MHD AND POTSHELL MECHANICAL DESIGN OF A 740 KA CELL

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In 2005 in another article published in ALUMINIUM [1], it was demonstrated that as far as the thermal balance aspect of the cell design is concerned, there is no limit to the size of cells that could be designed.

In order to substantiate that declaration, the thermal-electric design of a 740 kA cell was presented. But what about the cell MHD stability and the potshell mechanical design for that 9 risers, 26.2 meters long cell?

The present article covers both those aspect of the cell design. Results suggest that as far as the MHD cell stability aspect of the cell design is concerned, there is no limit to the size of cells that could be designed. Finally, as far as the potshell mechanical design is concerned, after taking care of the potshell thermal deformation issue [2], there is no limit in sight to the size of cells that could be designed either.

500 kA cell MHD design

In his TMS 2005 paper [3], Urata clearly indicates that, in addition to the average magnitude, it is the gradient of the vertical component of the magnetic field (Bz) in the longitudinal direction of the cell that is responsible for the main instability mechanism in a modern side by side high amperage cell.

So it is not surprising that in their 1987 busbar patent [4], Pechiney researchers describe how they minimized that Bz longitudinal gradient (see figure 2 of [4]) by using compensation busbars running along both sides of the row of cells carrying current in the same direction as the potline (see figure 3 of [4]). According to the Pechiney patent, this compensation busbar configuration will work well up to 500-600 kA cells.

This compensation busbar configuration has been analyzed using MHD cell stability modeling tool [5, 6 and 7] on a 500 kA cell (see figure 1 for the busbar configuration). It indeed reduced the Bz magnetic field gradient in the longitudinal direction to about 40 Gauss over 17.3 meters (from 20G to –20G, see figure 2) despite the fact that all 6 positive busbars are running under the cell.

Yet, even with that relatively low Bz longitudinal gradient, the MHD model is predicting that a coupled (2,0) and (0,1) bath metal interface deformation wave, the exact type of wave predicted in Urata's paper, will grow in the cell (see figure 3 and 4).

Of course, there was no attempt to really optimize the compensation busbar configuration, so for sure, a better setup can exist. But already in order to reduce the Bz longitudinal gradient to 40 Gauss over 17.3 meters, the compensation busbar on the side of the return line must carry 250 kA and the compensation busbar on the opposite side must carry 145 kA. So in the case presented here, a total of 395 kA or 79% of the potline current is been carry by the 2 compensation busbars. It is very doubtful that this compensation busbar configuration could be extend to a 740 kA cell.

In order to stabilize very high amperage cells, a new compensation busbar configuration has been developed. The resulting average Bz is so close to 0 (0.0003 T) that no distinctive low frequency wave can develop in the cell (see figure 5 and 6).

740 kA cell MHDdesign

Notably, this new compensation busbar configuration is working for any length of potshell and any number of positive busbars running under the cell. The 9 risers, 740 kA cell design presented before [1] has too a resulting Bz so close to 0 that no distinctive low frequency wave can develop in the cell (see figure 7 and 8).

Extrapolation to a 2380 kA cell design

This new compensation busbar configuration will equally well work for any reasonable length of potshell and any number of risers, for example a 85.8 meter long, 30 risers, 2380 kA cell [1] could too be magnetically compensated using the same approach. So it is possible to conclude that as far as the MHD cell stability aspect of the cell design is concerned, there is no limit to the size of cells that can be designed.

740 kA cell potshell mechanical design

It may sound hard to believe, but it quite possible that problems related to the potshell mechanical behavior are one of the main reasons why the industry trend to use bigger and bigger cells in new greenfield smelter projects has been considerably slowing down in recent years.

In [1], it was demonstrated that the usage of cooling fins or forced air convection are not required as far as the cell heat balance aspect of the cell design is concerned. Yet potshell cooling fins are now a standard feature of the AP30-35 technology and forced air convection is used in AP50 technology. Why then if is not used to enhance the heat loss dissipation?

The answer to that question has already been given is [2], those devices are required to reduce the thermally induced vertical potshell deflection which becomes quite harmful to the cell operation as the cells get bigger and bigger. It was also demonstrated in [2], that the use of forced air convection is more efficient than cooling fins to reduce or even completely eliminate the vertical potshell deflection. But should we conclude from these results that for cell amperage of 500 kA and more, the usage of forced air convection is mandatory in order to prevent the vertical potshell deflection to have an harmful effect on the cell operation?

In trying to answer this question, the first assumption is to assume that as the potshell gets longer, the problem of the vertical potshell deflection gets worse. Recent modeling results demonstrated that, depending on the potshell design, it might not be necessarily the case.

Figure 9 presents a 740 kA cell potshell mechanical model mesh and temperature loading for a standard design without cooling fins and forced air convection. Figure 10 presents the resulting vertical potshell deflection calculated using elasto-plastic mechanical steel properties. Figure 11 compares that vertical deflection with those obtained for 300 kA and 500 kA cell's potshell in similar conditions. Because of the change of aspect ratio the 26.2 meters long potshell behaves differently and, as a result, the vertical deflection is about the same as the 300 kA cell case instead of being worse than the 500 kA cell case.

It is also important to point out that for all three cases anyway, the vertical deflection remains small because that VAW 300 inspired potshell design [6] is very flexible in the upper section of the potshell side walls and deflect more laterally than vertically (see figure 12).

Of course, that vertical deflection can be reduced even further by using cooling fins, but following results presented in [2], it is important to ensure that those cooling fins are not increasing the upper side walls rigidity.

Unfortunately, it was not possible to find the time to run enough alternative cooling fins designs in order to discover one that actually improve the situation before this article publication deadline.

Conclusions

On the cell heat balance and MHD aspect of the cell design, it is clear that there is no limit to the size of cells that could be designed.

On the potshell mechanical design aspect, we don't have the data in hand to be so assertive, but there is no reason to believe that technically, we are facing a size limit. On the other hand, if for very high amperage cells, the solution to the potshell vertical deflection problem can only be solved by using expensive forced air convection devices, it is possible that the usage of those devices annihilates the financial incentive to keep designing bigger and bigger cells.

References

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

[2] M. Dupuis and D. Richard, "Study of the Thermally-Induced Shell Deformation of High Amperage Hall-Héroult Cellsl", *Proceedings of the 4th Conference on Light Metal, COM*, (2005), 35-47.

[3] N. Urata, "Wave Mode Coupling and Instability in the Internal Wave in the Aluminum Reduction Cells", *Light Metals, TMS,* (2005), 455-460

[4] J. Chaffy, B. Langon and M. Leroy, "Device for Connection Between Very High Intensity Electrolysis Cells for the Production of Aluminium Comprising a Supply Circuit and an Independent Circuit for Correcting the Magnetic Field", *US patent no 4,713,161,* (1987).

[5] V. Bojarevics and M.V. Romerio, "Long Wave Instability of Liquid Metal-electrolyte Interface in

Aluminium Electrolysis Cells: a Generalization of Sele's Criterion", *Eur. J. Mech., B/Fluids*, 13 (1) (1994), 33-56.

