DESIGNING CELLS FOR THE FUTURE –WIDER AND/OR EVEN HIGHER AMPERAGE?

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Plan of the Presentation

- Introduction
- Criteria applied to new designs
- The 760 kA cell
- Benefits of the RCC busbar concept design
- Extrapolation to a longer 1 MA cell
- Discussion
- Conclusions

Introduction

- The present approach of simply increasing the length of cells as we move to higher amperage has introduced operational issues. However, as recently presented, the existence of copper collector bar technology opens the door to designing cathode that extracts 100% of the current directly on the downstream side. It also obviously opens the door to designing wider cell without generating harmful horizontal current in the metal pad and increasing the cathode voltage drop. This design alternative is explored here and spectacular benefits are apparent while practical operating issues are minimised.

Introduction

- **Recently limitations arising from lengthening the cells have become apparent from both capital cost and operating performance.**

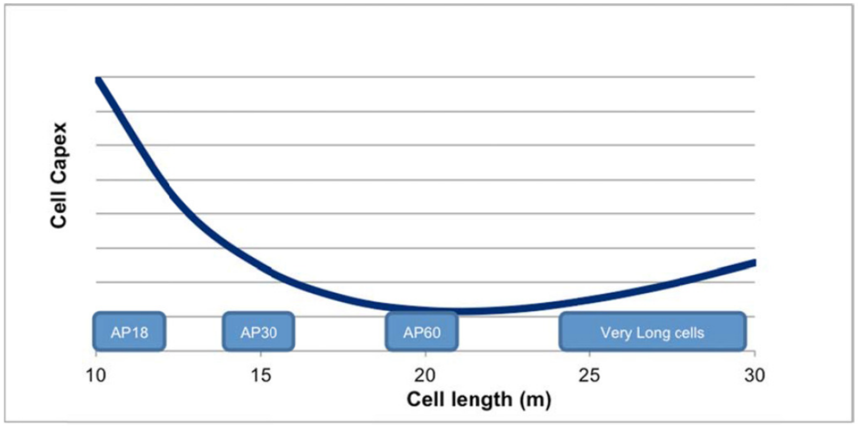


Figure 3: Cell Capex in relation to cell length

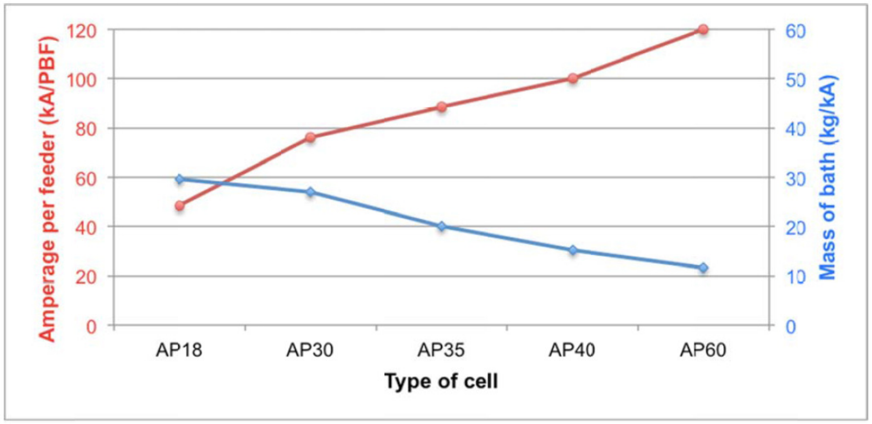
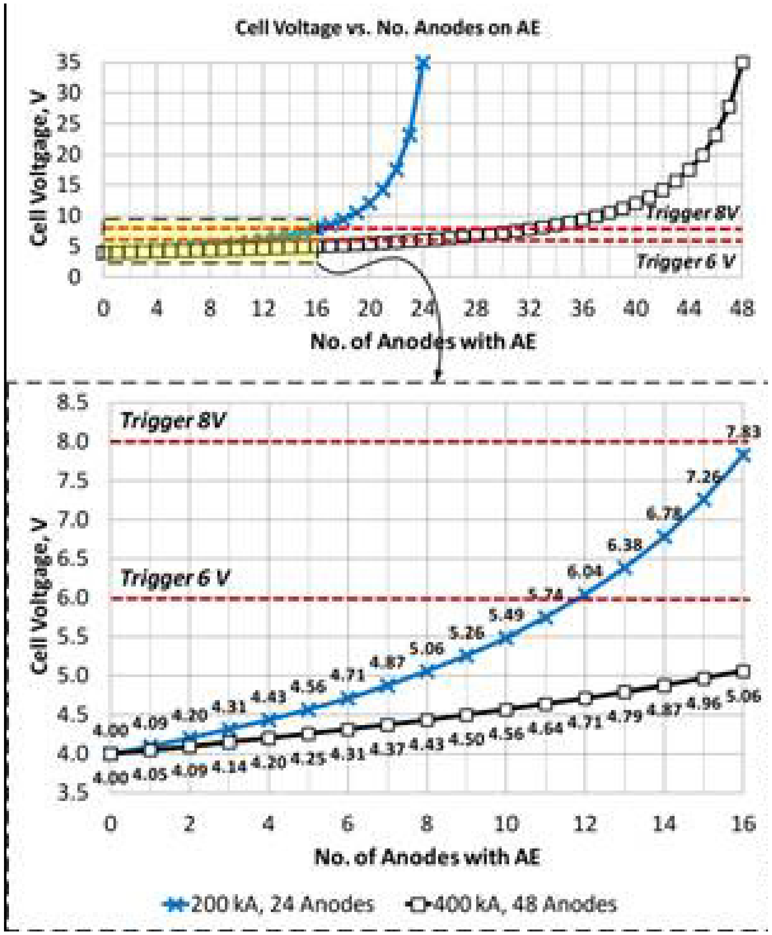


Figure 11: Effect of cell size on alumina feeding performance (PBF=Point Breaker Feeder)

Ref: O. Martin, R.Gariepy and G.Girault, "APXe and AP60: The New References for Low Energy and High Productivity Cells", 11th Australasian Aluminium Smelting Technology Conference ("AASTC"), Dubai, UAE, 6 - 11 December 2014.

Introduction

- The reduction in liquid bath volume combined with the higher amperage load per point feeder has accentuated the spatial variations within the cell, and in some situations giving rise to almost continuous co-evolution of perfluorocarbons as a consequence of temperature and alumina concentration gradients within the cell.

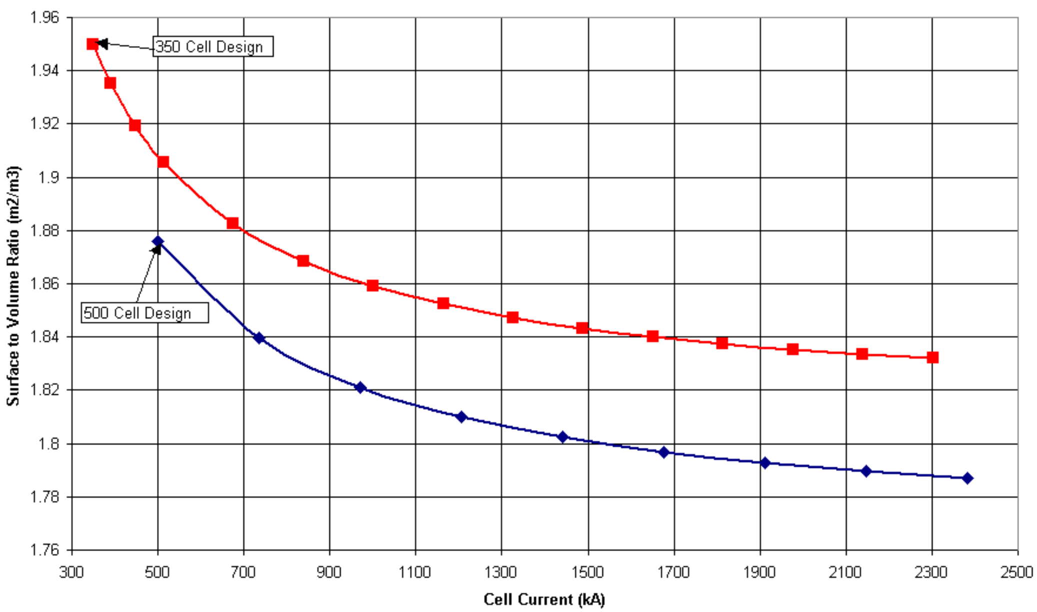


Ref: OA.T. Tabereaux, "Low Voltage Anode Effects and Unreported PFC Emissions", Proceedings of 34th International ICSOBA Conference, Québec City, Canada, 3 – 6 October 2016, Paper AL16, Travaux No. 45, 631-641.

Introduction

- **The benefits of increasing the amperage through length of the cells in reducing the heat loss steadily diminishes an almost an exponential decay, so future reductions in energy consumption are dependent on designs that can lead to lower heat loss.**

Figure 1: Extrapolation of the cell amperage vs the cell aspect ratio for the 350 kA and the 500 kA cell designs



Ref: M. Dupuis, "Thermo-Electric Design of a 740 kA Cell, Is There a Size Limit", ALUMINIUM 81(4) (2005), 324-327.

Introduction

- Designing wider cell would also open the door to reducing the heat loss per unit production and also increasing the productivity of the potroom by minimising the wasted space associated with the cell to cell interconnection.

