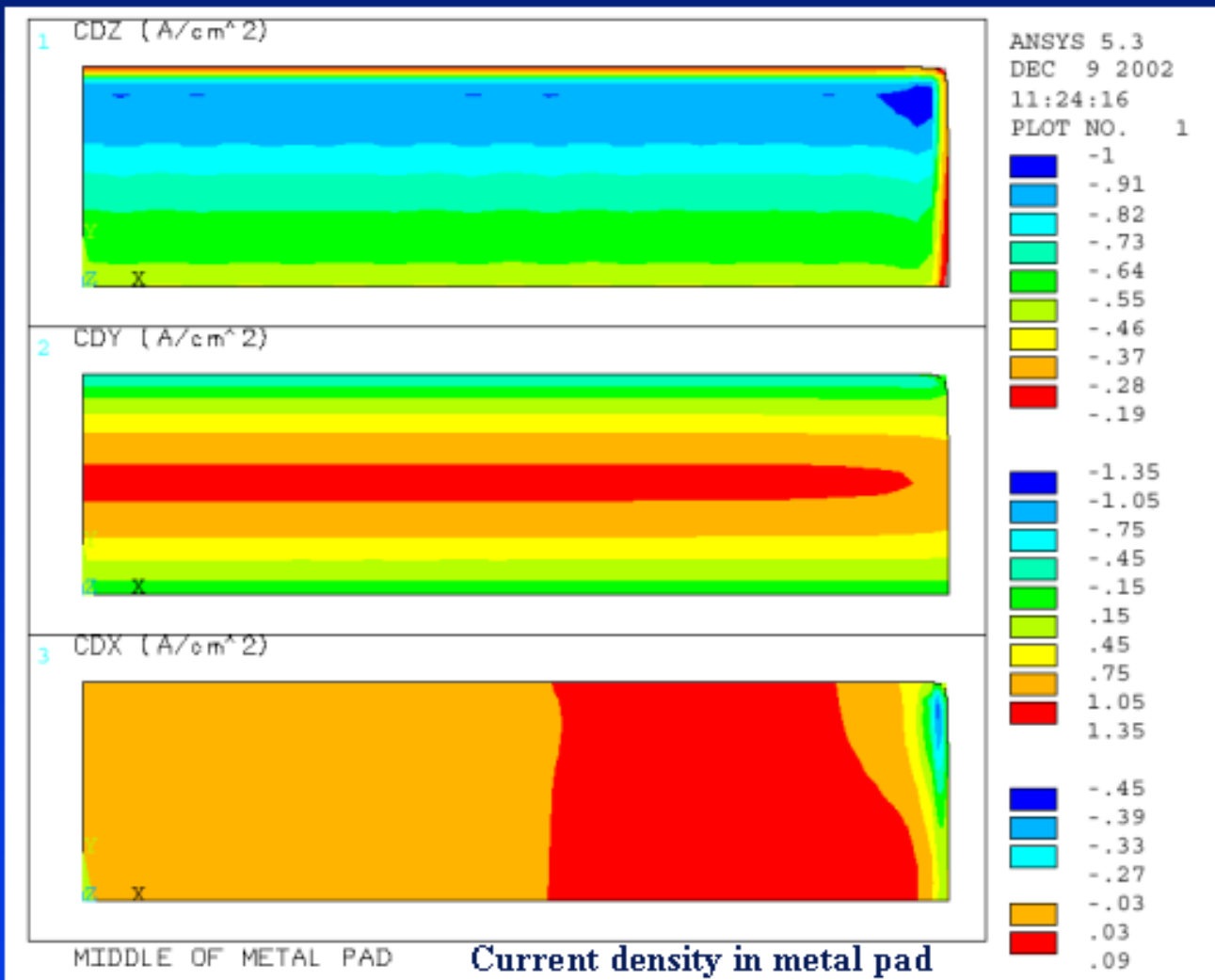
Thermo-Electric Design of a 500 kA Cell Using a Complete Full Cell Quarter Thermo-Electric Model



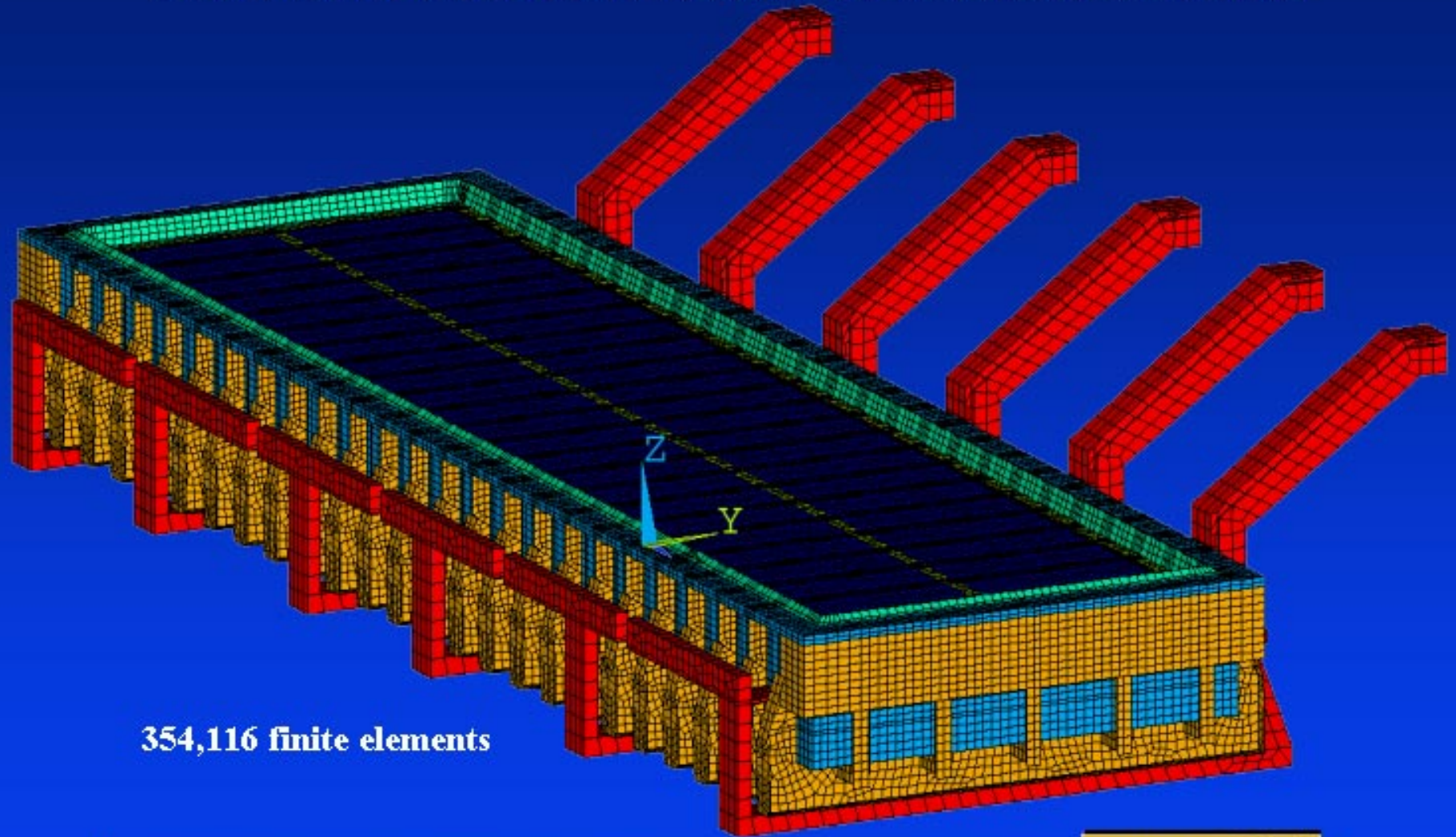
Thermo-Electric Design of a 500 kA Cell Using a Complete Full Cell Quarter Thermo-Electric Model