[6] V. Bojarevics, "Non-Linear Waves with Electromagnetic Interaction in Aluminium Electrolysis Cells", *Progr. Fluid Flow Res.: Turbulence and Applied MHD*, eds. H. Branover and Y. Unger, AIAA, (1998), Chapter 58, 833-848.

[7] M. Dupuis and V. Bojarevics, "Weakly Coupled Thermo-Electric and MHD Mathematical Models of an Aluminium Electrolysis Cell", *Light Metals, TMS*, (2005), 449-454.

[8] V.A. Kryukovski, G.A. Sirasutdinov, J. Klein and G. Peychal-Heiling, "Internanional Cooperation and High-Performance Reduction in Siberia", *JOM*, 46(2) (1994), 23-25.

Authors

Dr. Marc Dupuis is a consultant specialized in the applications of mathematical modeling for the aluminium industry since 1994, the year when he founded his own consulting company GeniSim Inc (www.genisim.com). Before that, he graduated with a Ph.D. in chemical engineering from Laval University in Quebec City in 1984, and then worked 10 years as a research engineer for Alcan International. His main research interests are the development of mathematical models of the Hall-Héroult cell dealing with the thermo-electric, thermo-mechanic, electro-magnetic and hydrodynamic aspects of the problem. He was also involved in the design of experimental high amperage cells and the retrofit of many existing cell technologies.

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Dr. Daniel Richard is specialized in numerical modeling of thermo-mechanical problems for metallurgical industries, including coupling with electrical or chemical fields. He graduated with a Ph.D. from Laval University in 2004, and is since working on process analysis and simulation at Hatch Associates Ltd (www.hatch.ca). His main research interests include the development of Object-Oriented finite element code, mechanical constitutive laws for refractory materials, and numerical modeling of the mechanical behavior of Hall-Héroult cells.

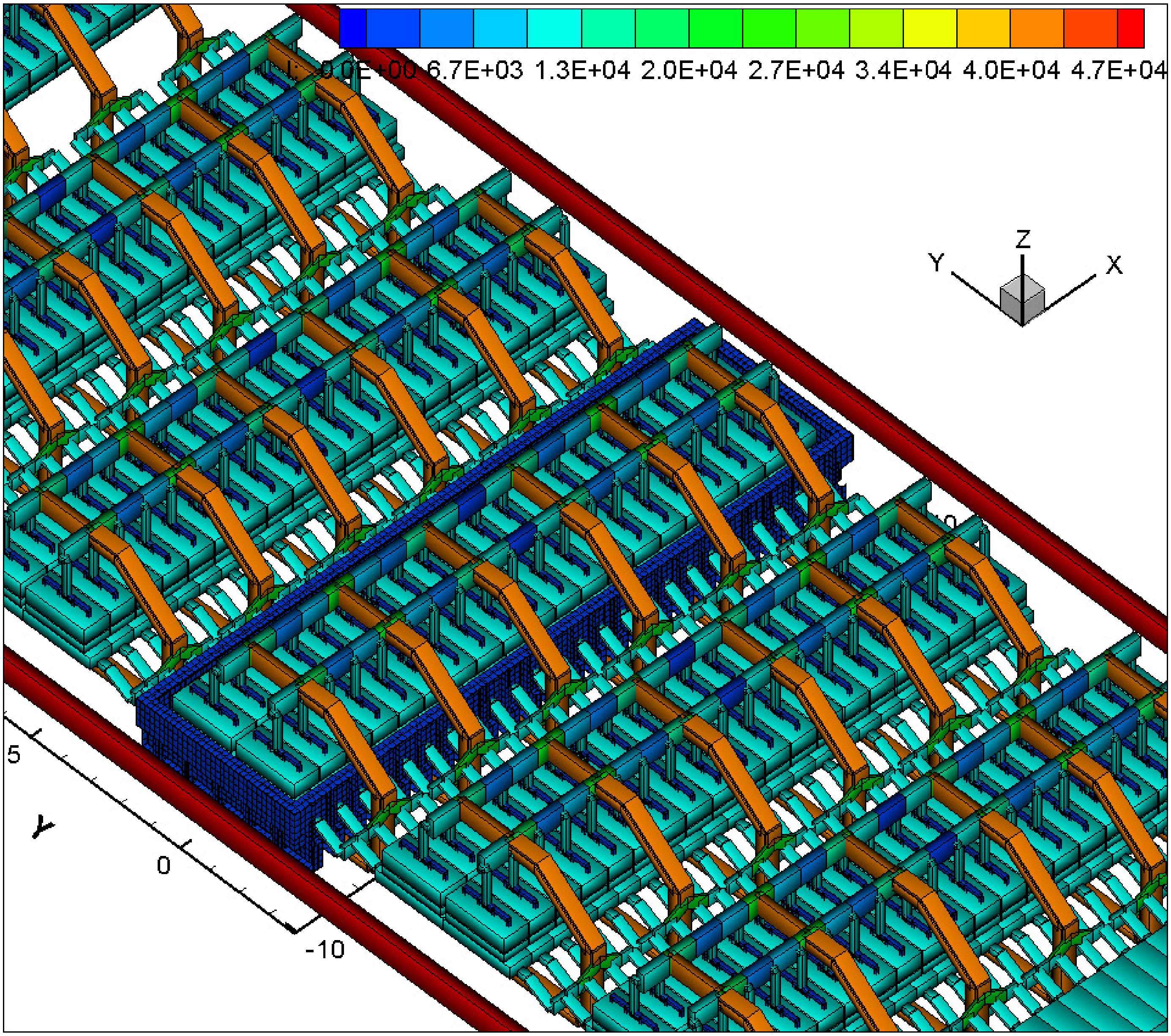


Figure 1: Demonstration 500 kA, 6 risers cell with the compensation busbars configuration patented by Pechiney in 1987.