Criteria applied to new designs

- In this paper the successful advanced models already developed have been applied to basic cell design when fitted with anodes that enable the width to be extended and hence the active electrode area per unit cell length increased.
- It also looks to applying the reversed compensation current (RCC) busbar concept, and utilising the benefits of utilising a greater proportion of strategically positioned copper in the collector bars.

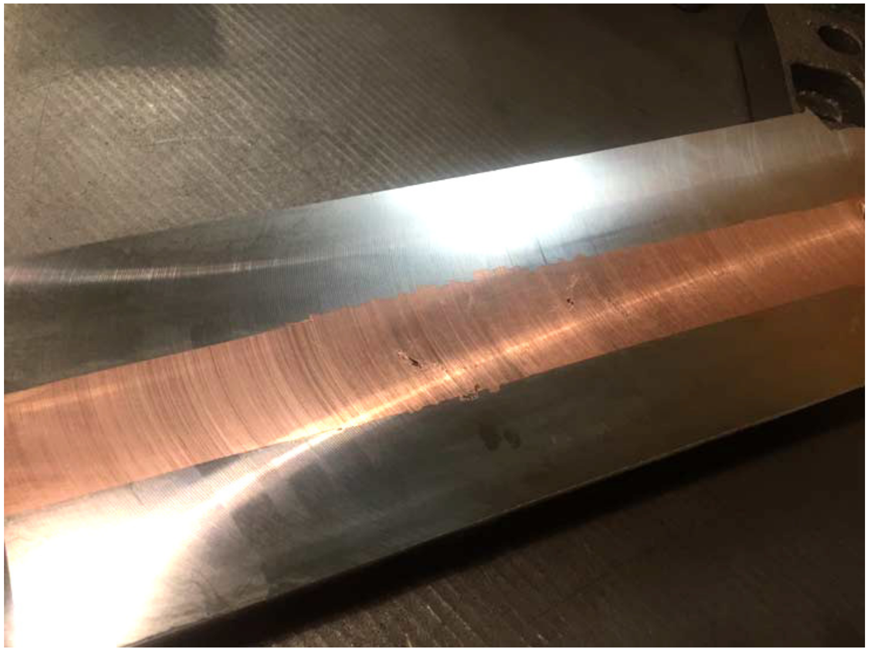
Ref: M. Dupuis, "Thermo-Electric Design of a 740 kA Cell, Is There a Size Limit", ALUMINIUM 81(4) (2005), 324-327.

M. Dupuis, V. Bojarevics and D. Richard, "MHD and pot mechanical design of a 740 kA cell" ALUMINIUM 82, (2006) 5, 442-446.

M. Dupuis and V. Bojarevis, "Retrofit of a 500 kA cell design into a 600 kA cell design," ALUMINIUM, 87 (1/2), 2011, 52-55.

Criteria applied to new designs

- For a time, it was speculative that mostly copper collector bar design could be actually build, but it is no longer the case.



Ref: Dag Sverre Sæsbøe, Storvik high conductivity anode yoke with copper core, Proceedings of 33rd International ICSOBA Conference, Dubai, UAE, 29 November – 1 December 2015, Paper AL23, Travaux No. 44, 717-726.

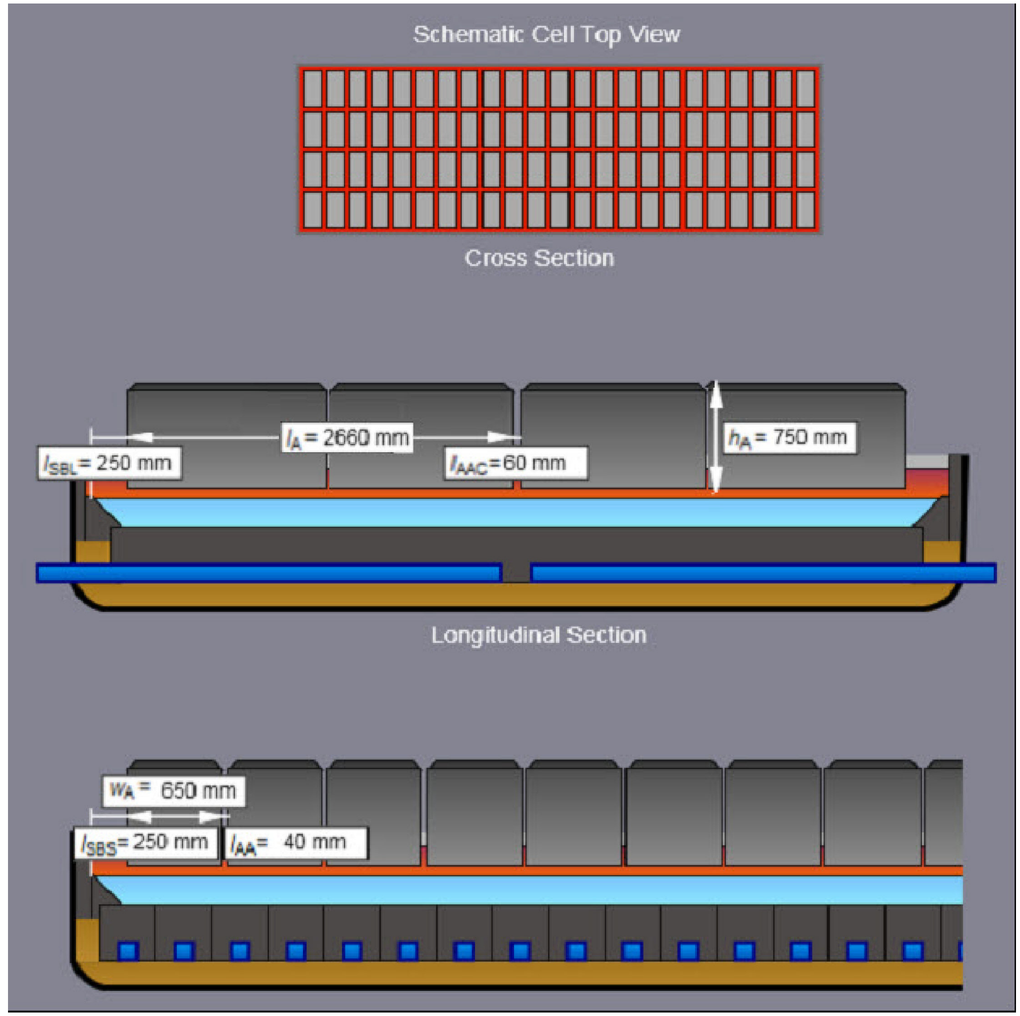
Ref: René von Kaenel and al., Copper Bars for the Hall-Héroult Process, VIII International Congress & Exhibition "NON-FERROUS METALS and MINERALS, Krasnoyarsk, Russia September 13-16, 2016.

Criteria applied to new designs

- The key features of the anode designs envisioned in this analysis are as for each anode rod supports two carbon blocks of a standard width and height but arranged end on end giving and total overall length of 2.66 m.
- The gap between the two anodes would provide a channel to enhance electrolyte flow and mixing of the alumina to minimise concentration gradients thus minimising spatial problems and lowering the risk of PFC co-evolution.