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



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

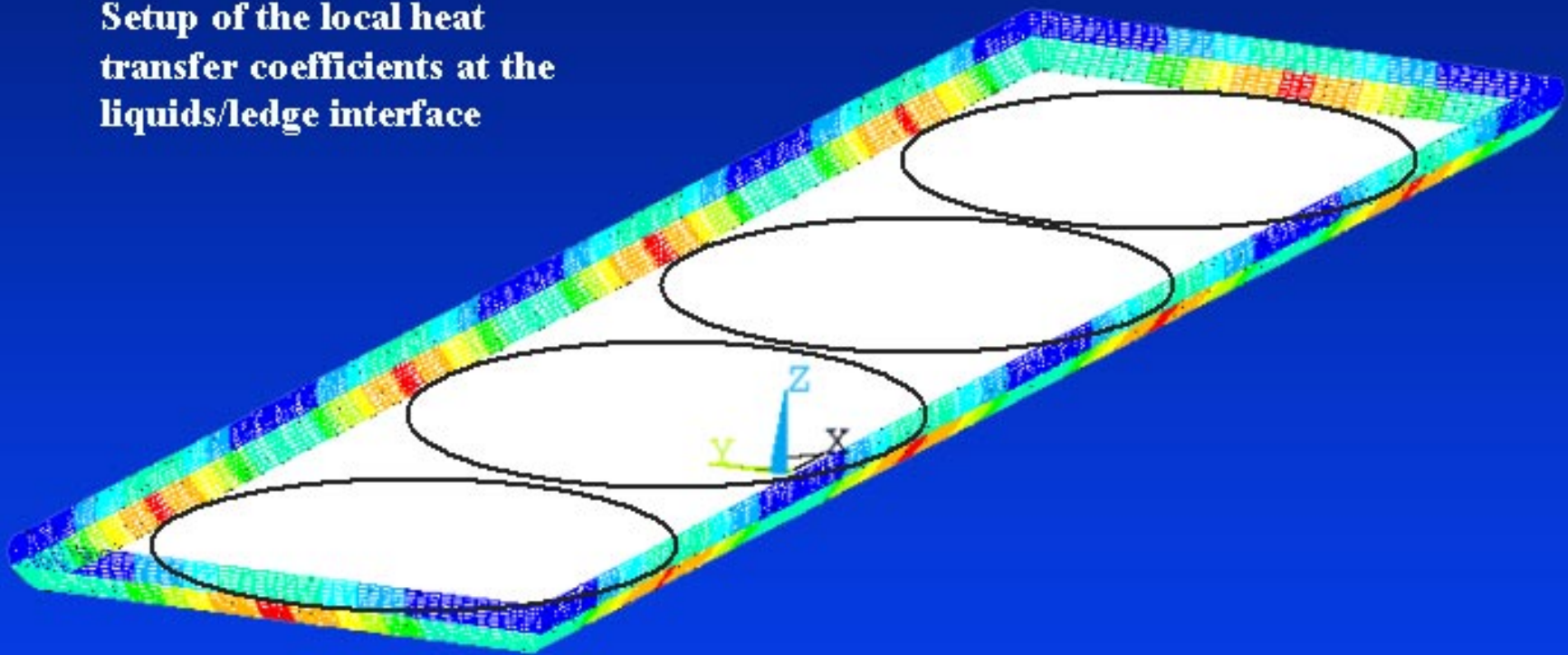


354,116 finite elements

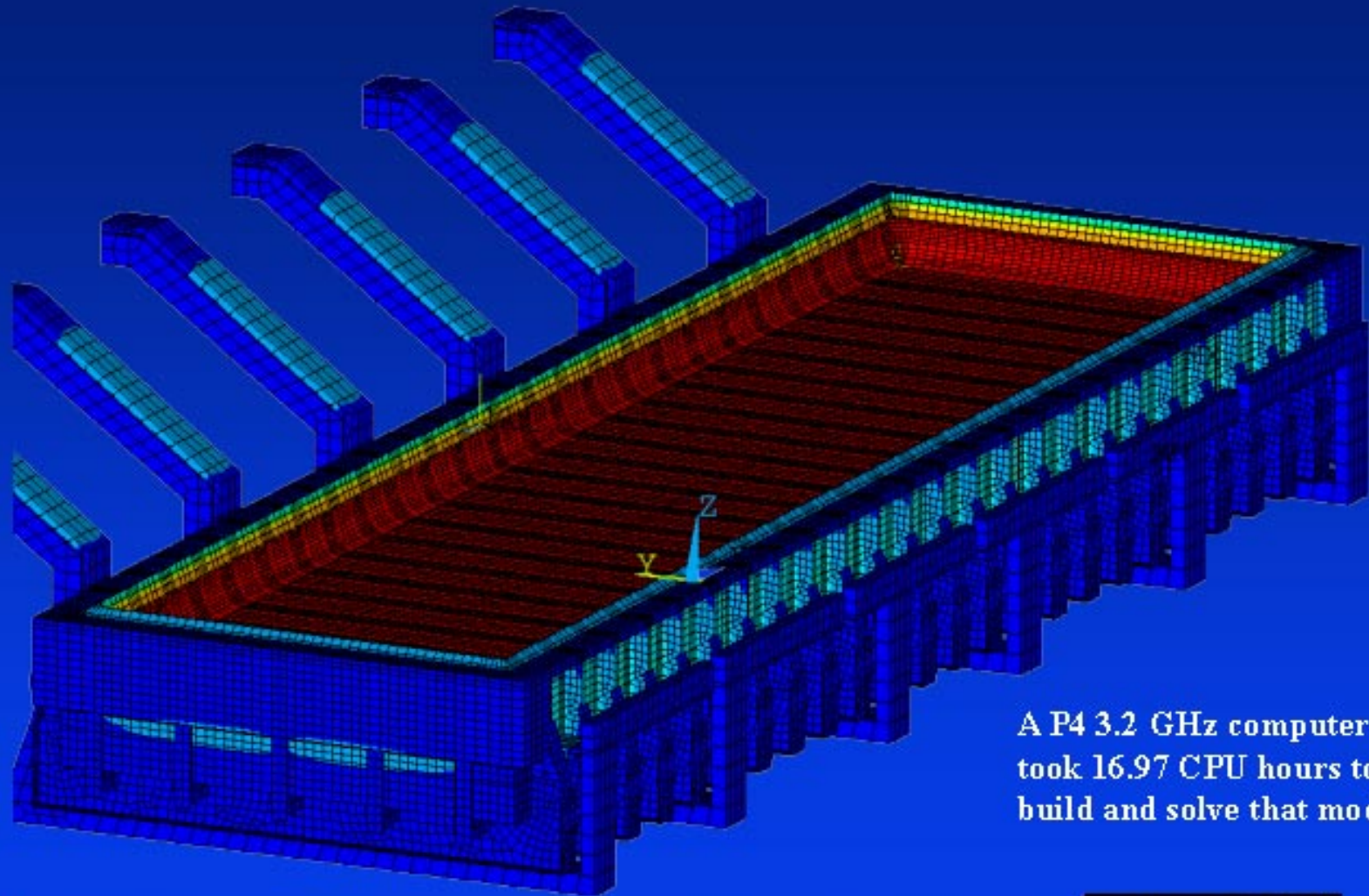
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Thermo-Electric Design of a 500 kA Cell Using a Full Cell Cathode Thermo-Electric Model

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



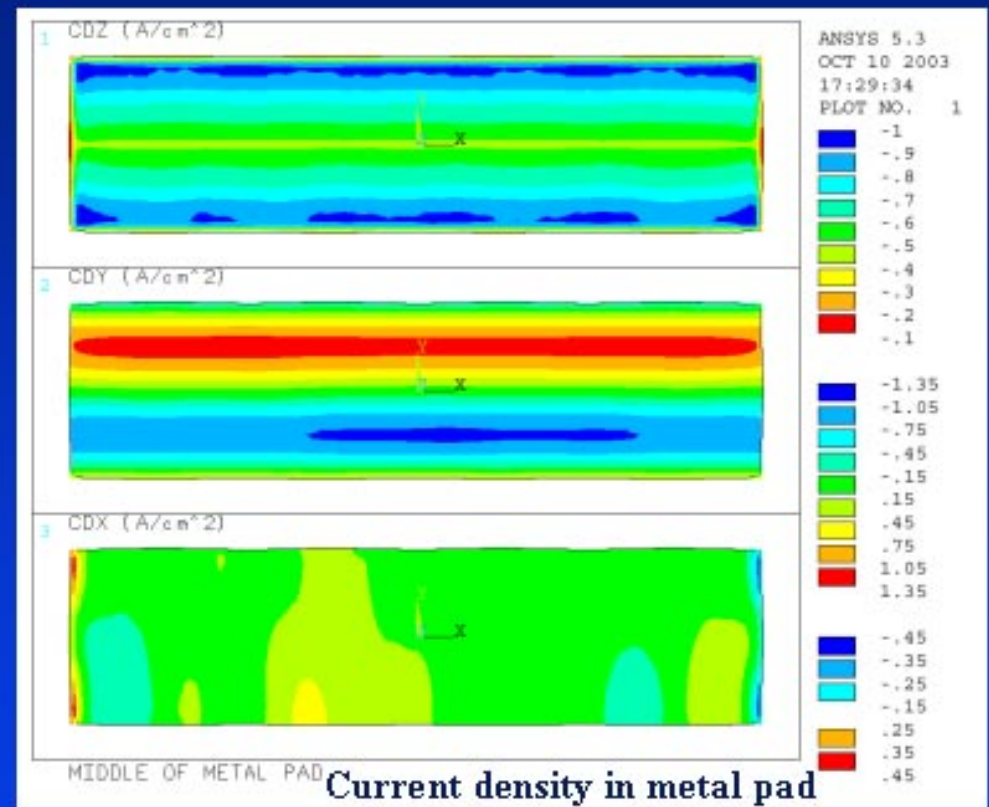
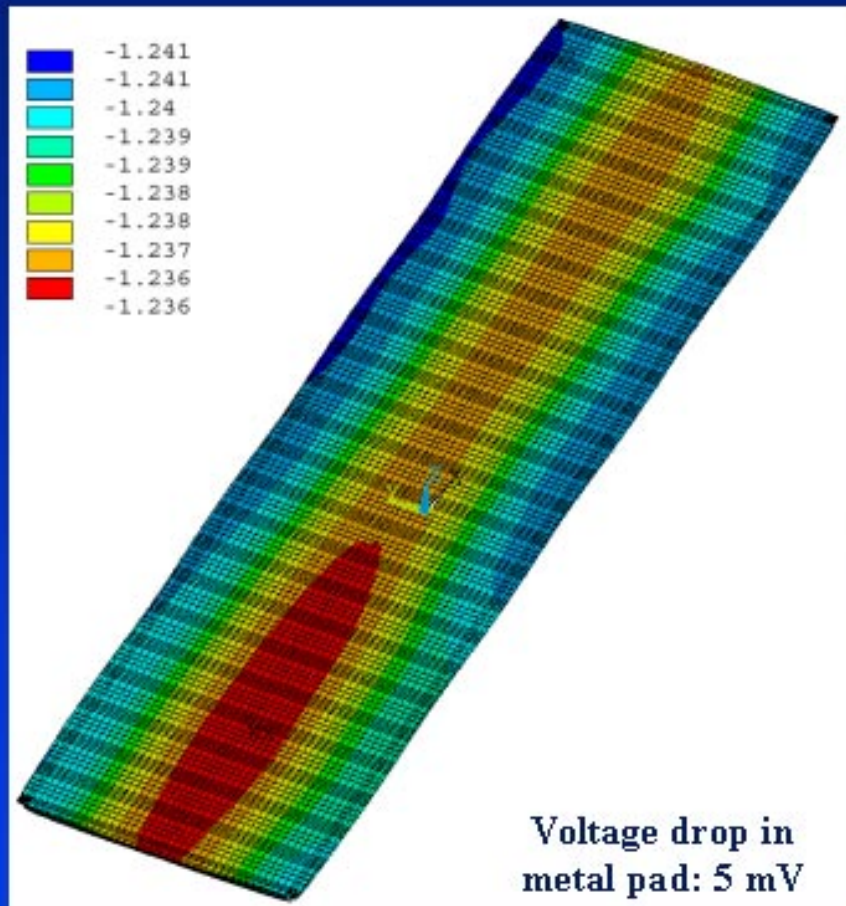
Thermo-Electric Design of a 500 kA Cell Using a Full Cell Cathode Thermo-Electric Model