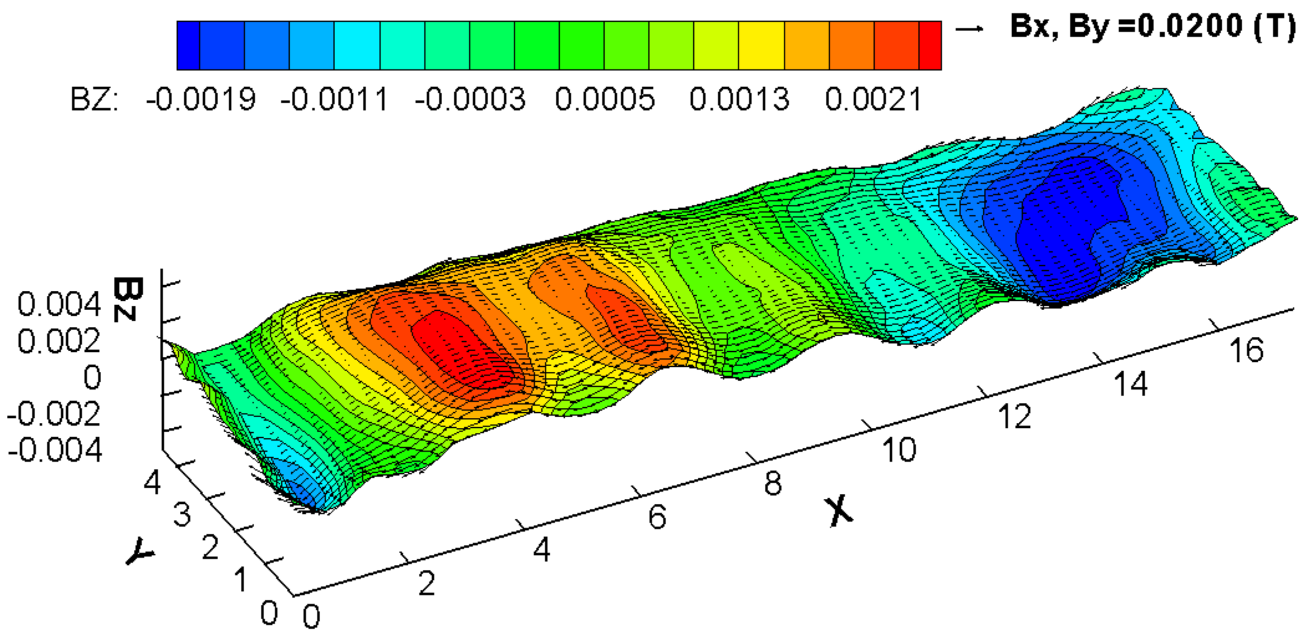
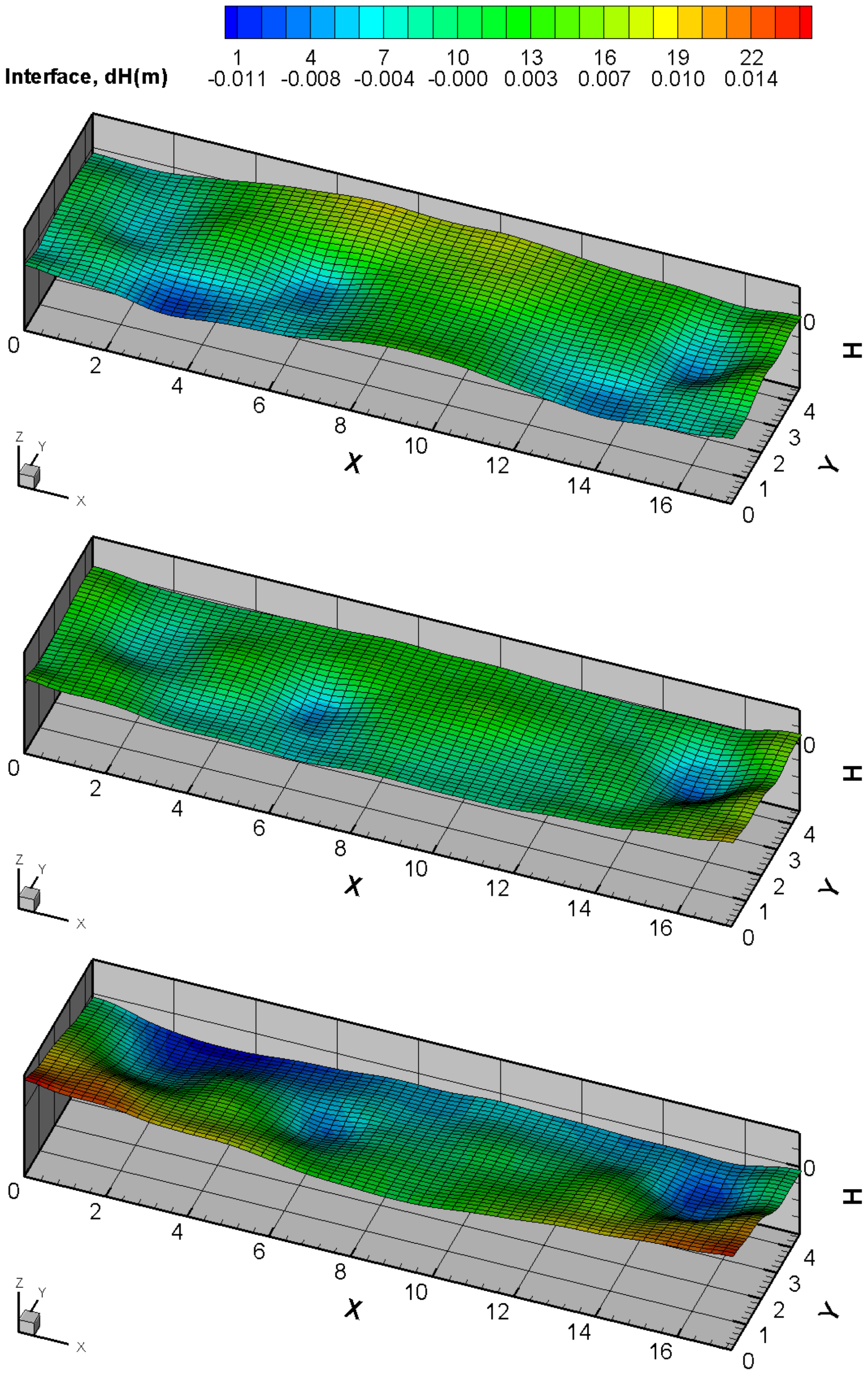


Figure 2: Resulting Bz magnetic field for that magnetically compensated 500 kA cell