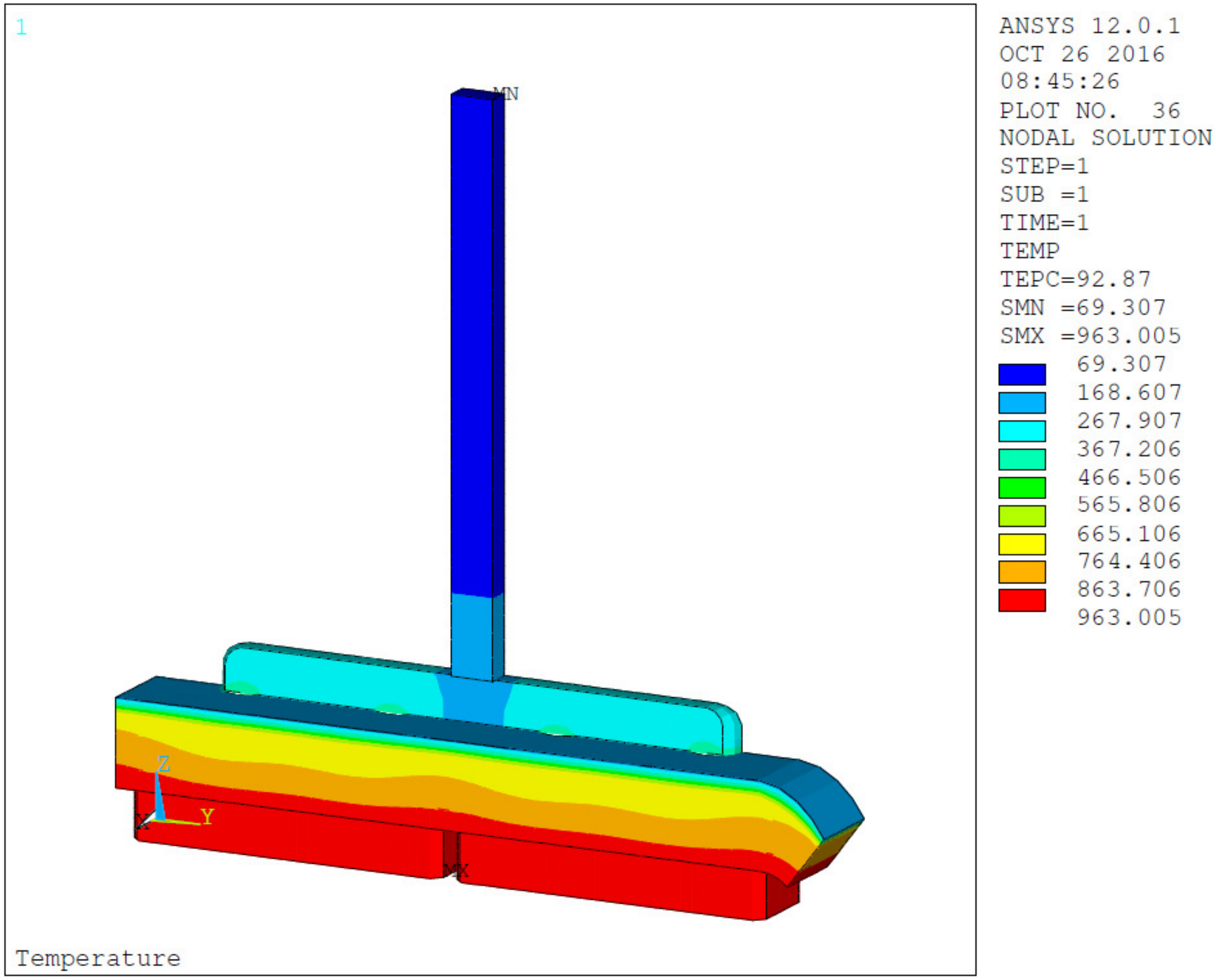
The 760 kA cell

- The first cell design evaluated has internal dimensions of the cavity 17.02 m long by 5.88 m wide and this would be fitted with 48 anode assemblies giving rise to an operating current of 762 kA.



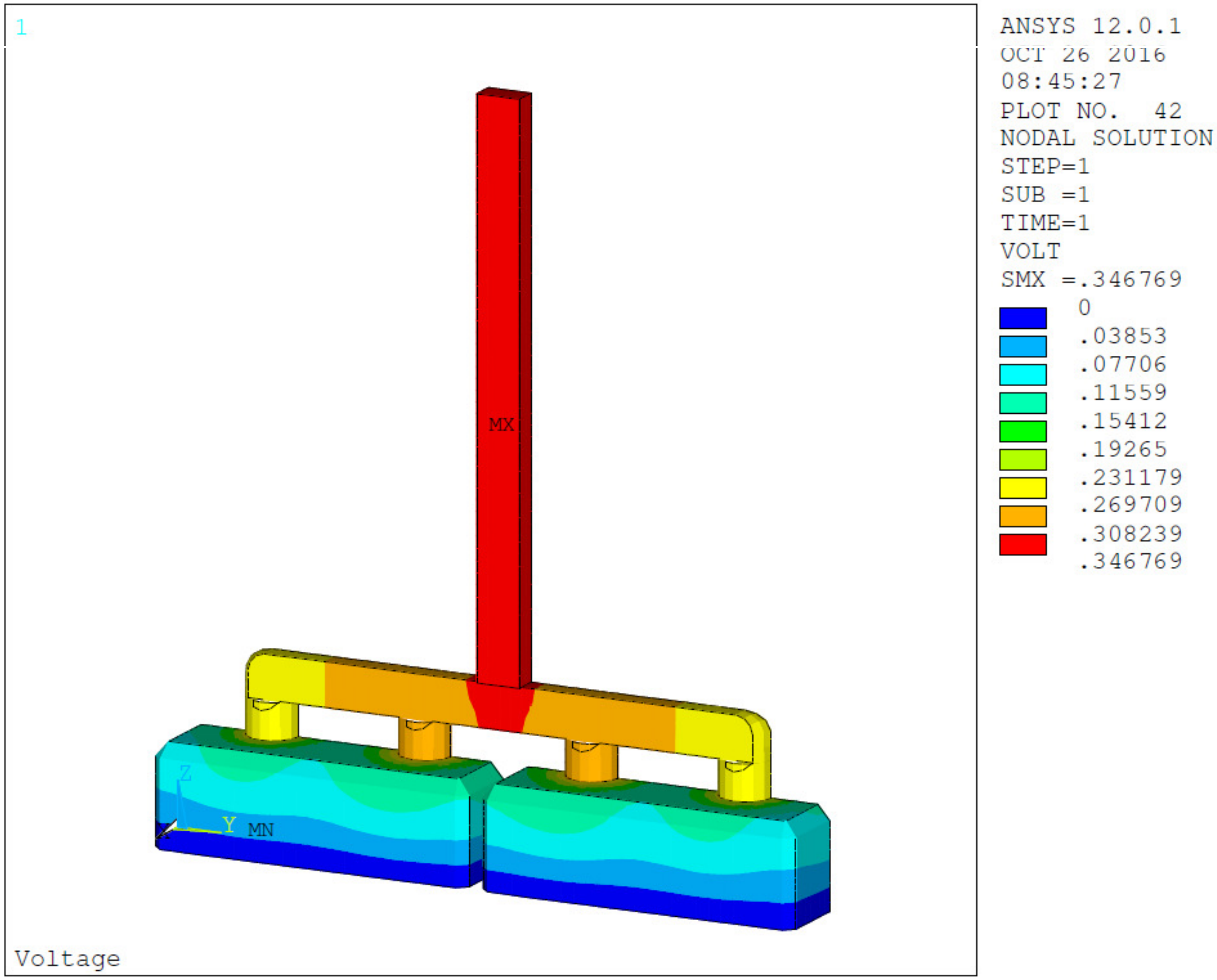
Ref: P. Entner, CellVolt AlWeb application: http://peter-entner.com/ug/windows/cellvolt/toc.aspx