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

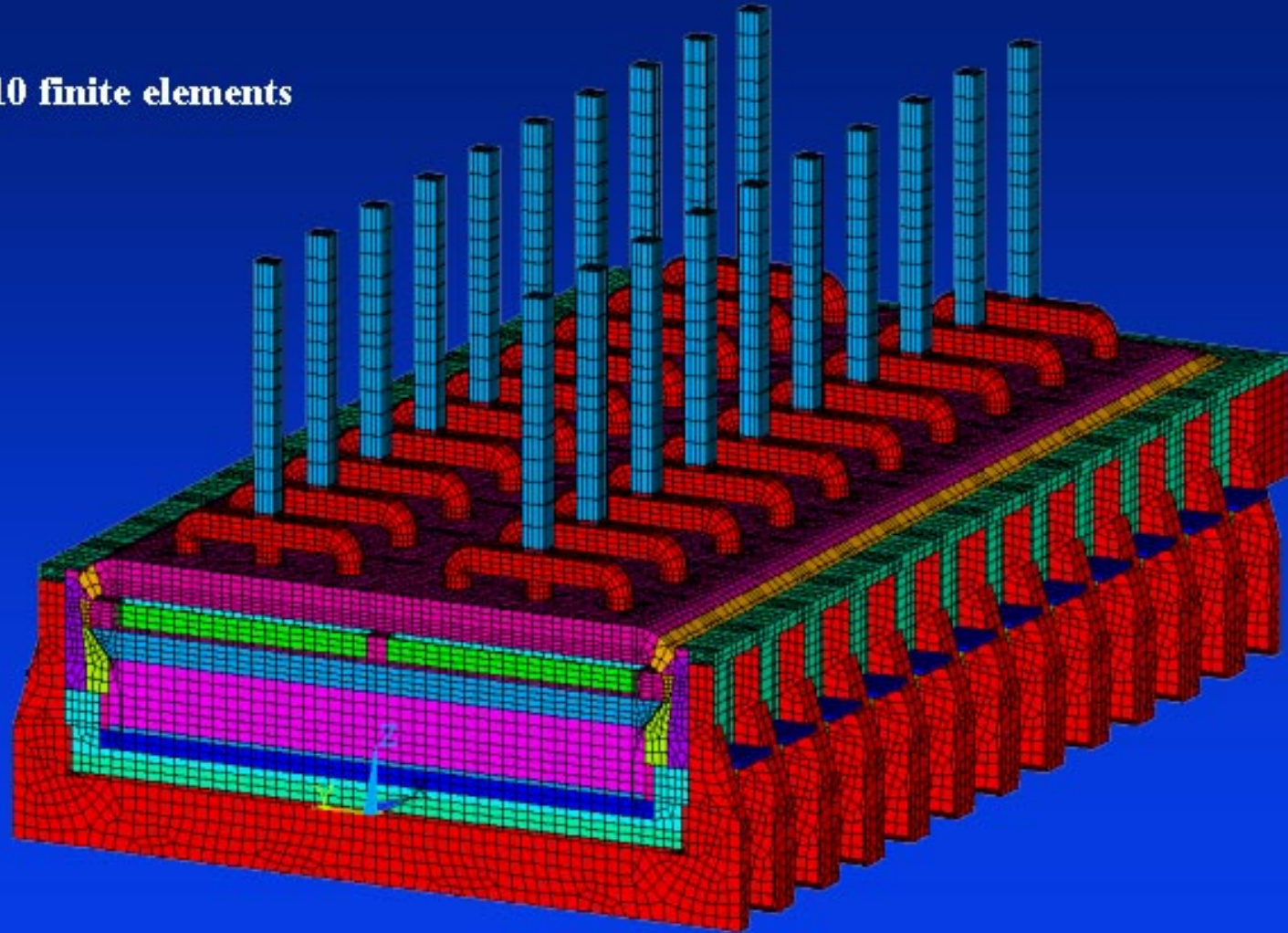
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Thermo-Electric Design of a 500 kA Cell Using a Full Cell Cathode Thermo-Electric Model



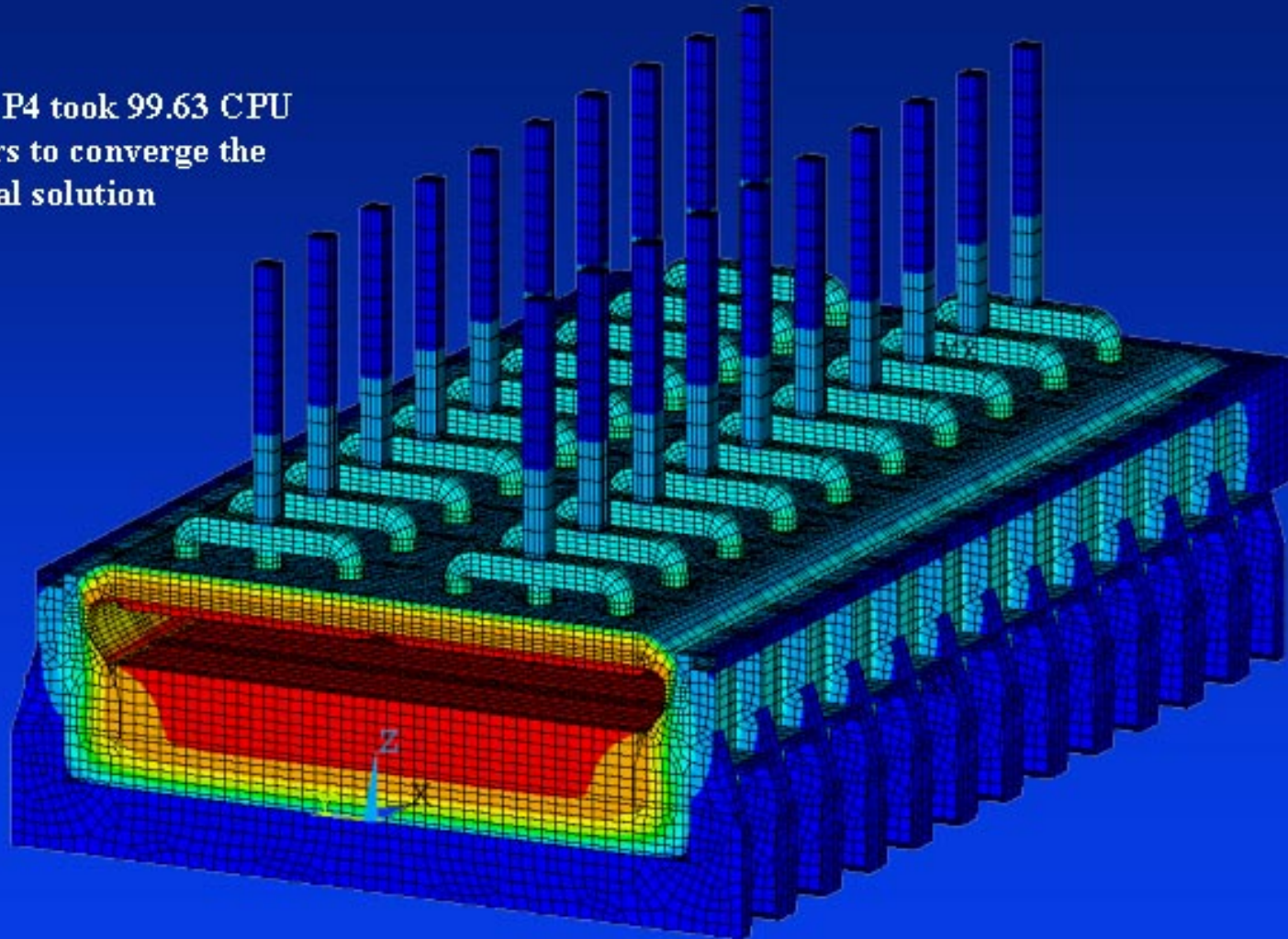
Thermo-Electric Design of a 500 kA Cell Using a Full Half Cell Thermo-Electric Model

290,410 finite elements

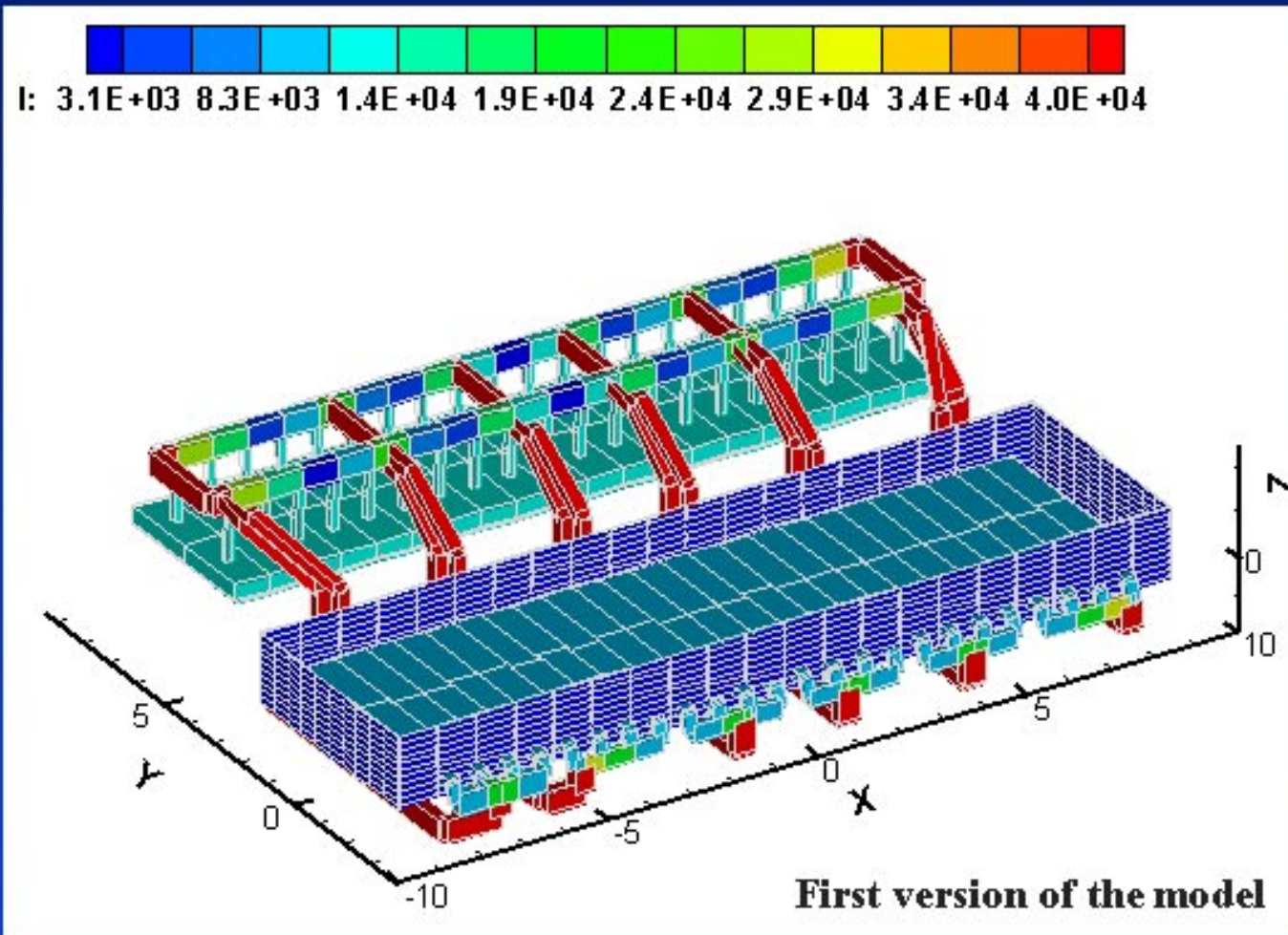


Thermo-Electric Design of a 500 kA Cell Using a Full Half Cell Thermo-Electric Model