Interface, dH(m)
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-0.011 -0.008 -0.004 -0.000 0.003 0.007 0.010 0.014
X
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0 2 4 6 8 10 12 14 16
0 1 2 3 4
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Z
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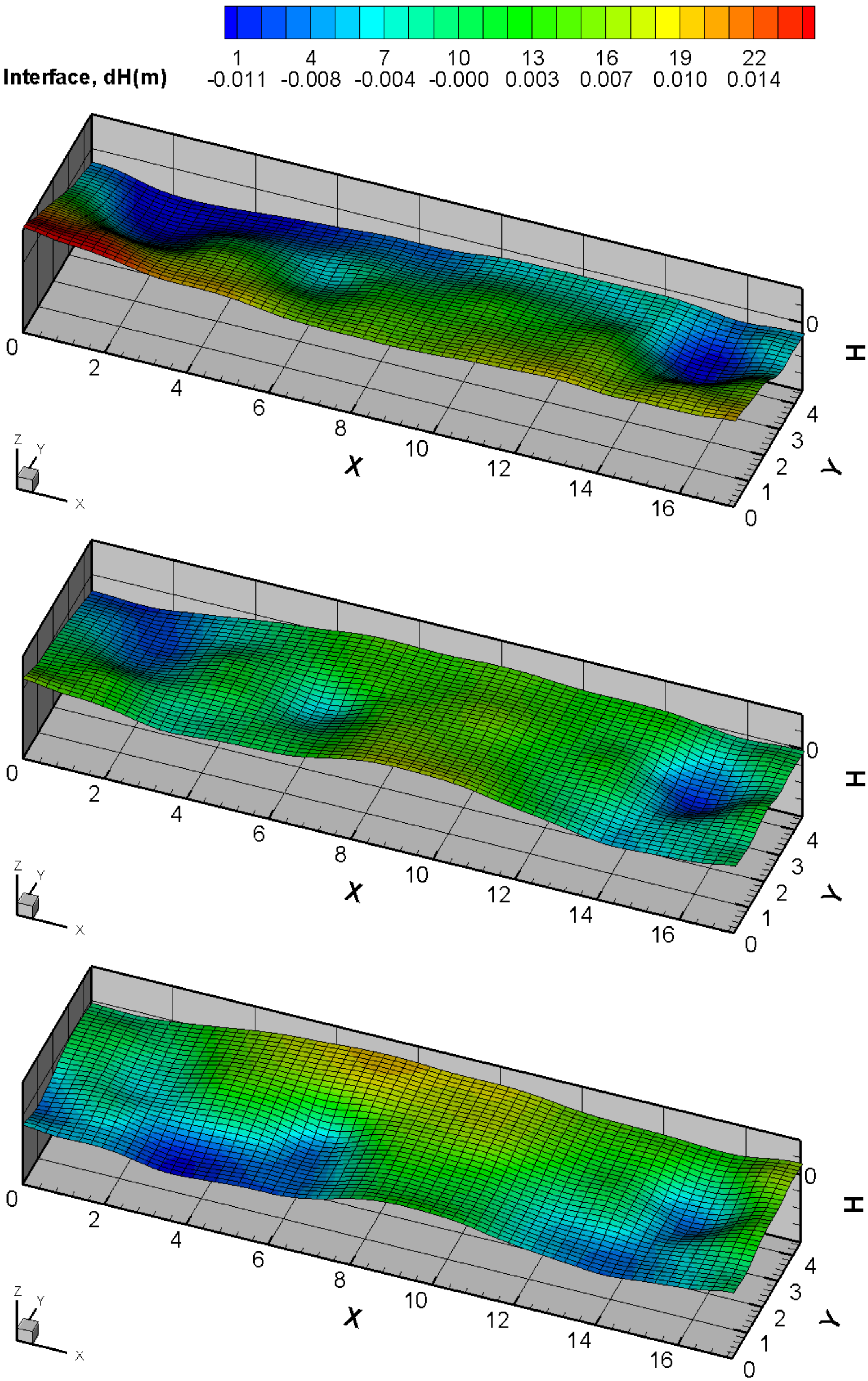

Figure 3: Coupled (2,0) and (0,1) MHD wave resulting from that busbar configuration

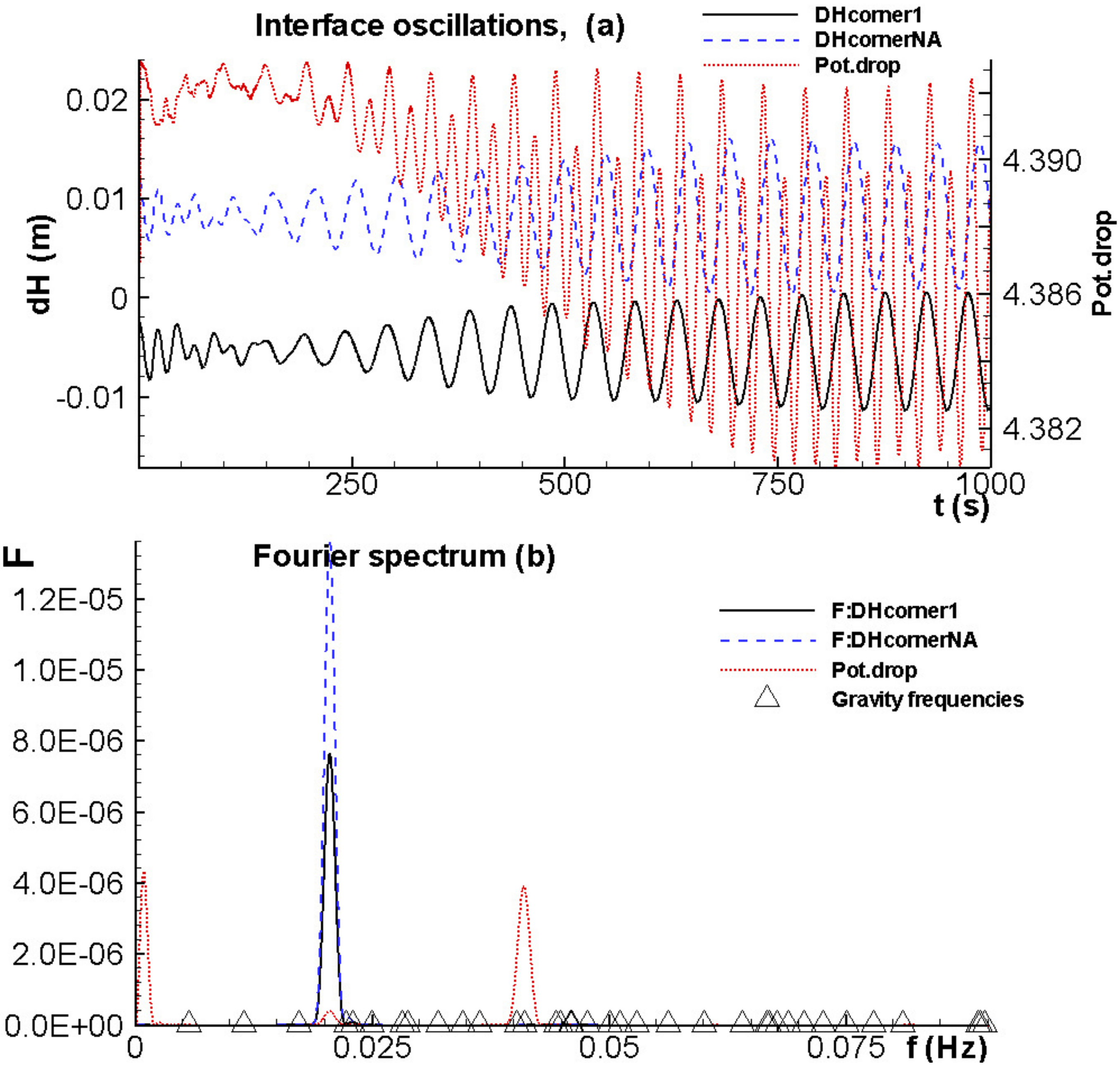

Figure 4: Liquid metal pad and cell voltage oscillations and Fourier power spectra for that magnetically compensated 500 kA cell