The 760 kA cell



Thermal profile of the wide anode

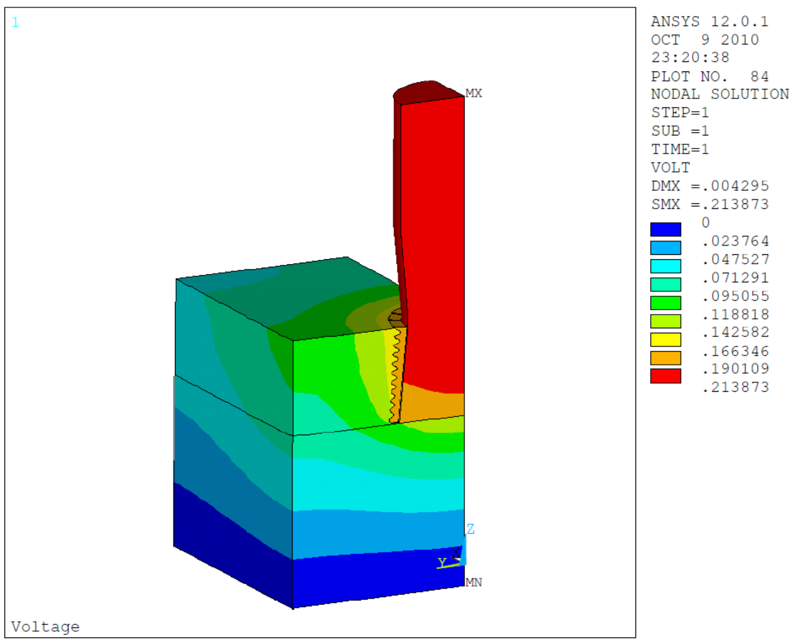
The 760 kA cell

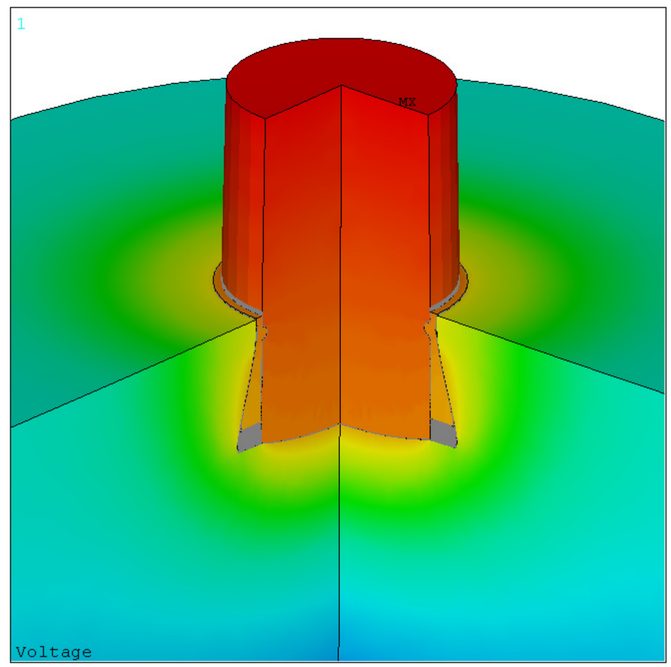


Voltage solution

The 760 kA cell

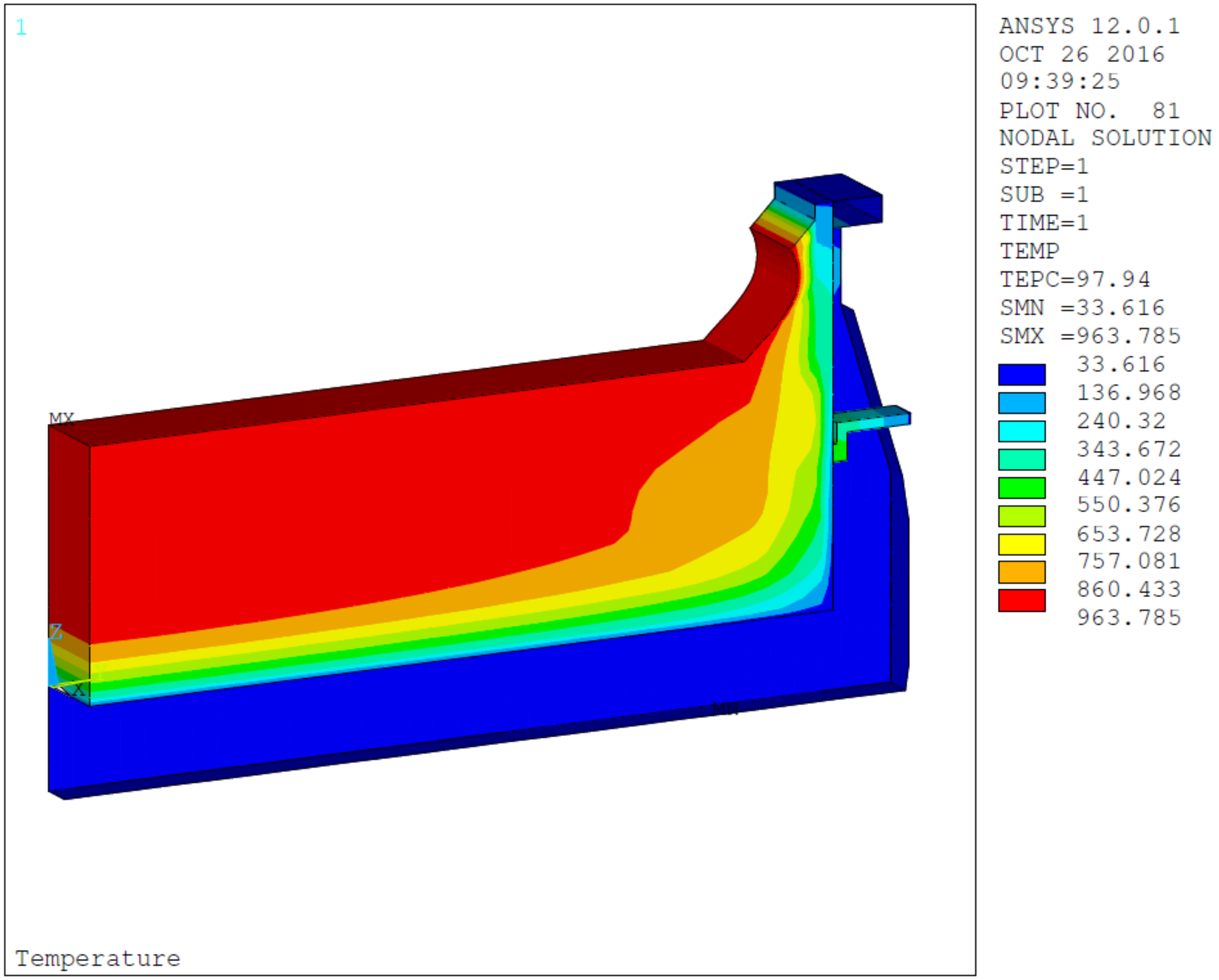
- Each anode assembly is predicted to have a resistance of 22 μΩ giving a voltage drop of 347 mV at 0.94 A/cm^2 anodic current density when using the anode stub hole design presented recently.





Ref: M. Dupuis, "Presentation of a New Anode Stub Hole Design Reducing the Voltage Drop of the Connection by 50 mV", VIII International Congress & Exhibition "Non-Ferrous Metals and Minerals", Krasnoyarsk, Russia, 13 – 16 September 2016

The 760 kA cell



Thermal profile of the wide cathode

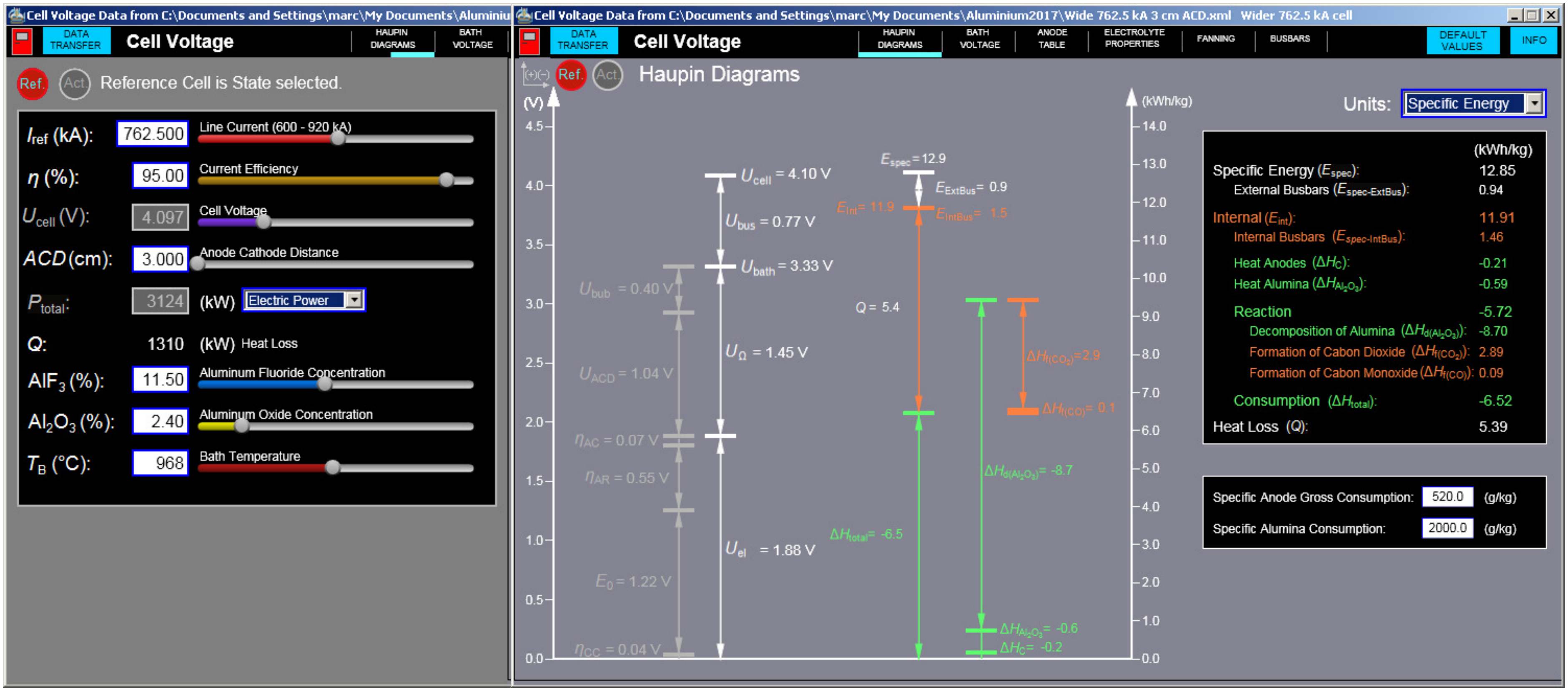
The 760 kA cell

- The cathode voltage drop is predicted to be 118 mV when the cell operates at 762 kA.
- Assuming a busbar drop of 300 mV, a global busbar resistance of 0.394 micro ohms is obtained.
  - Only busbar capex would inhibit lowering it if desired
- Assuming an operating anode to cathode distance (ACD) of 3.0 cm, a global cell pseudo-resistance of 3.21 micro ohms is obtained, which corresponds to a cell voltage of about 4.10 V.

The 760 kA cell

- Current efficiencies of 95% have been achieved at similar and even slightly lower model based ACD's.
- This combination of operating conditions would correspond to comparable and achievable energy consumption of 12.8 kWh/kg.
- The consequential cell heat loss would be approximately 1300 kW which is consistent with both the thermodynamic dynamics of the process and the modelling output for the proposed anode cover depth.

The 760 kA cell



Ref: P. Entner, CellVolt AlWeb application: http://peter-entner.com/ug/windows/cellvolt/toc.aspx

The 760 kA cell

DYNA/MARC 14.0 - [Wide 762.5 kA]

Steady State Solution

Cell amperage	762.5	[kA]
Anode to cathode distance	3.00000	[cm]
Operating temperature	968.978	[C]
Ledge thickness, bath level	4.49081	[cm]
Ledge thickness, metal level	0.52254	[cm]
Mass of metal	42404.2	[kg]
Mass of bath	10626.25	[kg]
Mass of dissolved alumina	255.030	[kg]
Mass of dispersed alumina	97.335	[kg]
Mass of alumina sludge	2.5787	[kg]
Mass of dissolved aluminum fluoride	1222.019	[kg]
Mass of dispersed aluminum fluoride	1.378	[kg]
Mass of aluminum fluoride sludge	0.0003	[kg]
Mass of calcium fluoride	637.575	[kg]
Alumina feeding rate	469.110	[kg/hr]
Aluminum fluoride feeding rate	4.21936	[kg/hr]

Ref: M. Dupuis and H. Côté, Dyna/Marc Version 14 User's Guide, (2012).