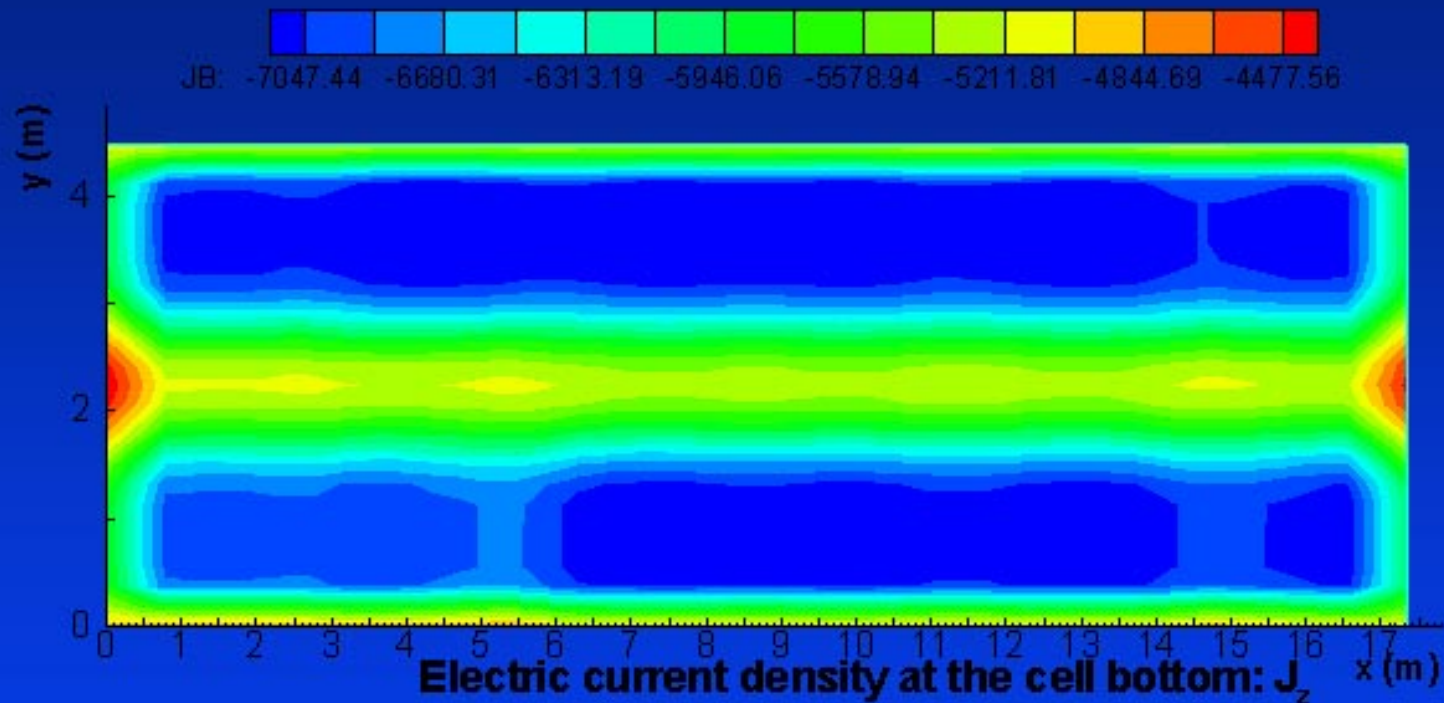
The P4 took 99.63 CPU hours to converge the initial solution



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

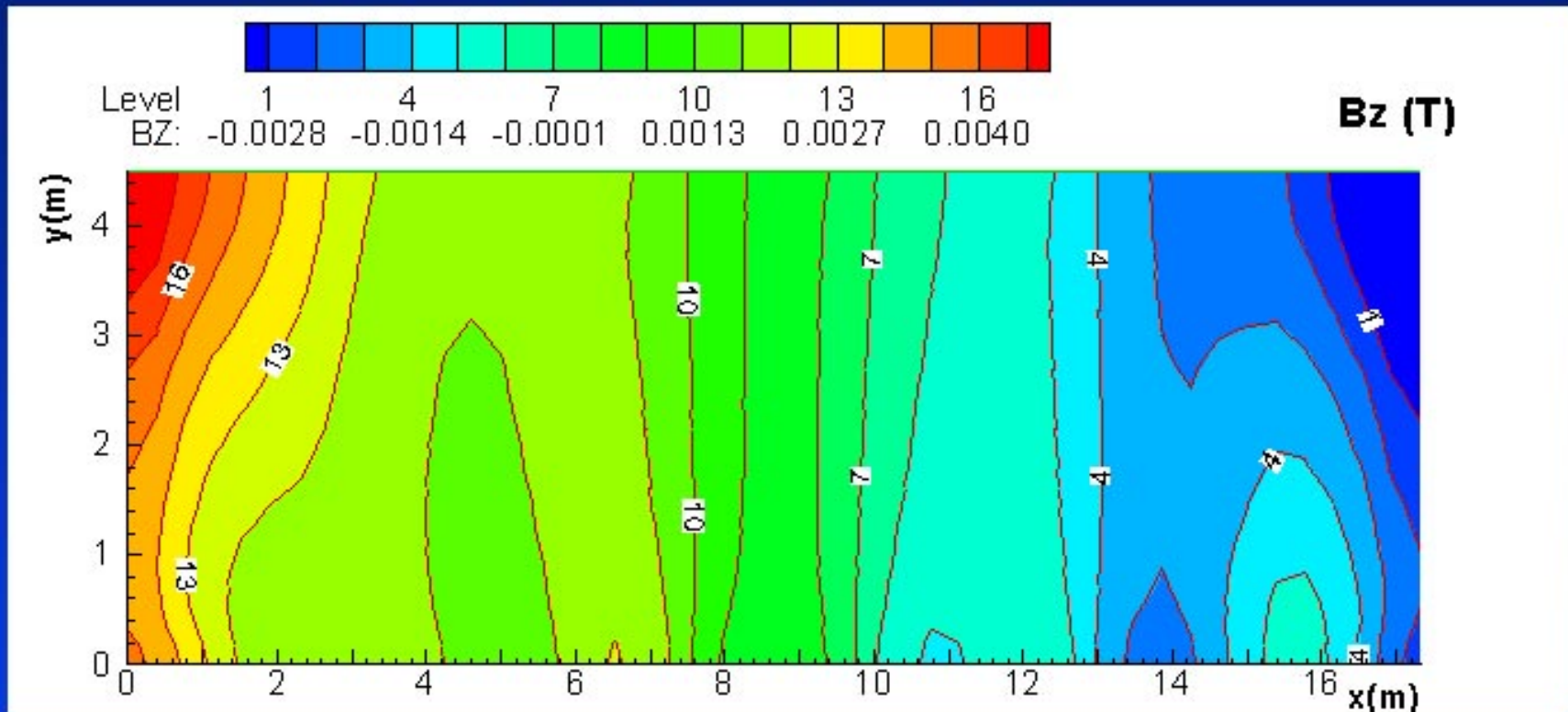


MHD Design of a 500 kA Cell Using Bojarevics' Cell Stability Model



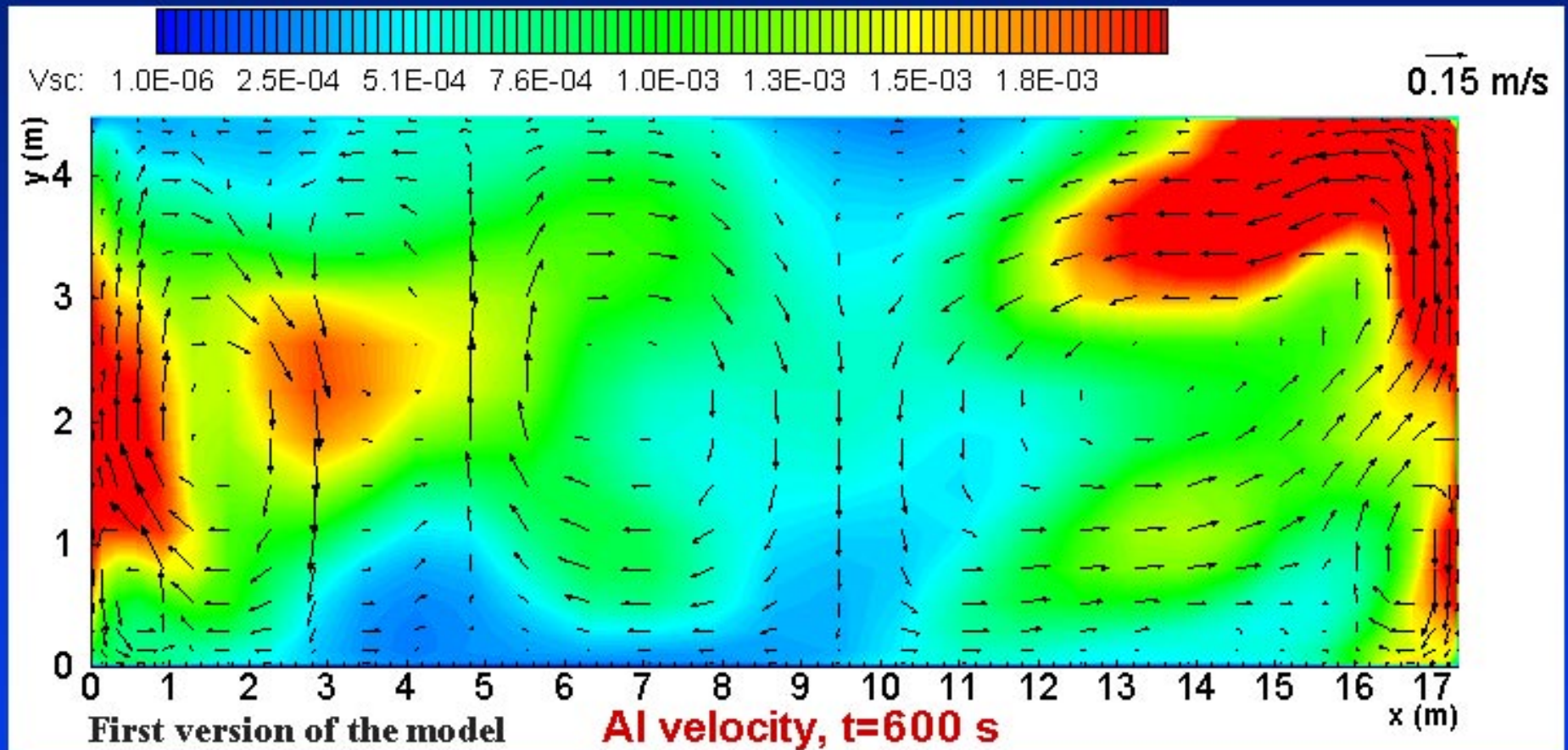
First version of the model: current density