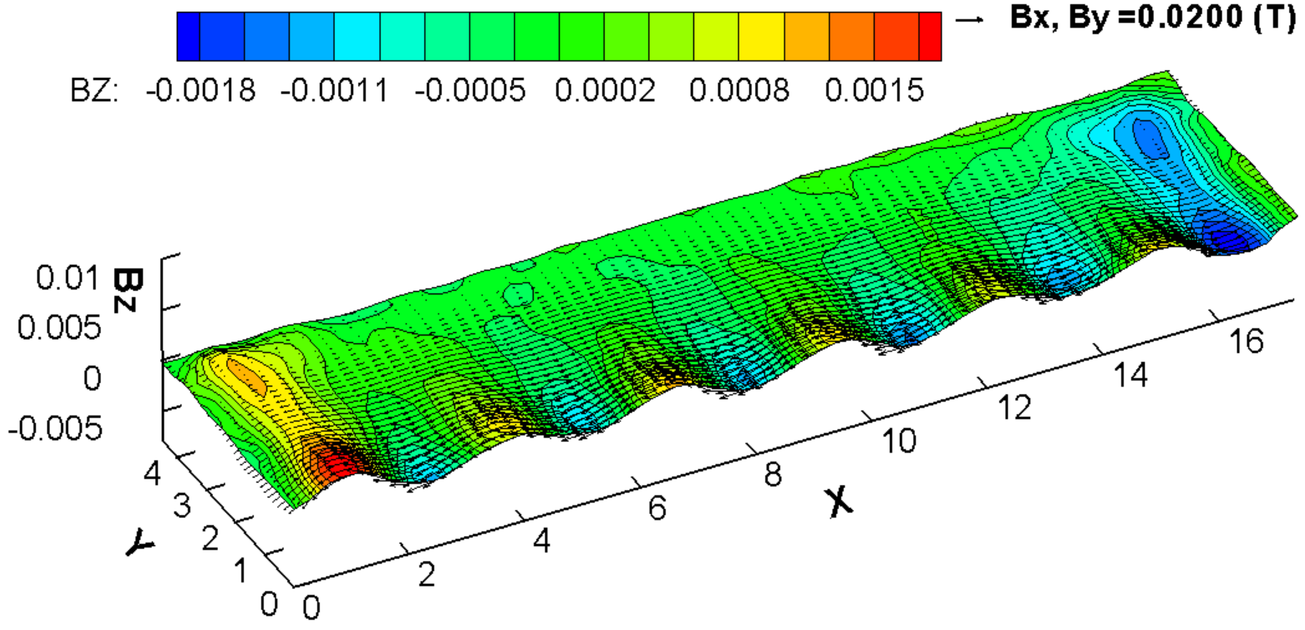

Figure 5: Bz magnetic field for a demonstration 500 kA, 6 risers cell with the new compensation busbars configuration.

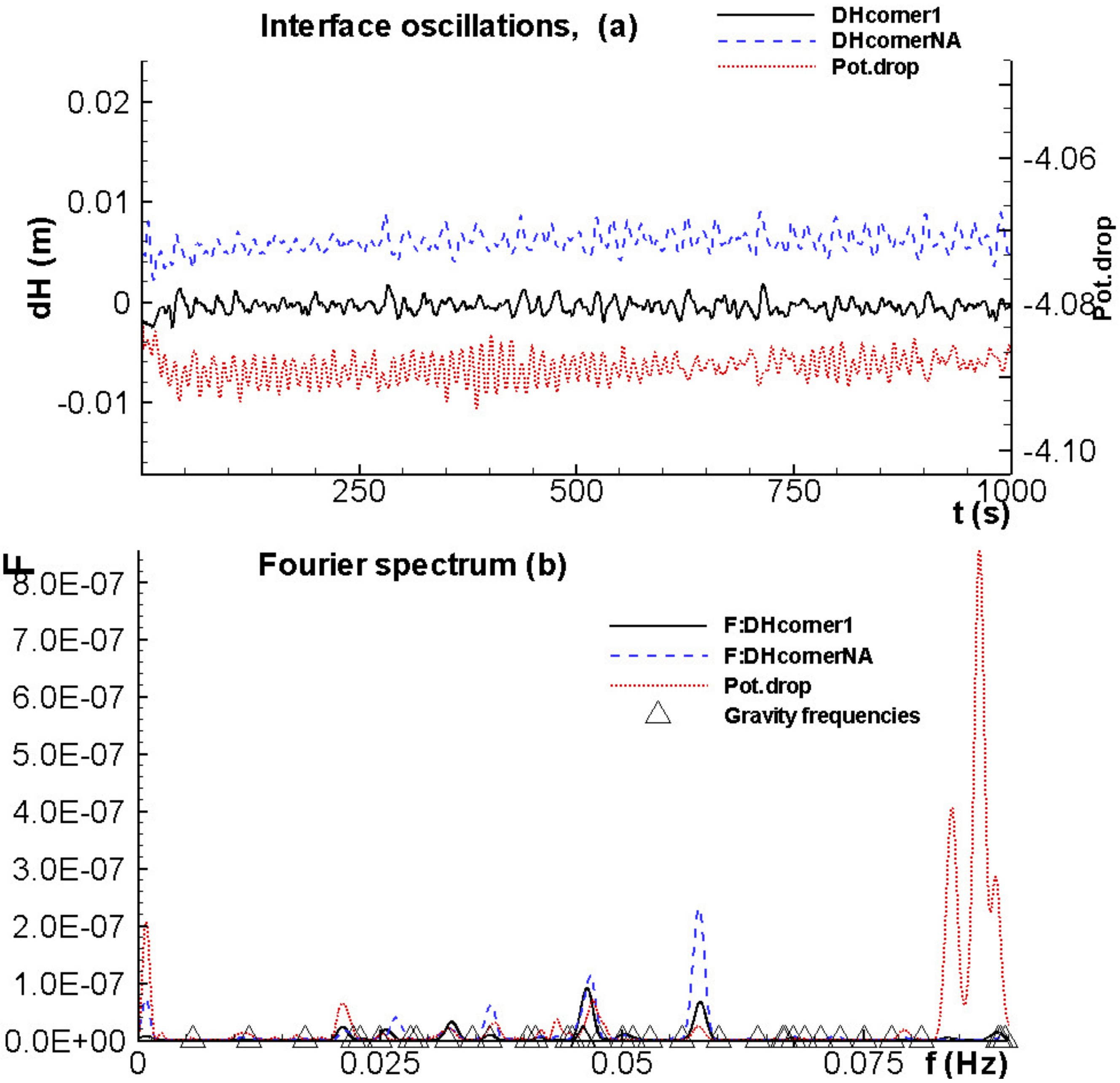

Figure 6: Liquid metal pad and cell voltage oscillations and Fourier power spectra for that magnetically compensated 500 kA cell