The 760 kA cell

DYNA/MARC 14.0 - [Wide 762.5 kA]

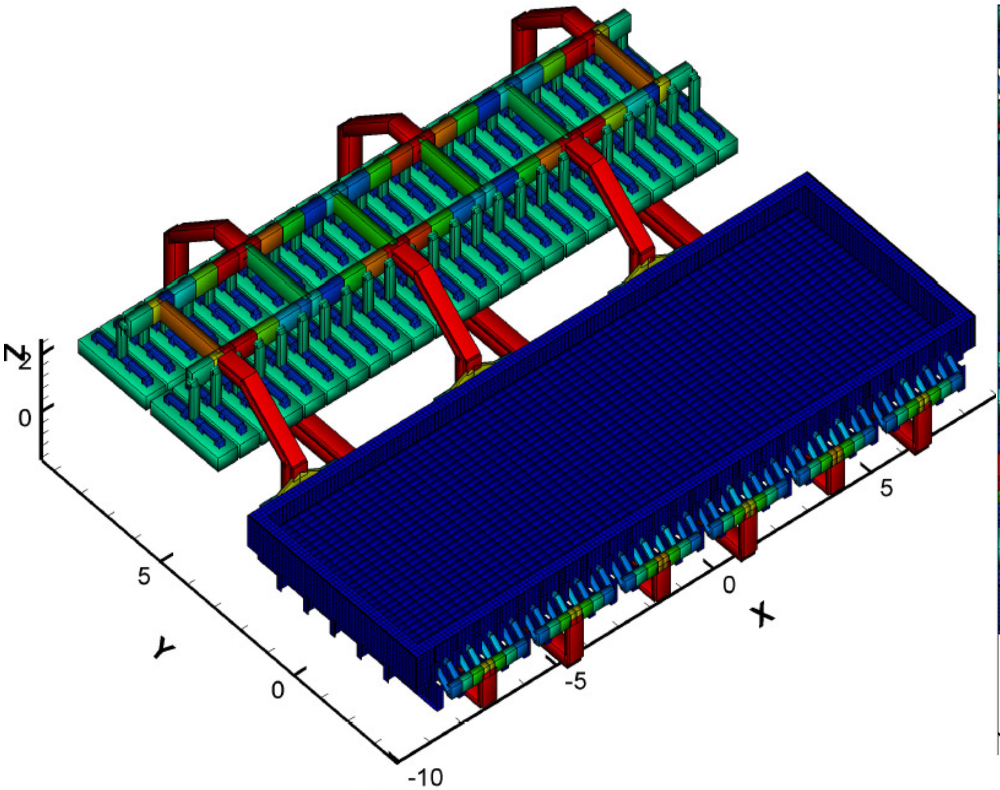
Steady State derived Variables

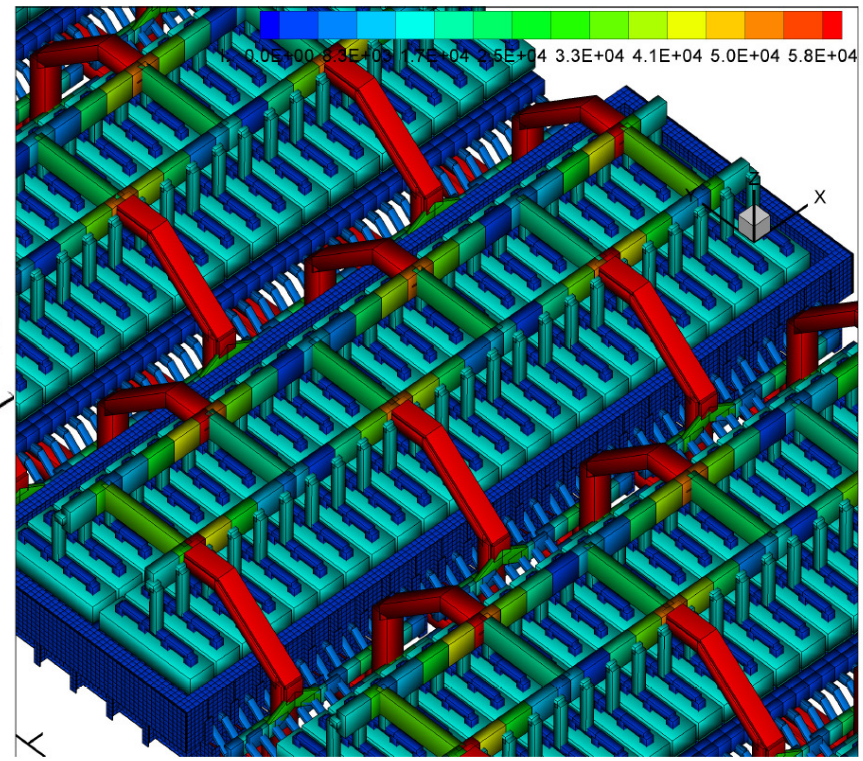
Heat balance:		
Superheat	10.0829	[C]
Cell energy consumption	12.8476	[kWhr/kg]
Total heat loss	1328.232	[kW]
Total electrical input energy	2898.16	[kW]
Internal heat generation	1328.232	[kW]
Electrical characteristics:		
Current efficiency	95.1398	[%]
Anode current density	0.939965	[A/cm*cm]
Bath resistivity	0.449033	[ohm-cm]
Cell pseudo-resistance	3.21425	[micro-ohm]
Bath voltage	1.31323	[V]
Electrolysis voltage	2.02463	[V]
Cell voltage	4.10086	[V]
Voltage to make the metal	2.04914	[V]
Geometric variables:		
Height of bath	20.0000	[cm]
Height of metal	20.0000	[cm]
Area of cell cavity	97.6948	[m*m]
Area of anode panel	81.1200	[m*m]
Area of bath	95.6587	[m*m]
Area of metal	92.1884	[m*m]
Perimeter of ledge, bath level	45.3404	[m]
Perimeter of ledge, metal level	45.0311	[m]

Ref: M. Dupuis and H. Côté, Dyna/Marc Version 14 User's Guide, (2012).

Benefits of the RCC busbar concept design

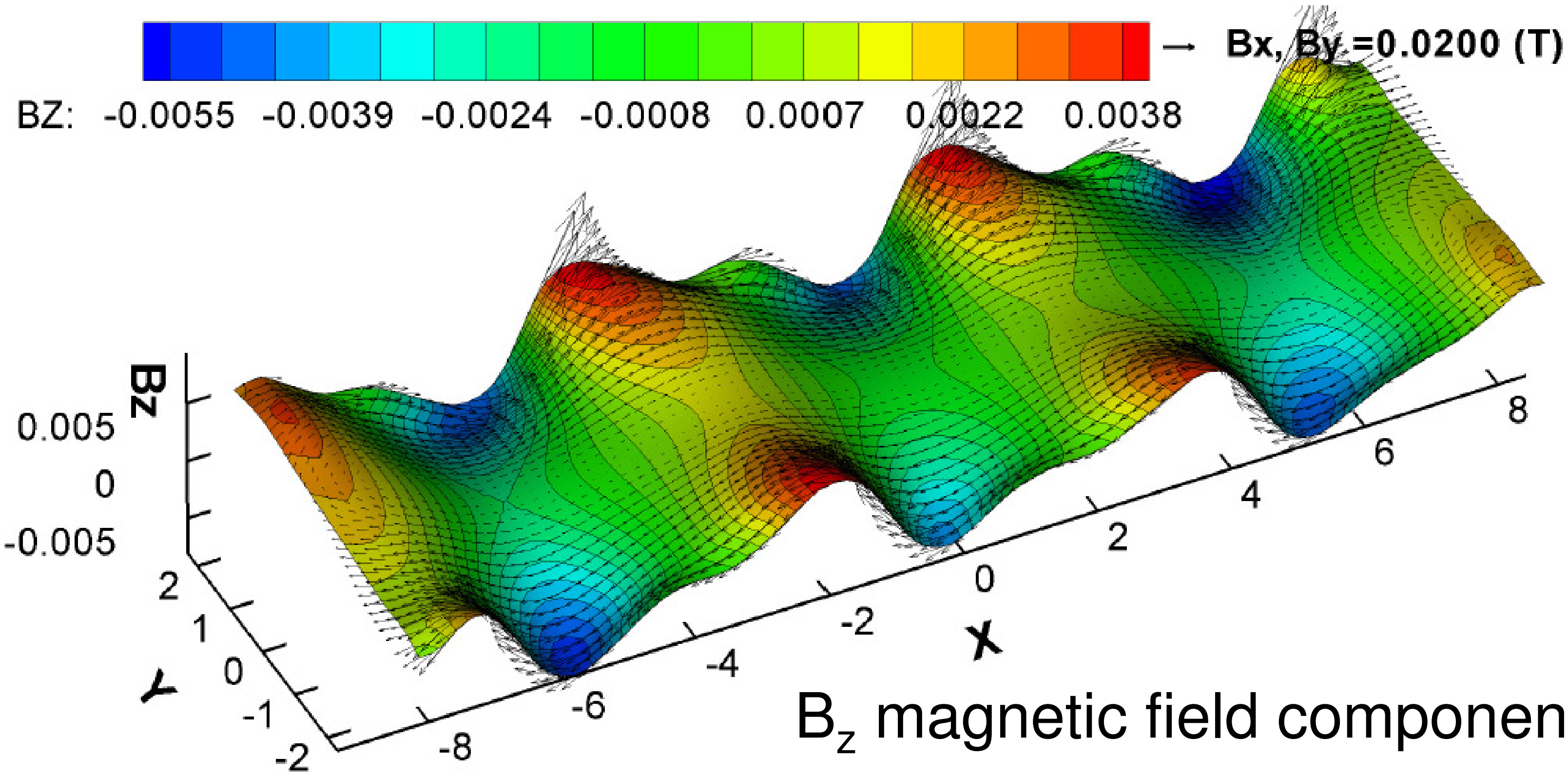
- The reversed compensation current (RCC) busbar concept used in the modelling incorporates alternating upstream and downstream anode risers.