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

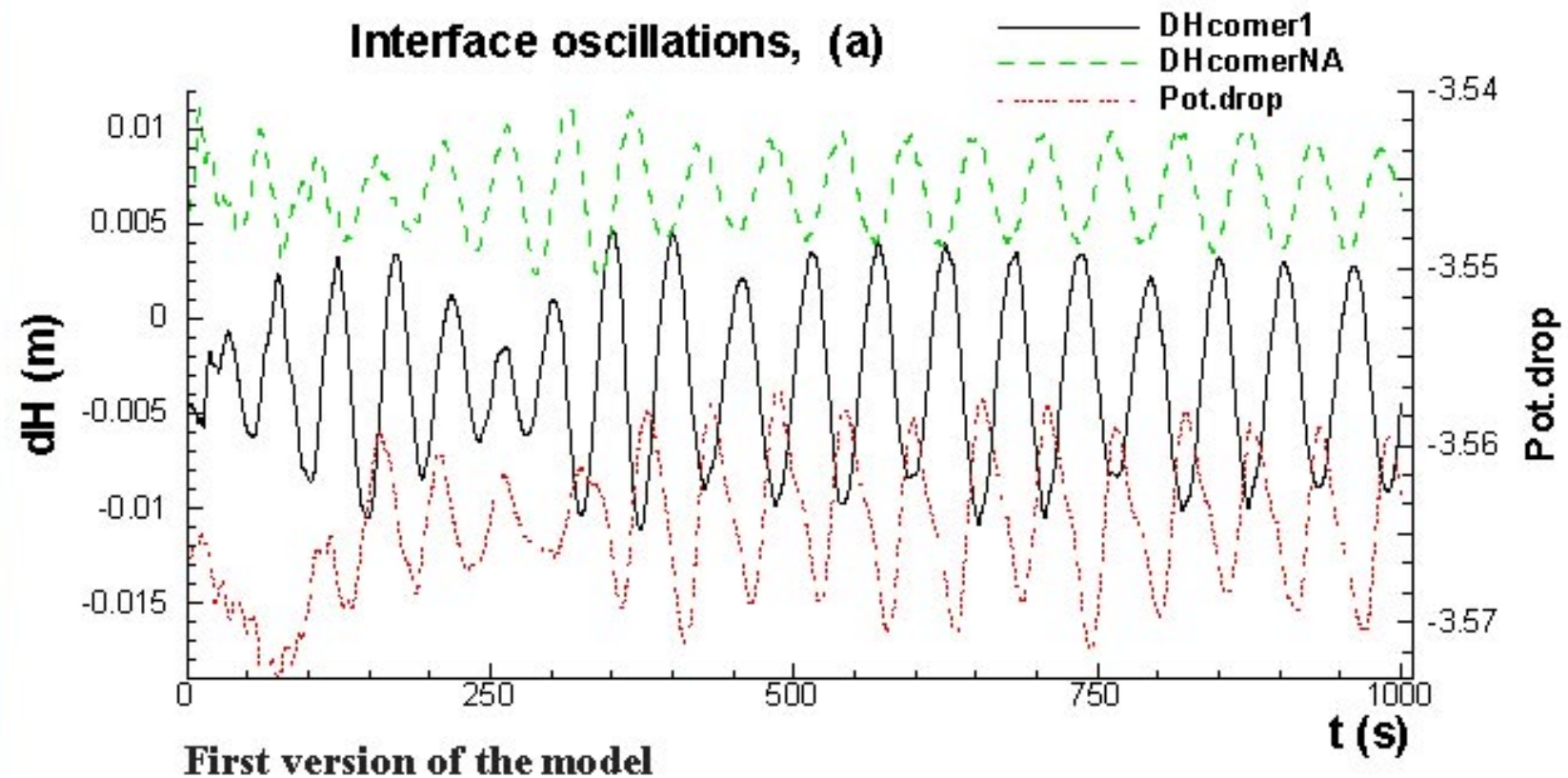


First version of the model: magnetic field including shell shielding effect

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

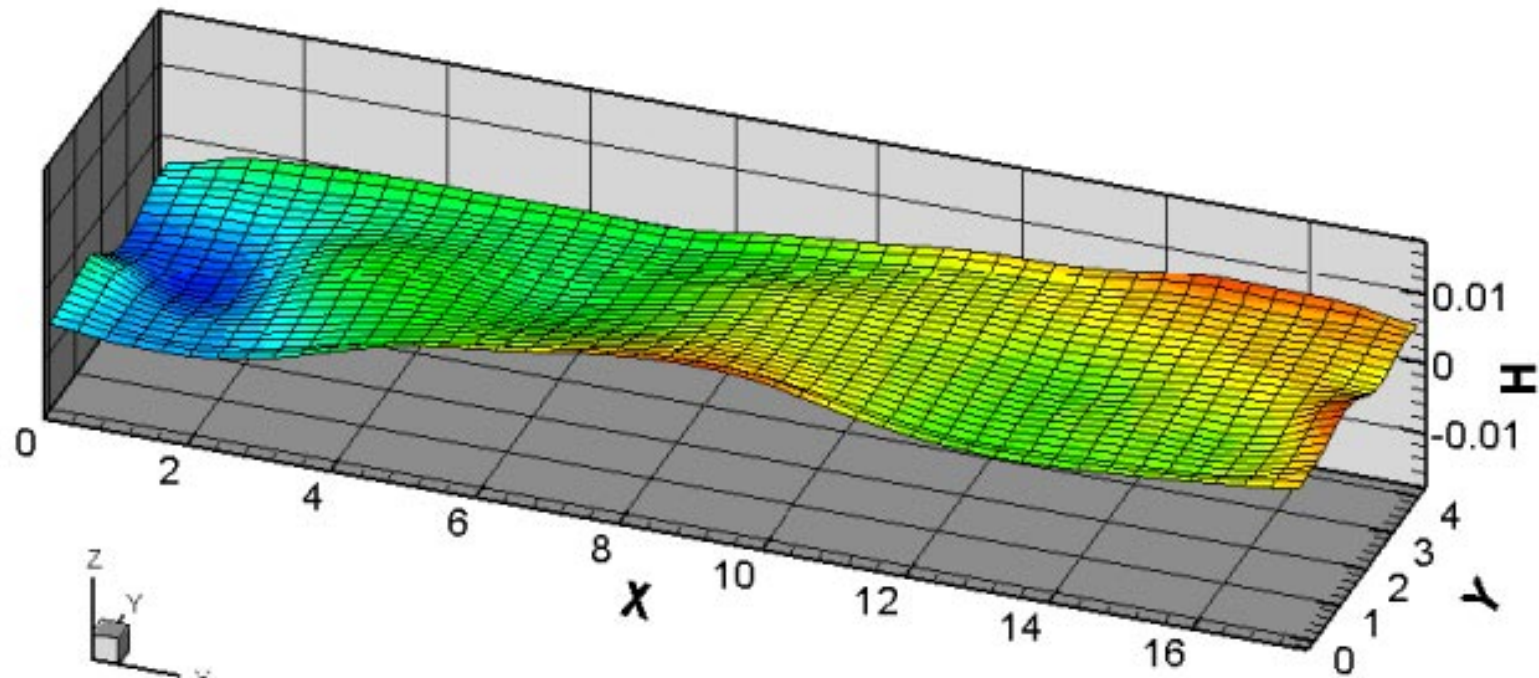
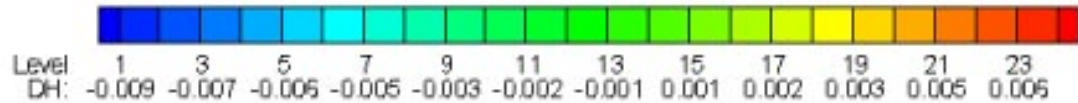


MHD Design of a 500 kA Cell Using Bojarevics' Cell Stability Model



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

Interface, dH(m)