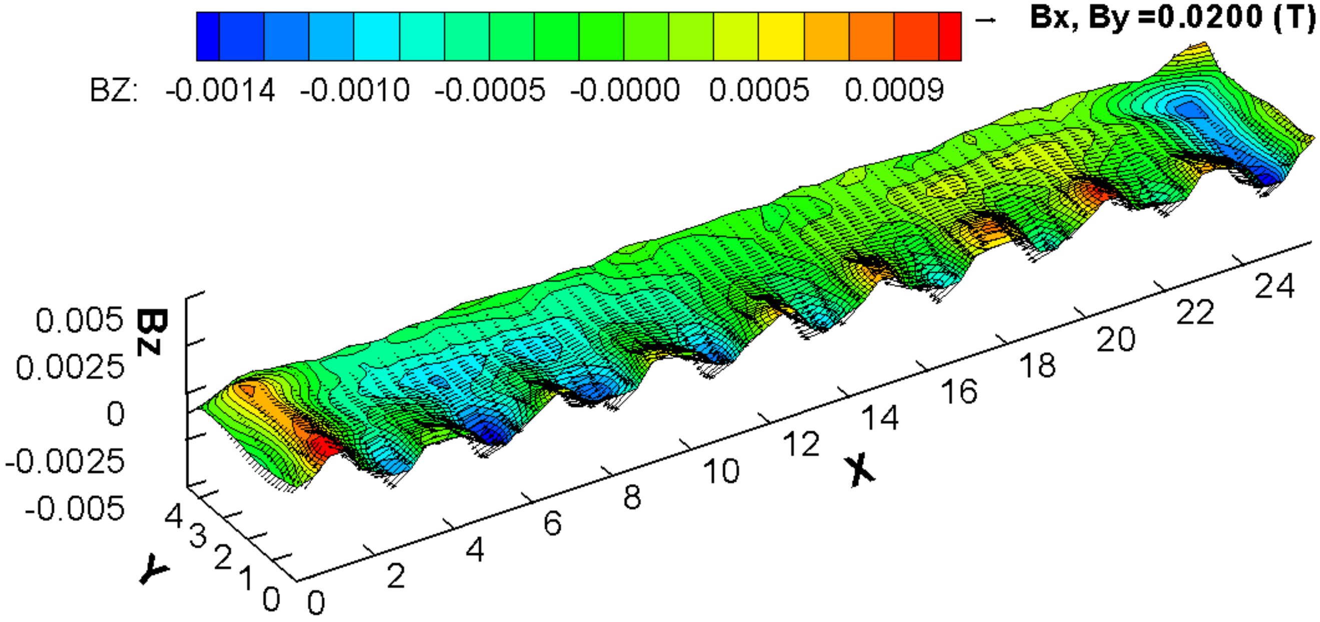

Figure 7: Bz magnetic field for a demonstration 740 kA, 9 risers cell with the new compensation busbars configuration.

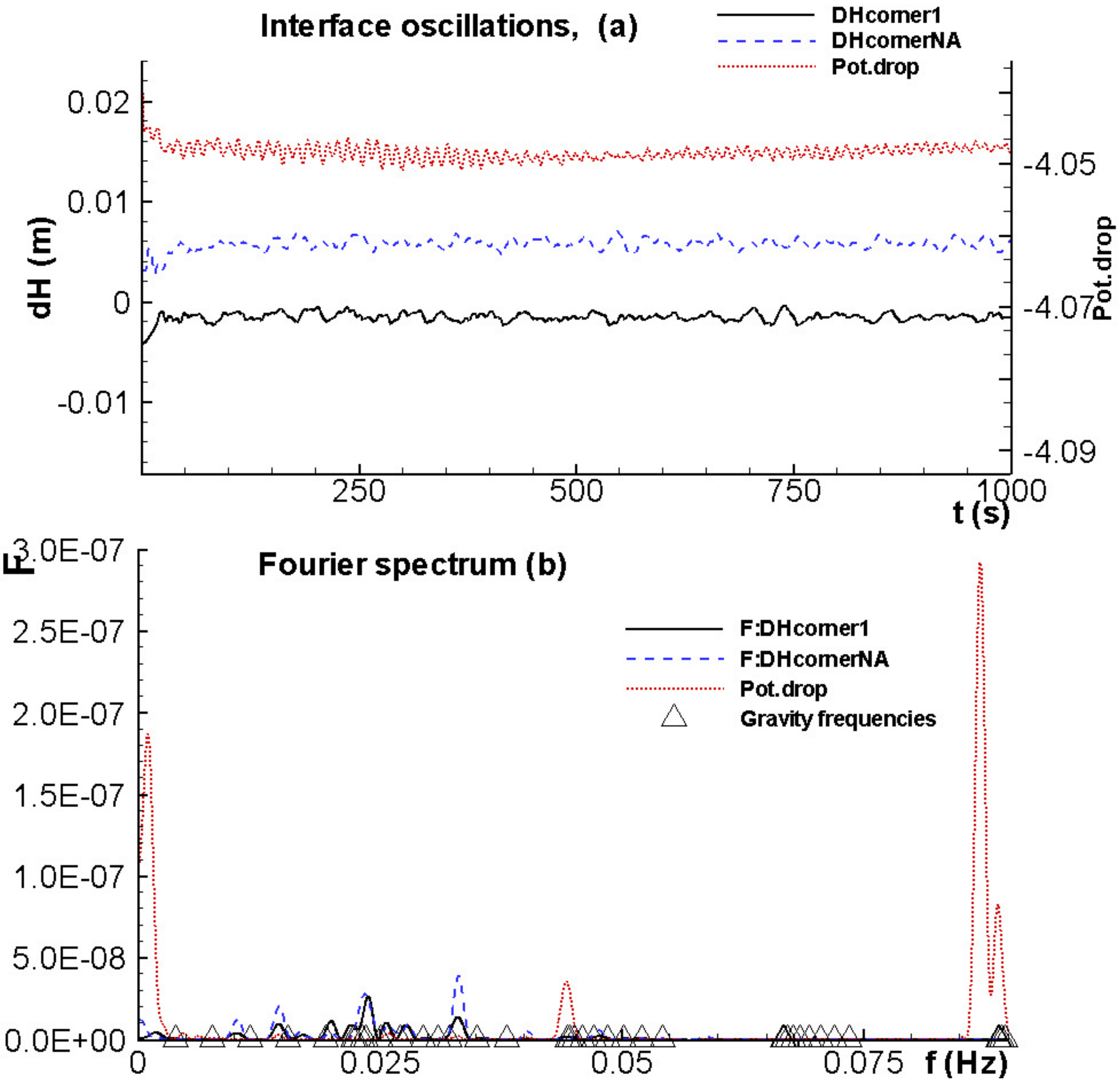

Figure 8: Liquid metal pad and cell voltage oscillations and Fourier power spectra for that magnetically compensated 740 kA cell