Benefits of the RCC busbar concept design

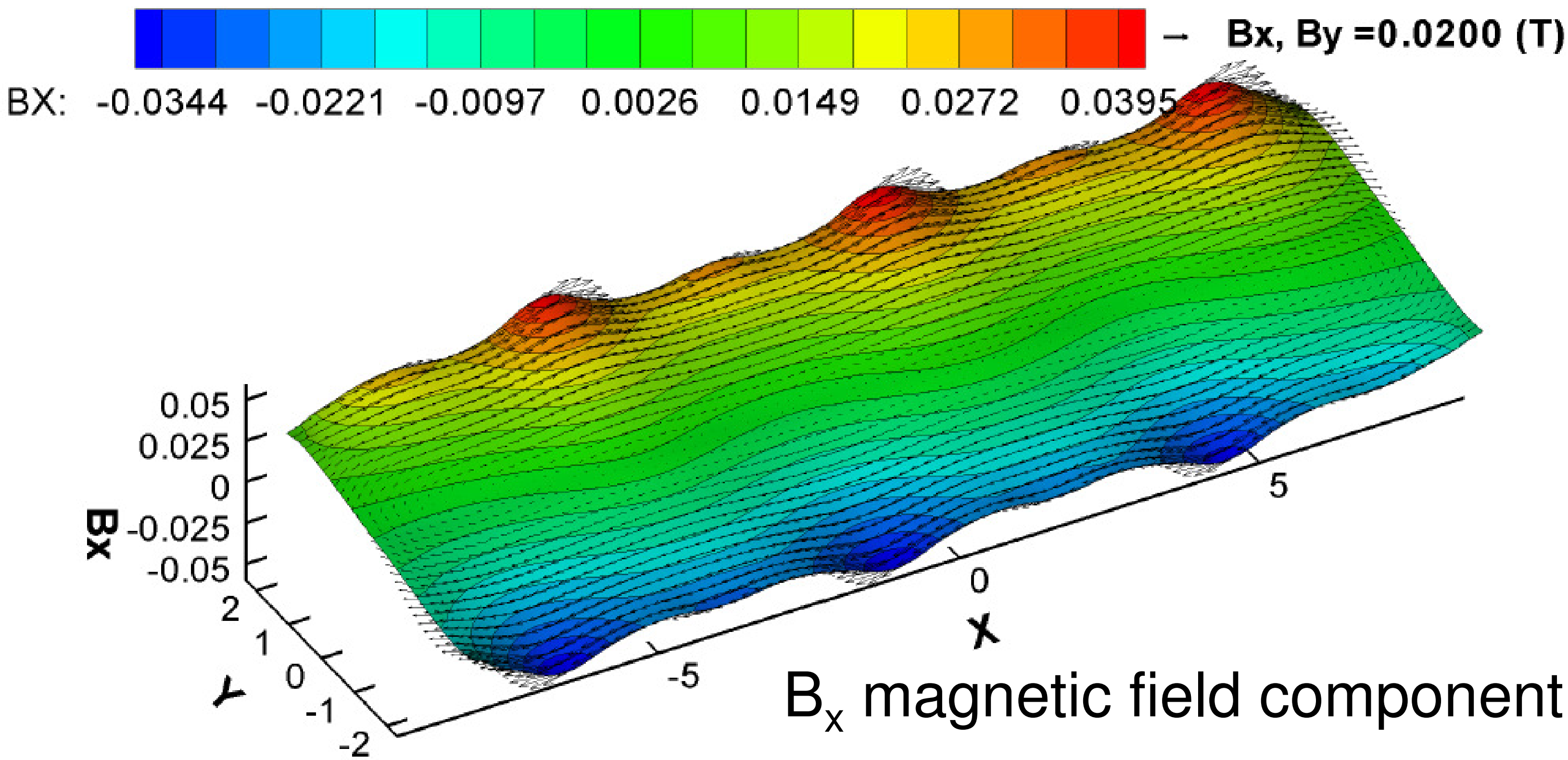
- Resulting vertical component of the magnetic field (B_z) obtained while using this busbar configuration.



B_z magnetic field component

Benefits of the RCC busbar concept design

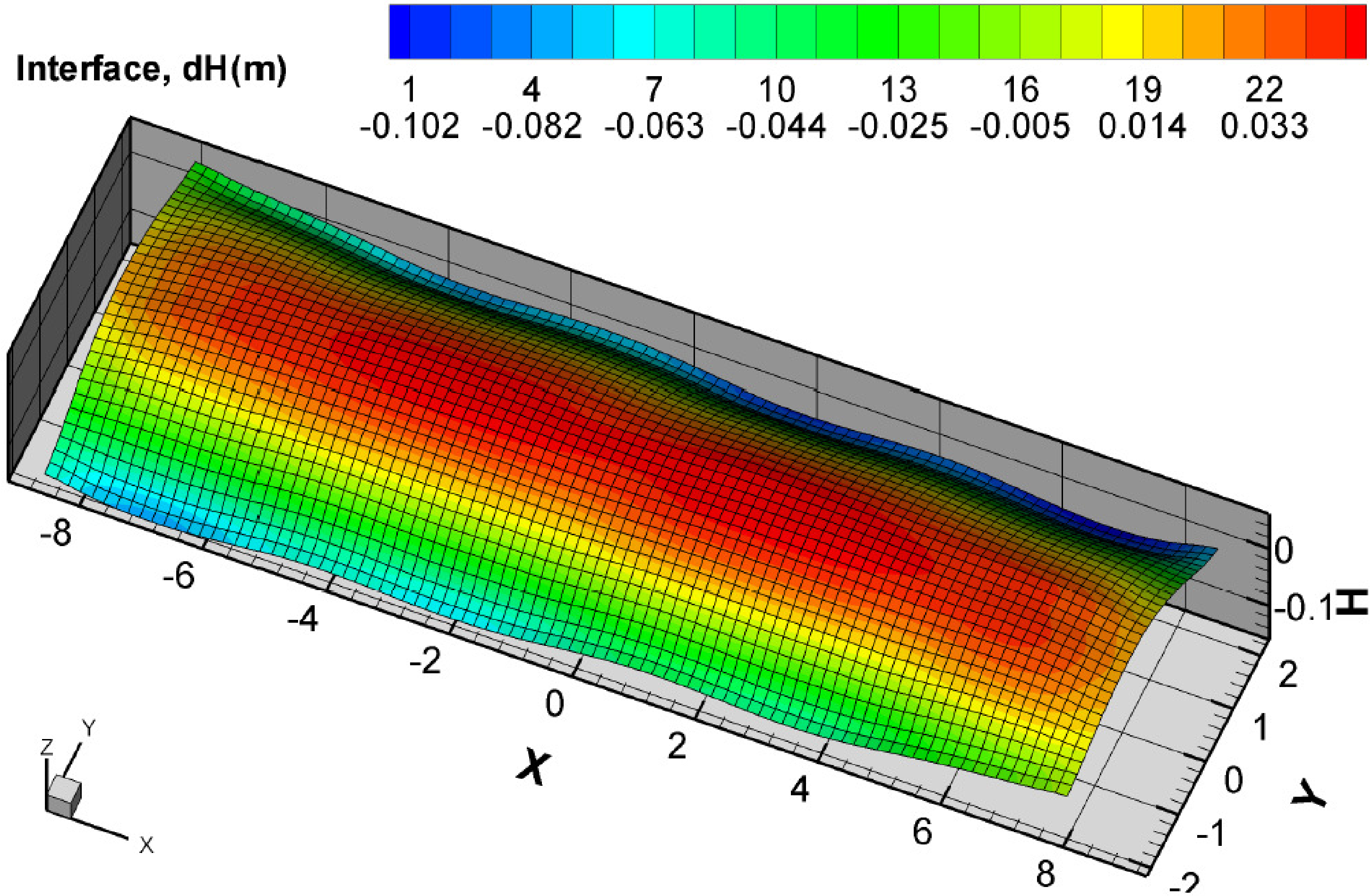
- **Resulting longitudinal horizontal component of the magnetic field (B_x) obtained.**