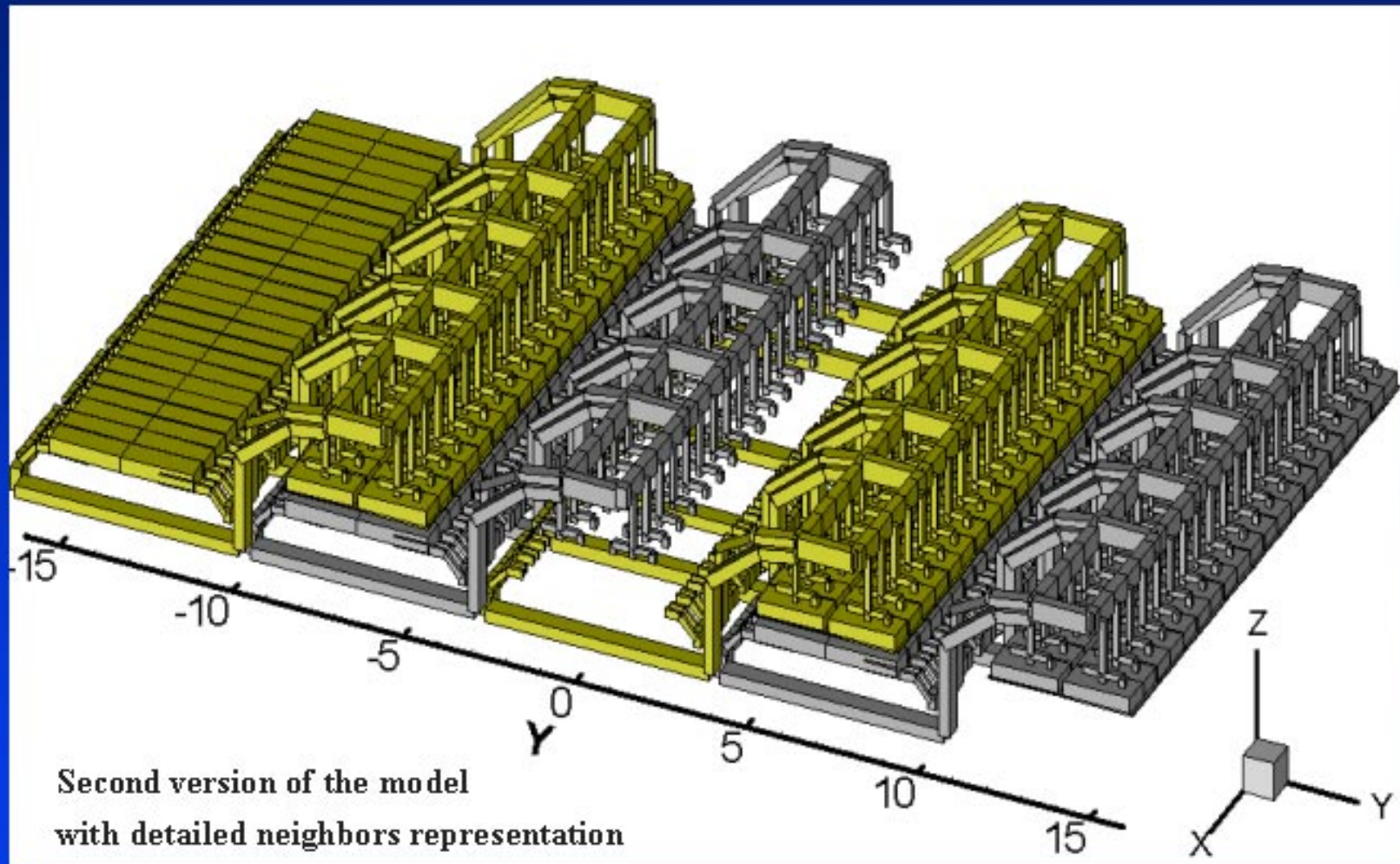


First version of the model

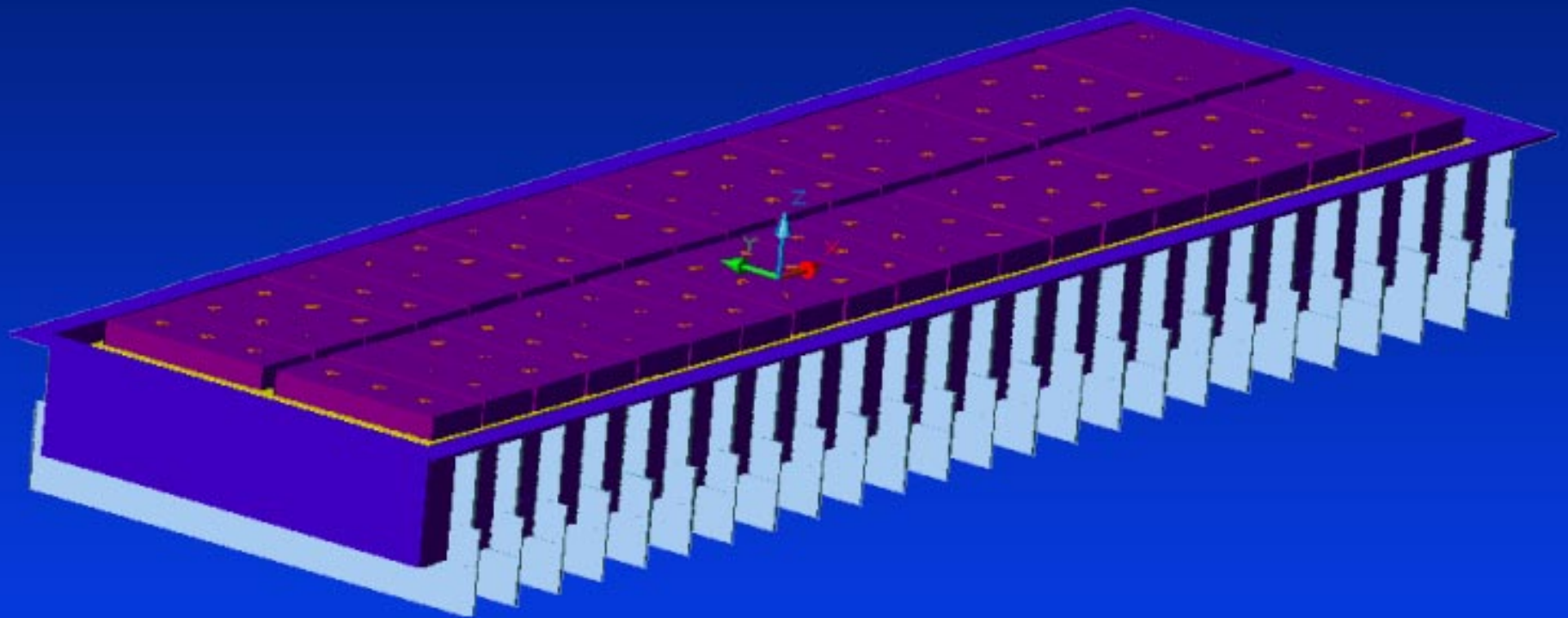
New500kA DH t= 495.0s

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



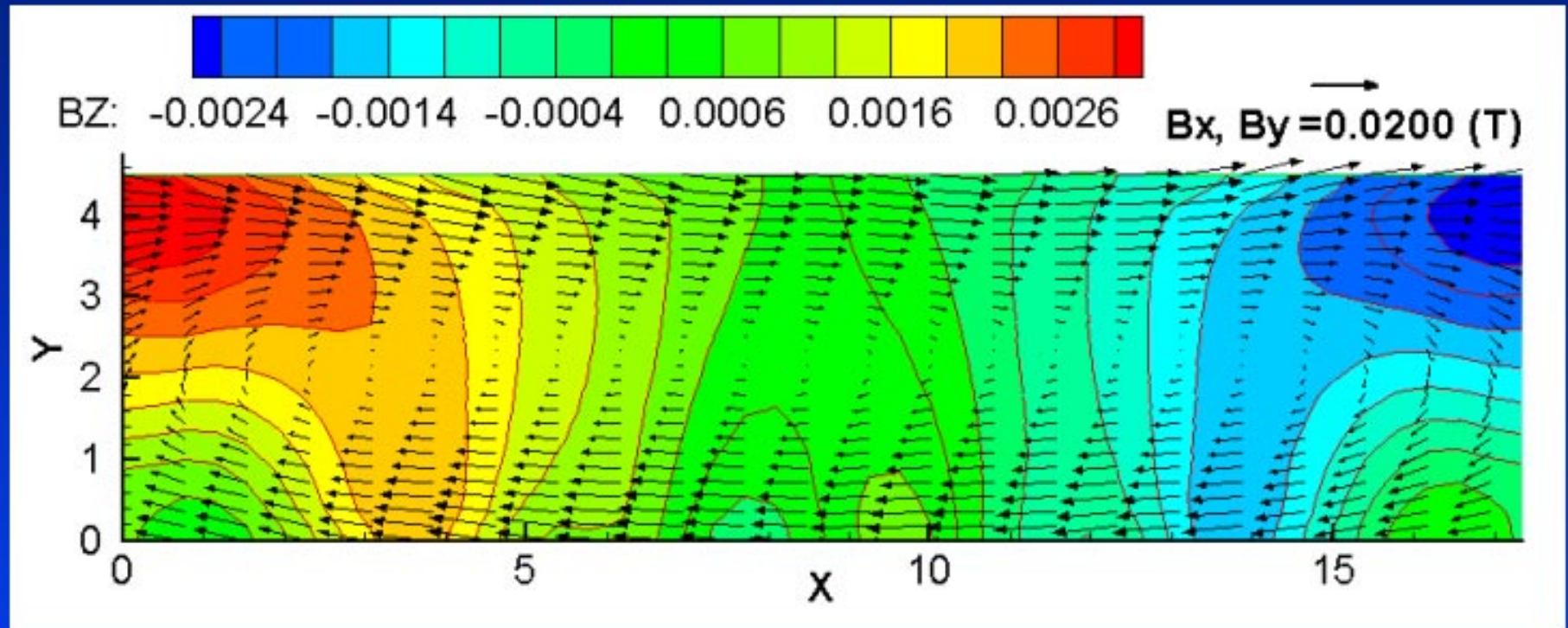
MHD Design of a 500 kA Cell Using Bojarevics' Cell Stability Model



Second version of the model with detailed shell representation

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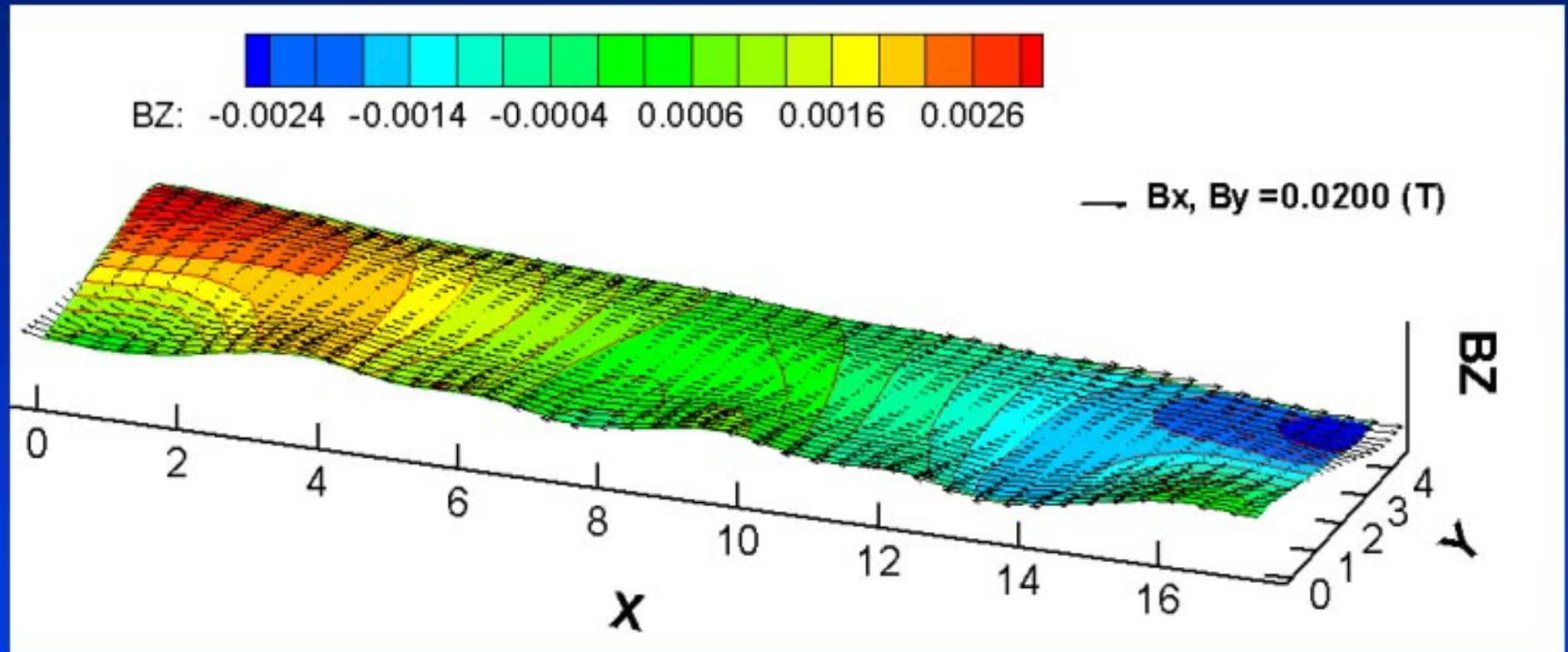
MHD Design of a 500 kA Cell Using Bojarevics' Cell Stability Model



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

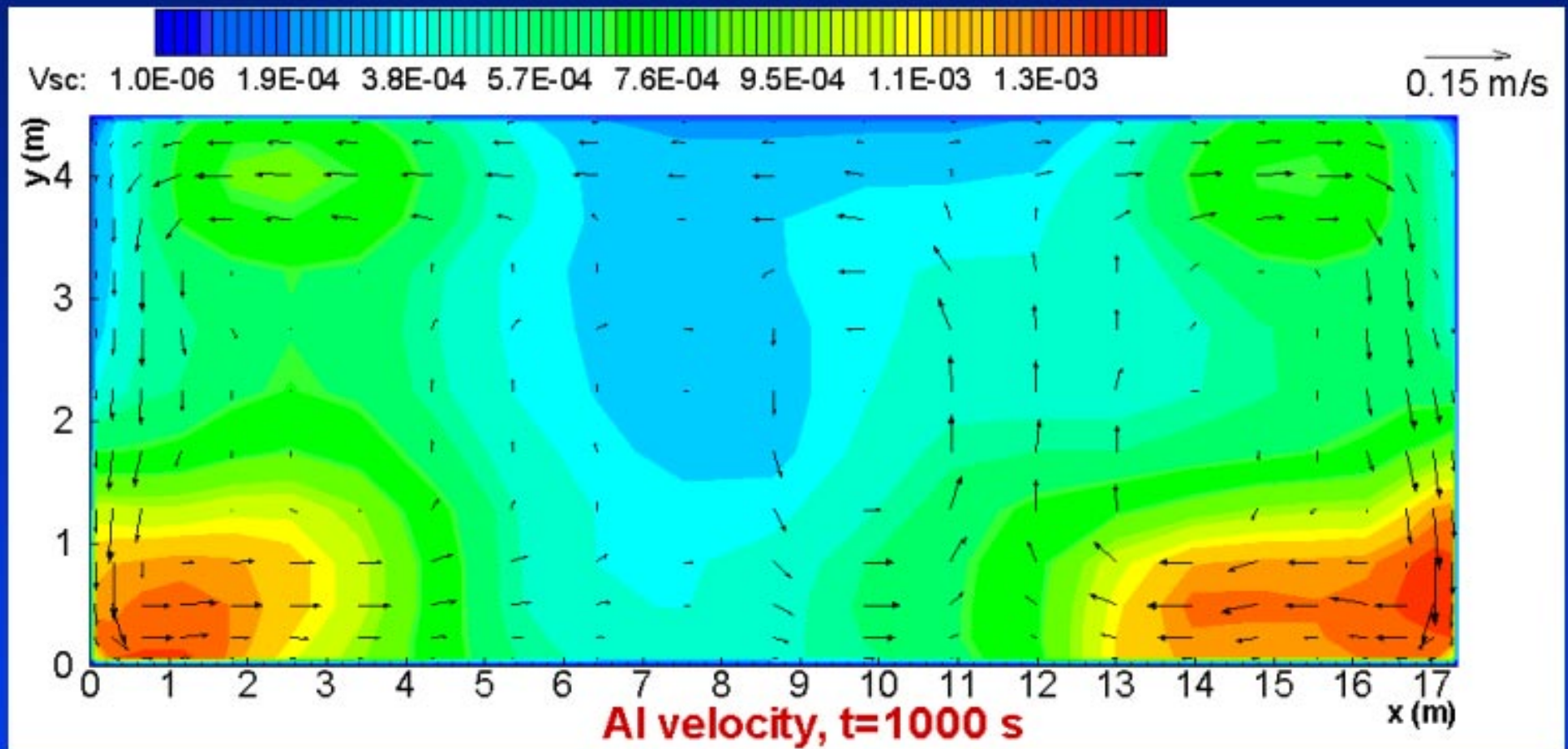
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MHD Design of a 500 kA Cell Using Bojarevics' Cell Stability Model