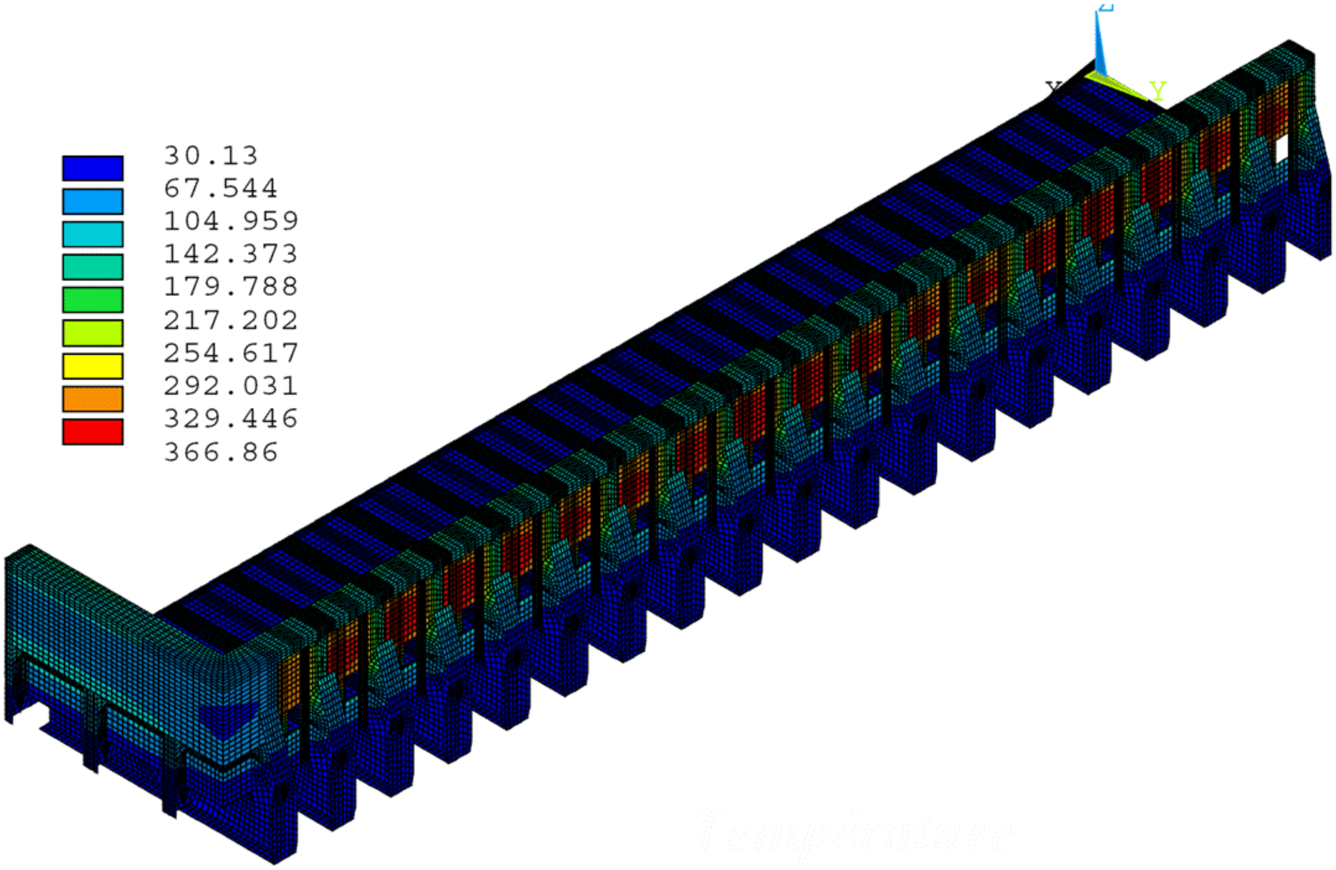

Figure 9: Mesh and temperature loading of the 740 kA cell potshell model

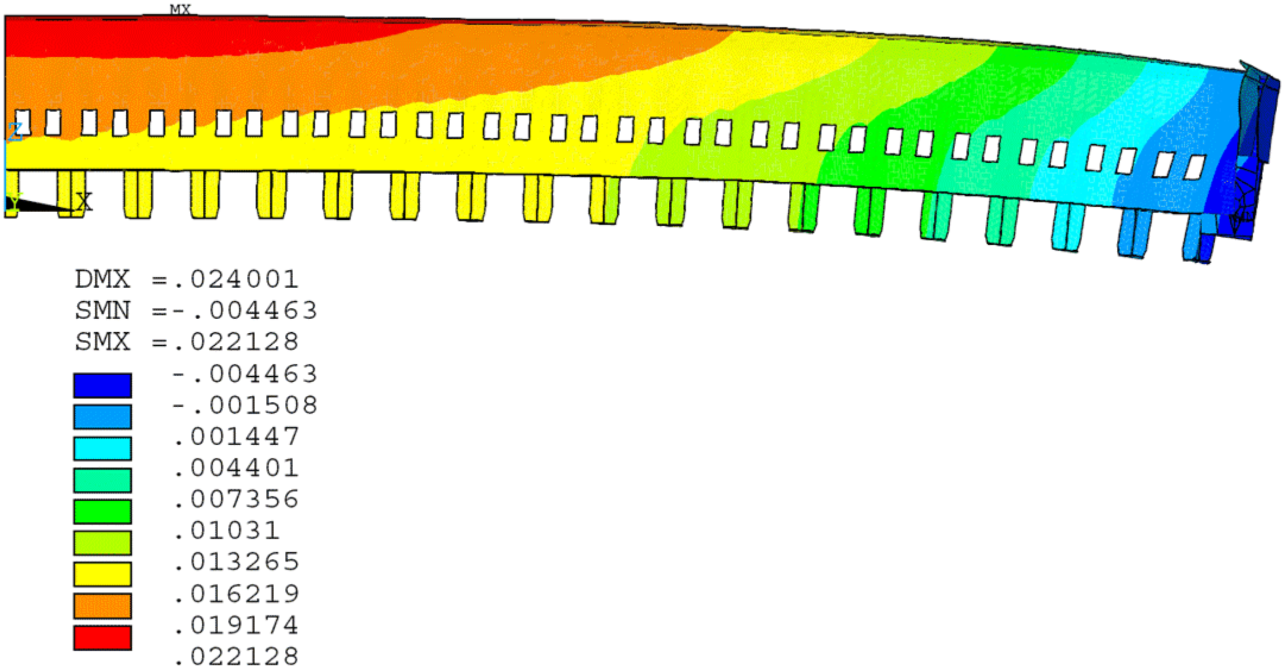

Figure 10: Vertical potshell displacement as predicted by the elasto-plastic mechanical model