B_x magnetic field component

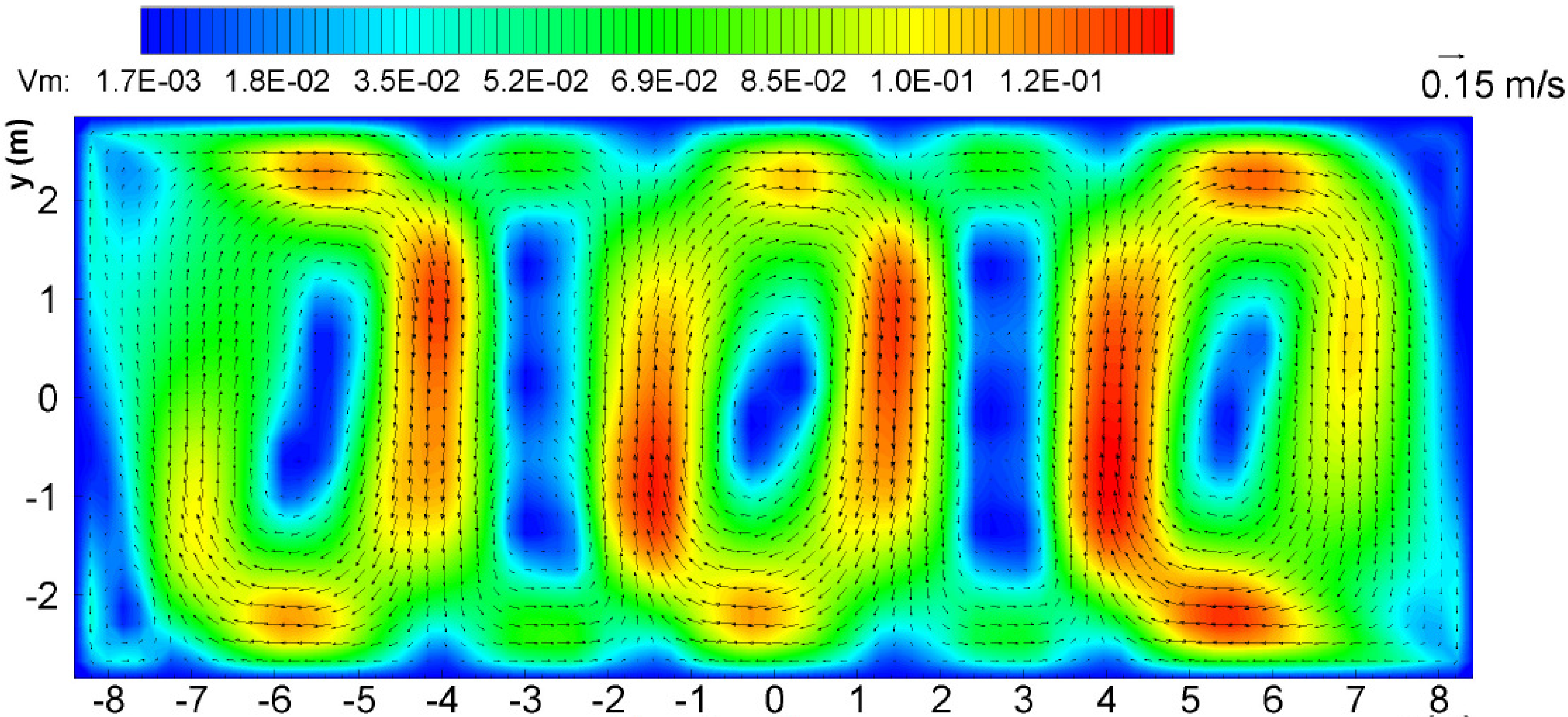
Benefits of the RCC busbar concept design

- **Resulting steady-state bath-metal interface deformation.**



Benefits of the RCC busbar concept design

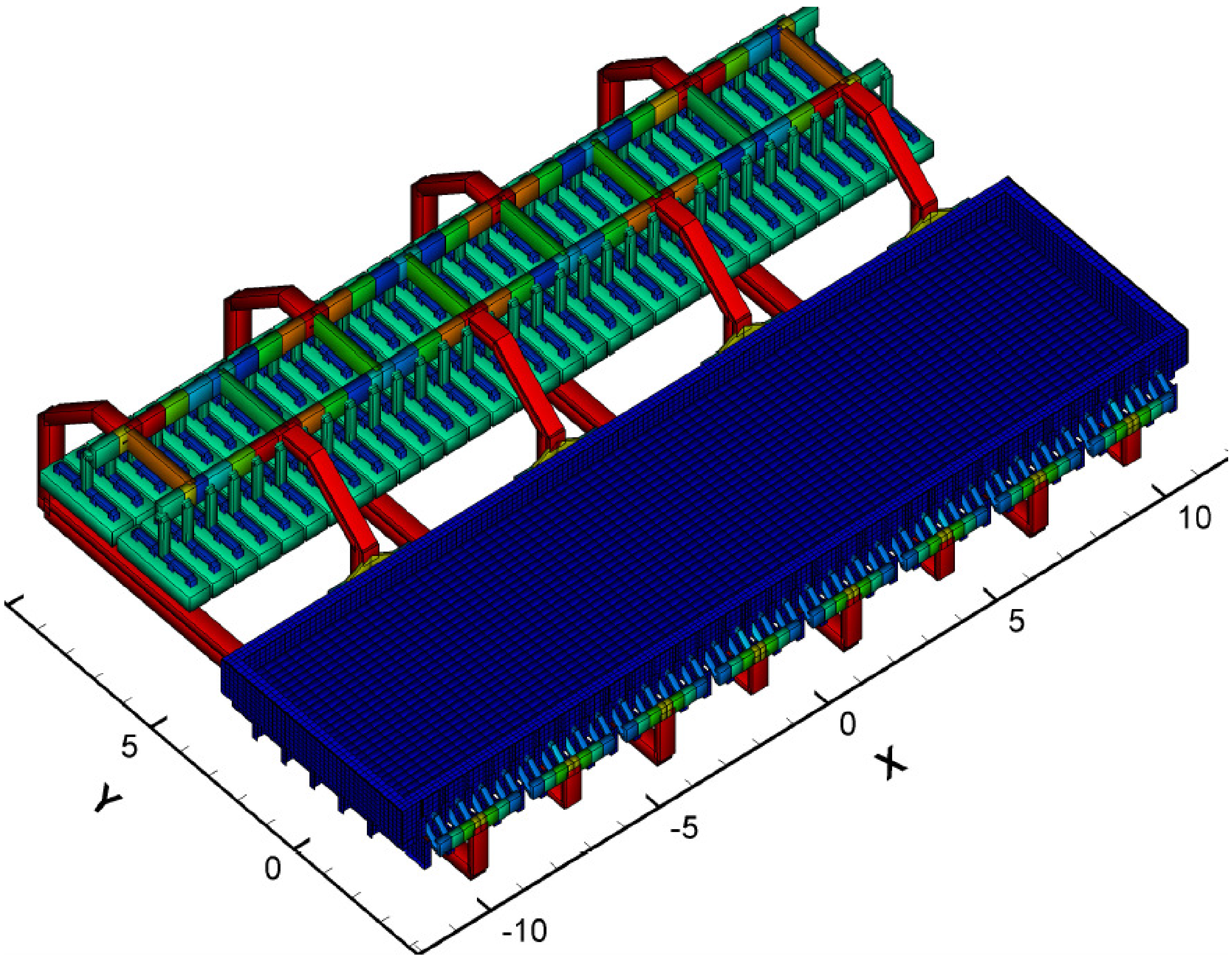
- Resulting steady-state metal pad flow velocity field.



Al velocity

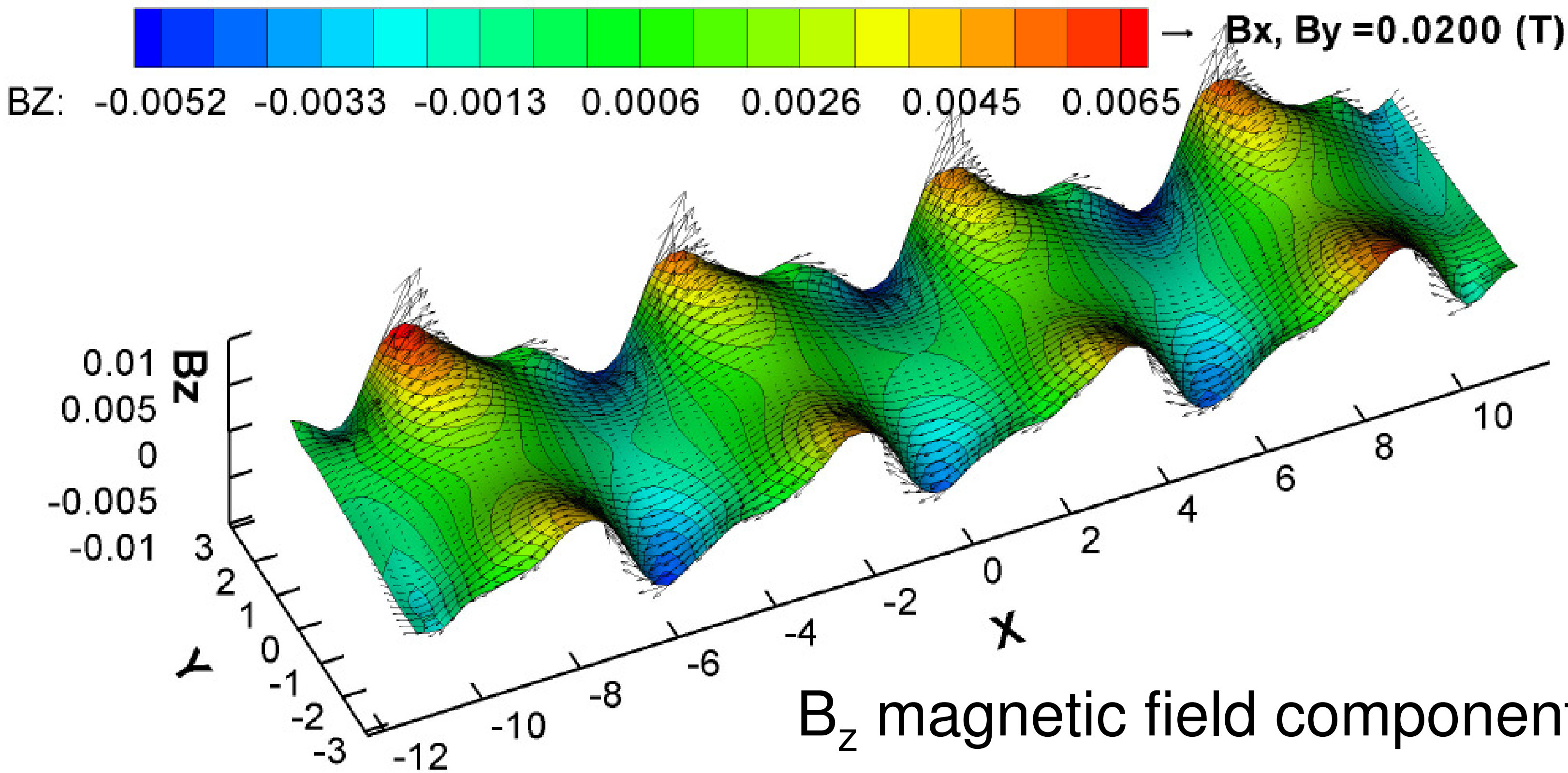
Extrapolation to a longer 1 MA cell

- As previously demonstrated, the RCC busbar concept is applicable to any cell length. This is the RCC busbar layout of a 64 anodes, 8 anode risers 1 MA cell.