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

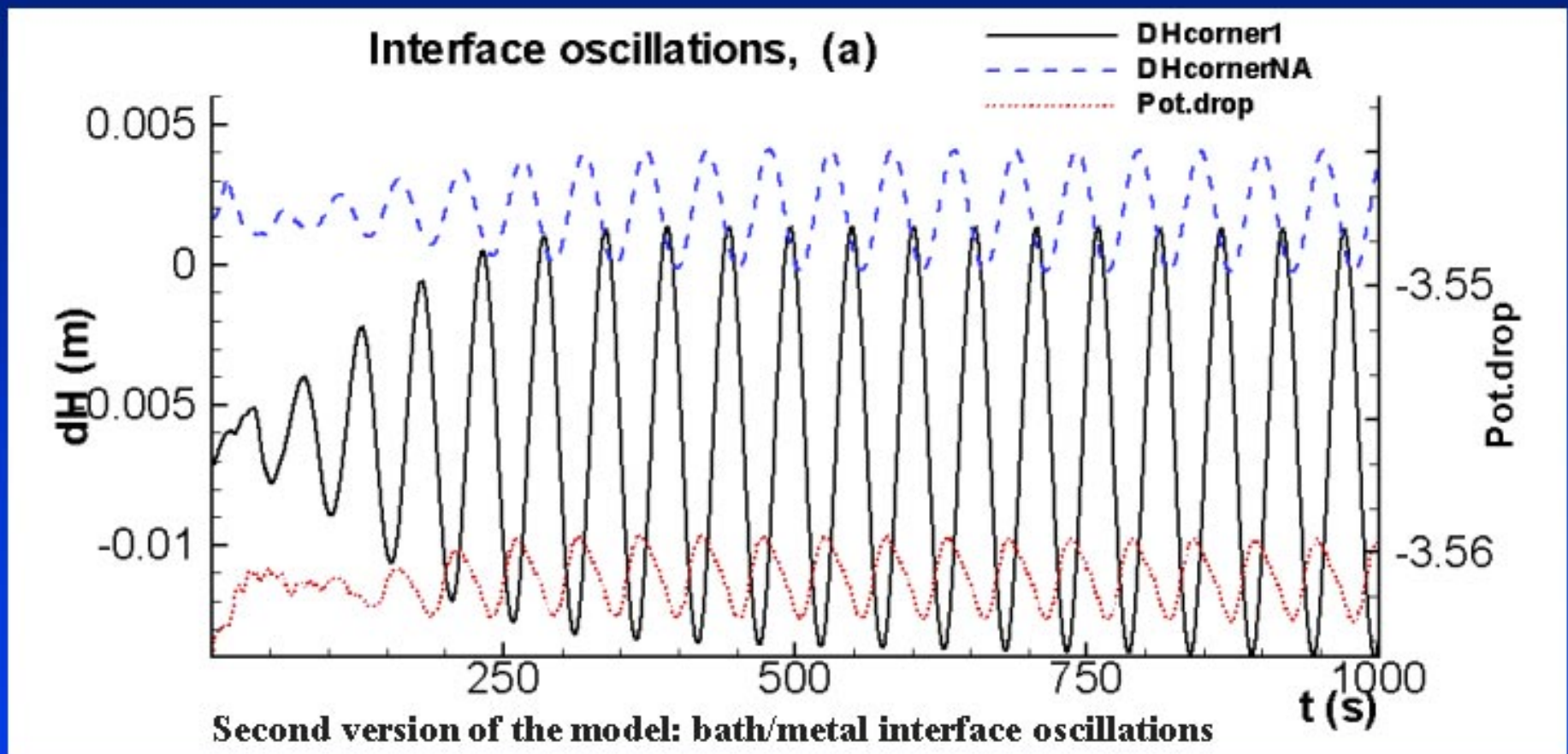
MHD Design of a 500 kA Cell Using Bojarevics' Cell Stability Model



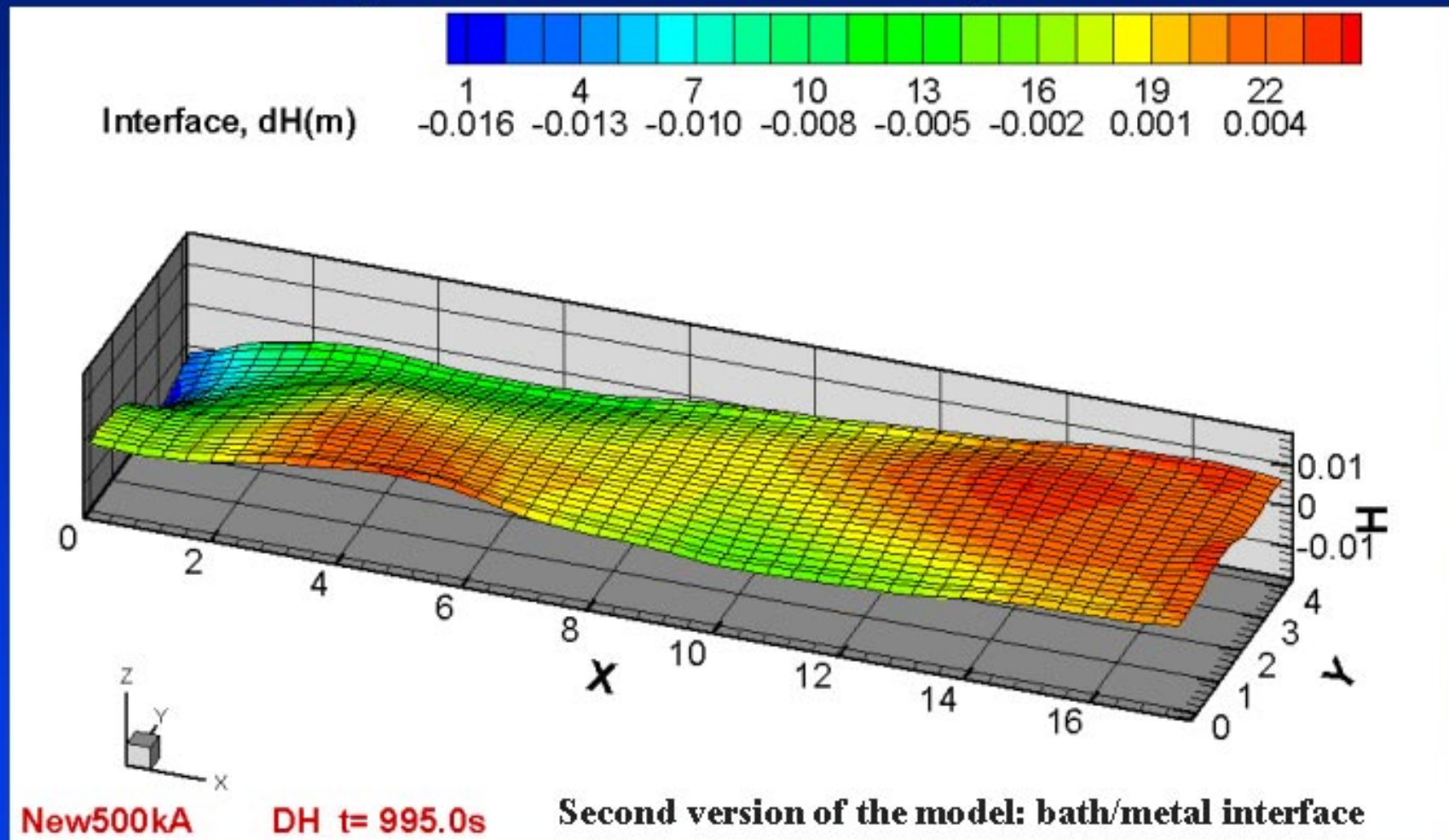
Second version of the model: velocity in the metal pad