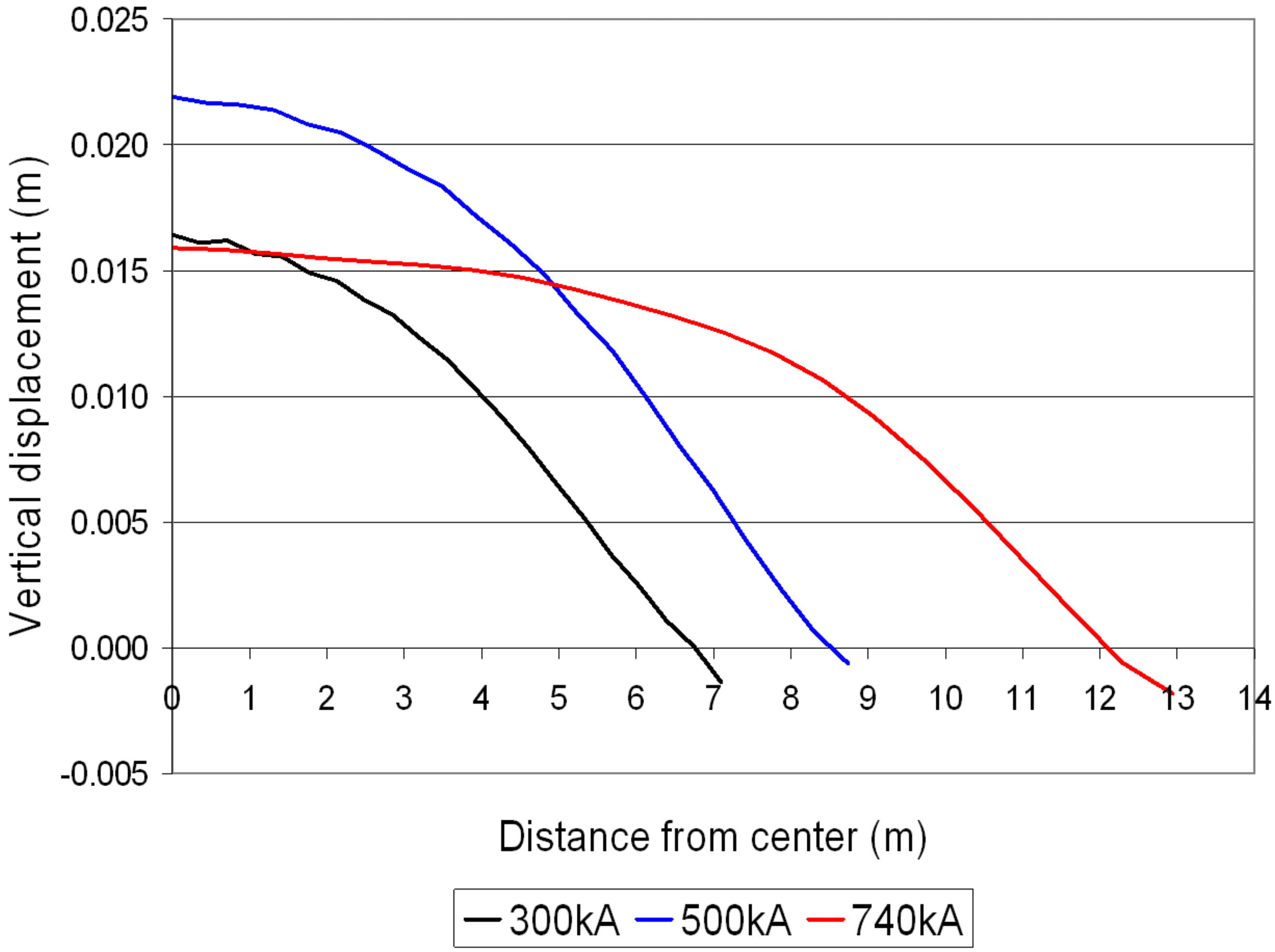

Figure 11: Potshell vertical displacement comparison

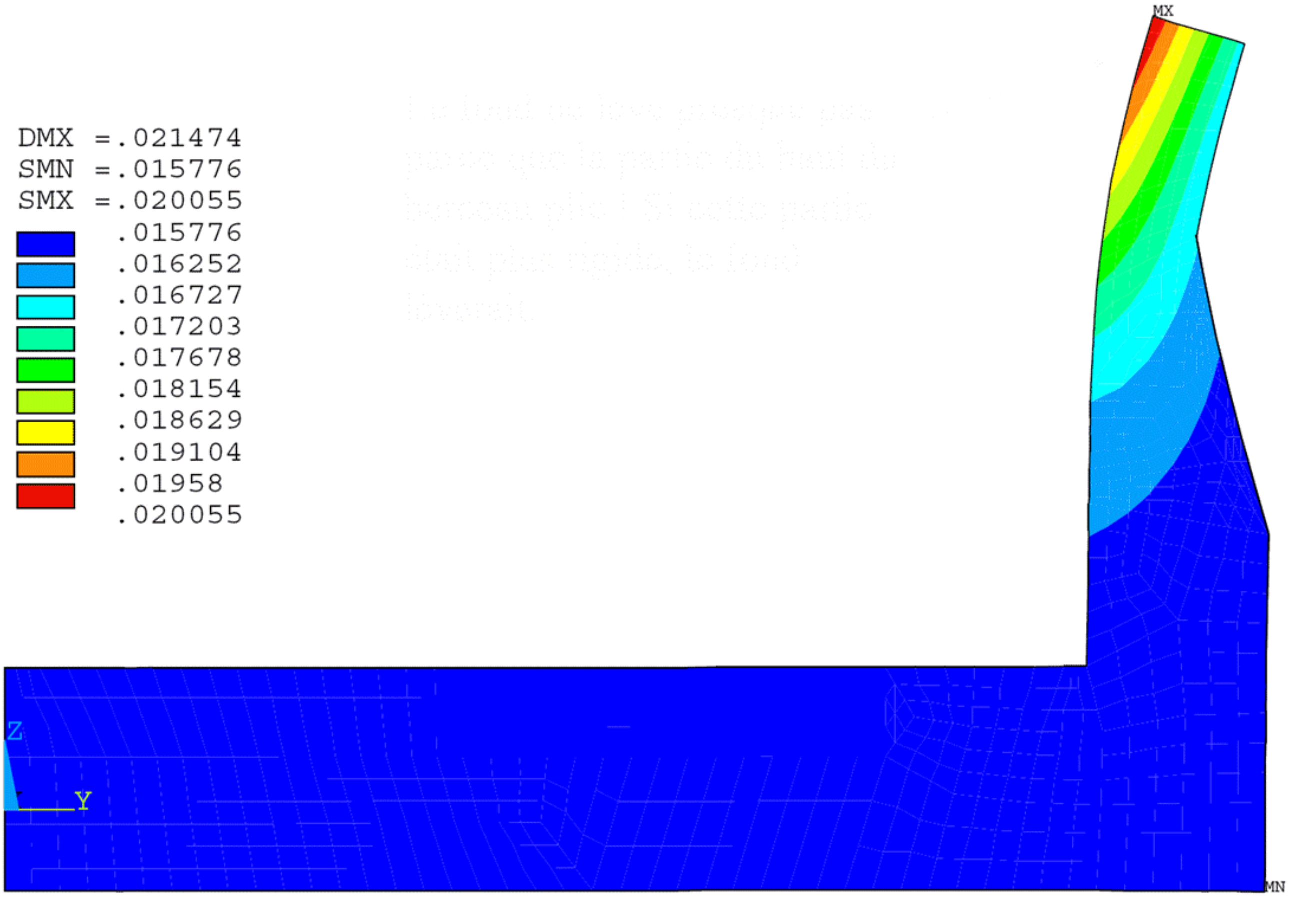

Figure 12: Lateral center cradle deflection for the 740 kA cell case