Extrapolation to a longer 1 MA cell

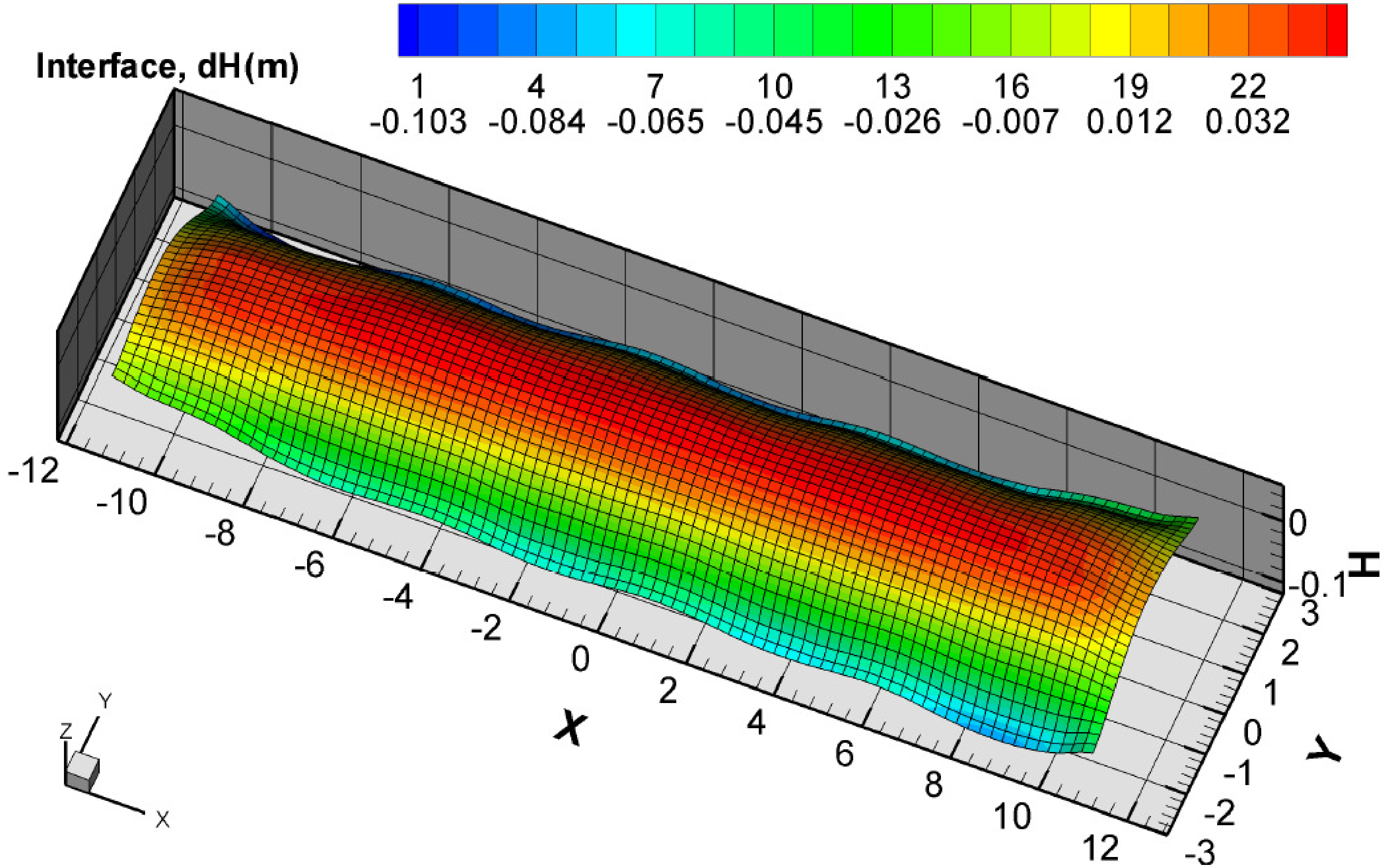
- **Resulting vertical component of the magnetic field (B_z) obtained while using this busbar configuration.**



B_z magnetic field component

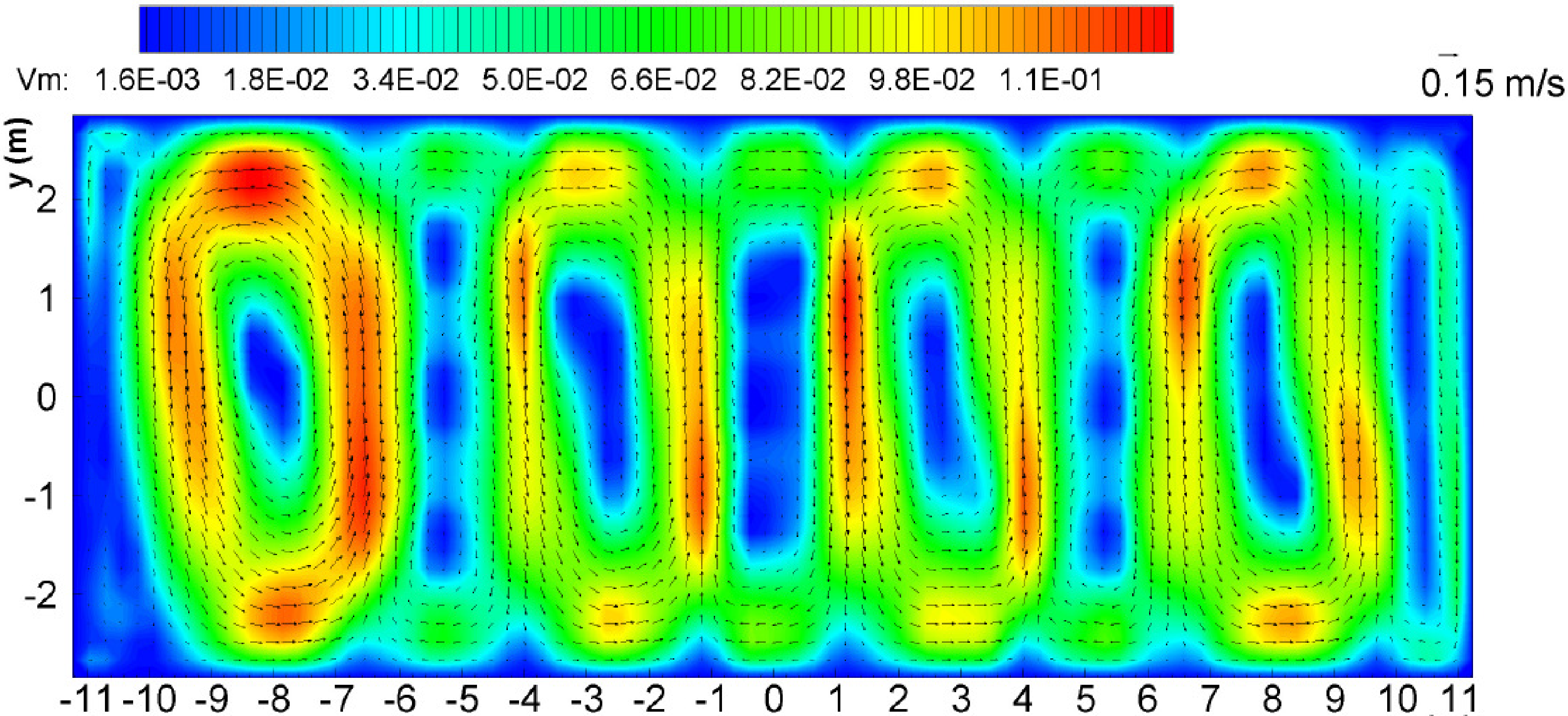
Extrapolation to a longer 1 MA cell

- **Resulting steady-state bath-metal interface deformation.**



Extrapolation to a longer 1 MA cell

- **Resulting steady-state metal pad flow velocity field.**



Al velocity

Discussion

- The modelling outputs clearly show several advantages of the combination of RCC, and increasing the width of the shell and simultaneously bath mixing channels for a alumina distribution to bring about an improved environmental performance.
- The new anode and superstructure design features enable introduction of features that can minimise the spatial variations in temperature and alumina concentration which are the root cause of the low level of perfluorocarbons that are coevolved in the long narrow high amperage cells.

Conclusions

- The innovative practical design features modelled here clearly open the door to significant advantages. Reductions in capital and operating costs of greenfield smelters are likely, while the new cells would give new benchmark levels of environmental performance.