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



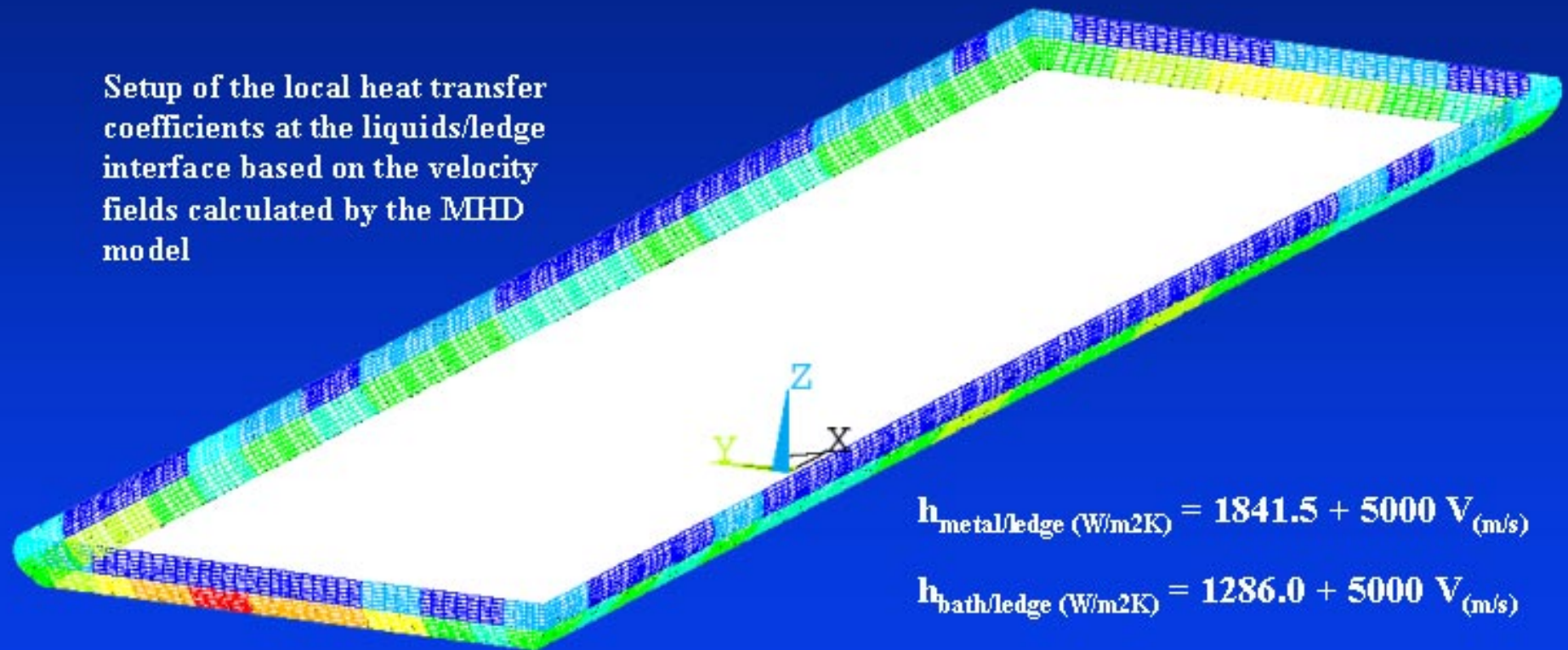
MHD Design of a 500 kA Cell Using Bojarevics' Cell Stability Model



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

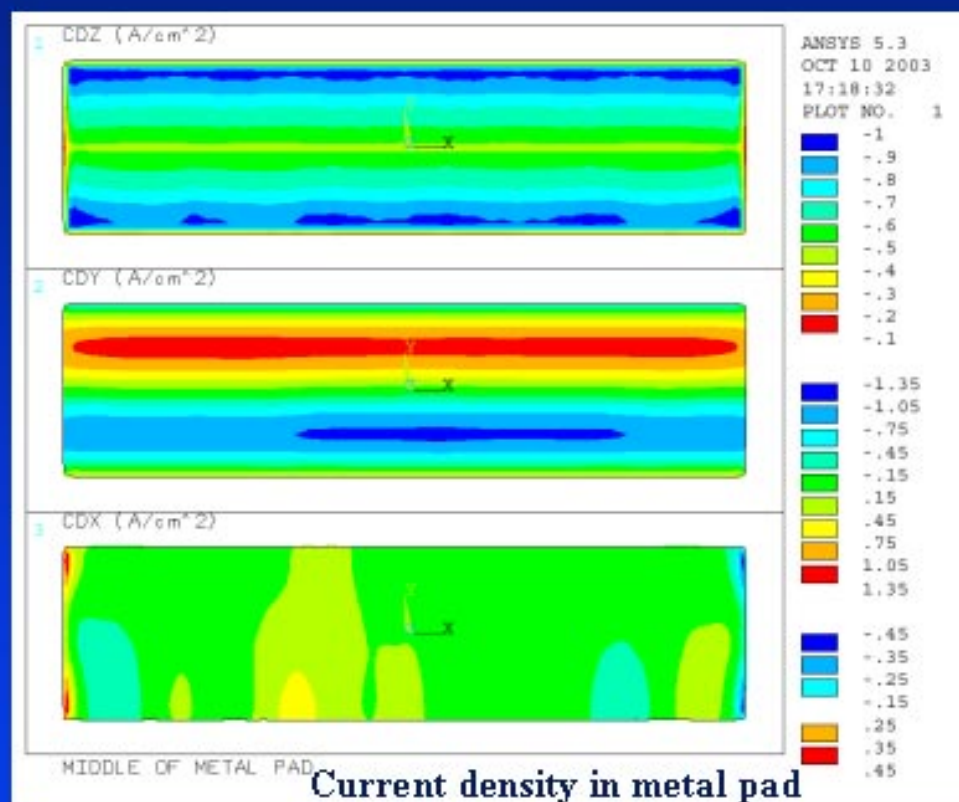
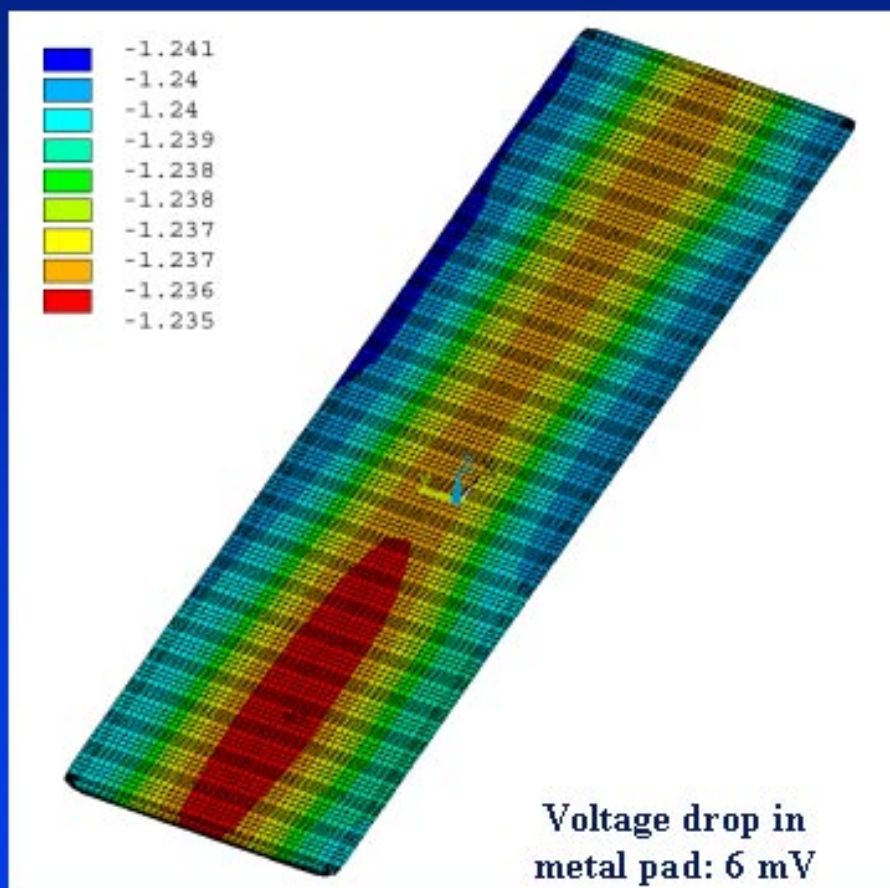


$$h_{\text{metal/ledge}} \text{ (W/m}^2\text{K)} = 1841.5 + 5000 V_{\text{(m/s)}}$$

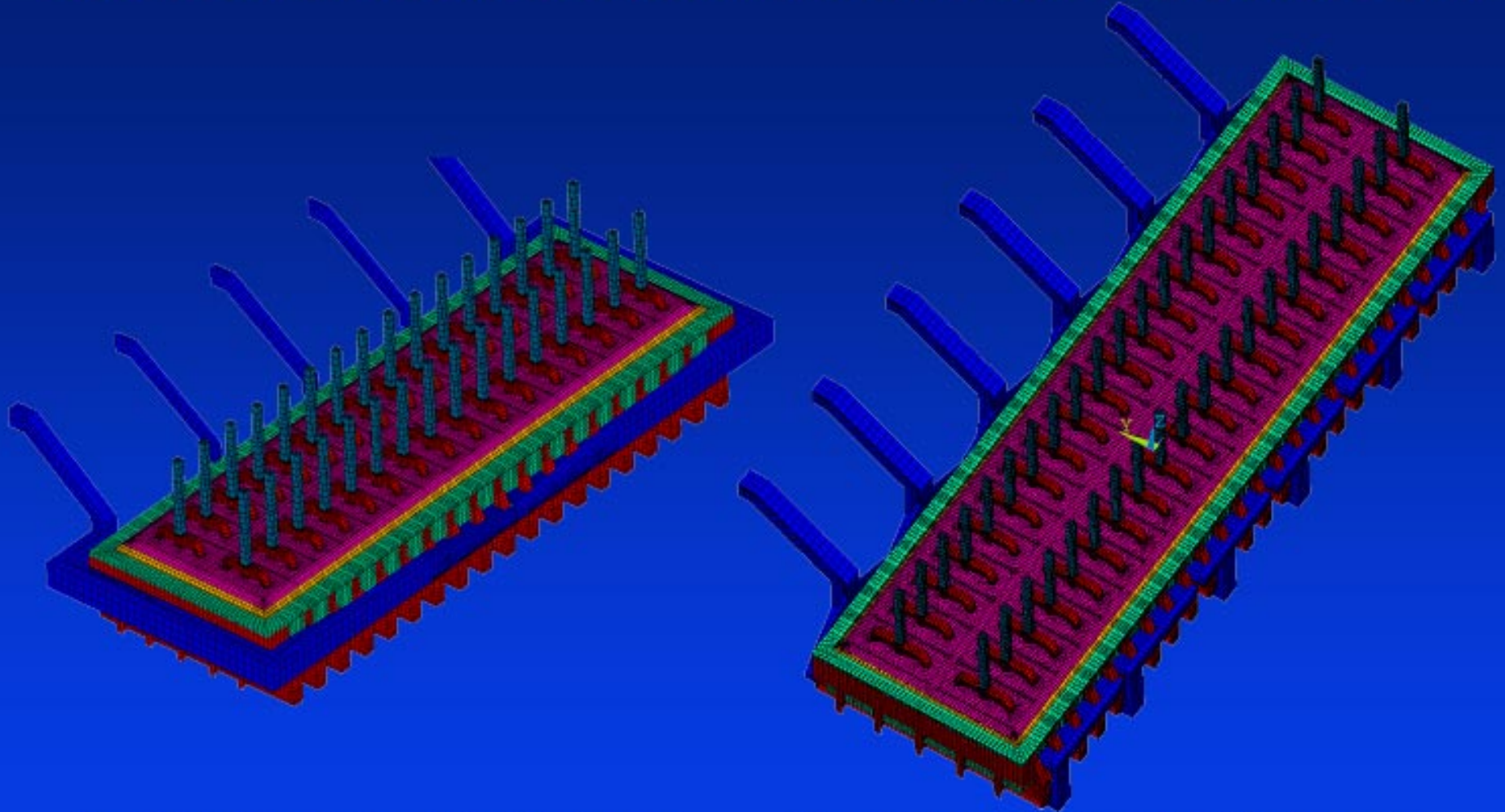
$$h_{\text{bath/ledge}} \text{ (W/m}^2\text{K)} = 1286.0 + 5000 V_{\text{(m/s)}}$$

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

First Interaction Trial Between Models



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.**