Comparing the MHD cell stability of an aluminium reduction cell at different metal pad height and ledge thickness

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ABSTRACT

It is well known that horizontal current density in the metal pad contributes greatly to the generation of MHD driven bath-metal interface wave.

It is possible to compute very accurately the metal pad current density using a very detailed finite element model [1], but a MHD model must be compatible to this level of mesh refinement and to recalculate the current distribution at each time step, including the full busbar supply system.

The accuracy of the instability prediction of the cell depends on the accuracy of the metal pad current density calculation.

This study presents the comparison of the metal pad current density calculation of the detailed finite element model and the MHD-Valdis model for different metal pad heights and ledge thickness. It also presents the corresponding cell MHD stability predictions.

INTRODUCTION

As it has been discussed previously [2,3], there are many aspects of the cell design and operation that will have an impact on the metal pad current density field. For example: the metal pad height, the ledge thickness, the cathode block/collector bar(s) connection design, the cathode block carbon grade, the busbar design, etc.

It has also been demonstrated in [4] that the intensity of the stationary metal pad current density field has an impact on the cell stability in a very similar way as the vertical intensity of the magnetic field has [5]. In that context, it is very important for an MHD cell stability analysis code like MHD-Valdis not only to be able to compute rapidly and accurately the magnetic field [6] and the non-linear bath-metal interface wave dynamic evolution [7], but also to be able accurately and rapidly compute the metal pad current density field.

A first step in that direction has been achieved in [8] by demonstrating that MHD-Valdis 1D mesh busbar representation is able to calculate accurately the busbar network current distribution. Having done that, the current work concentrates on the main remaining items affecting the calculation of the metal pad current density field, namely the metal pad height and the ledge thickness.

FULL CELL 3D ANSYS® BASED MODEL

As stated previously, a non-linear MHD cell stability analysis model like MHD-Valdis must be able to compute the metal pad current density field rapidly and accurately. Computation time is important because the magnetic field, the current density field, the bath and metal flow fields and the bath/metal interface wave evolution must be recomputed at each time step. Considering that a typical transient cell stability analysis requires the solution of 4000 time steps, it is clear that practically it is not possible to spend many CPU hours to solve one time step magnetic field or current density field.

Fortunately, CPU time constraints do not apply to benchmark or comparison models that can be built in order to verify the accuracy of MHD-Valdis metal pad current density calculation. Of course, it is always better to validate a mathematical model solution using measured data, but in the case of the metal pad current density field, it is unfortunately not an option.

The full 3D ANSYS® based thermo-electric (T/E) model built for the purpose of weakly coupling T/E and MHD models [1] is one such model that can compute very accurately the metal pad current density field but does require a lot of CPU time in order to do it. For example, the metal pad current density field presented in Figure 6 of [1] took 40.6 CPU hours to compute. Of course, it is important to point out that that T/E model (presented in Figure 4 of [1]) consists of 329,288 elements and is converging the steady-state ledge shape as part of the solution.

In order to save some CPU time, the inside shell section of that T/E model was converted into an electric only model (see Figure 1). This simplified model is no longer able to converge the steady-state ledge shape, therefore it is using a fixed, user defined, metal pad shape in order to compute the metal pad current density field presented in Figure 2. The solution was obtained after “only” 1 hour and 39 minutes of CPU time of computation.

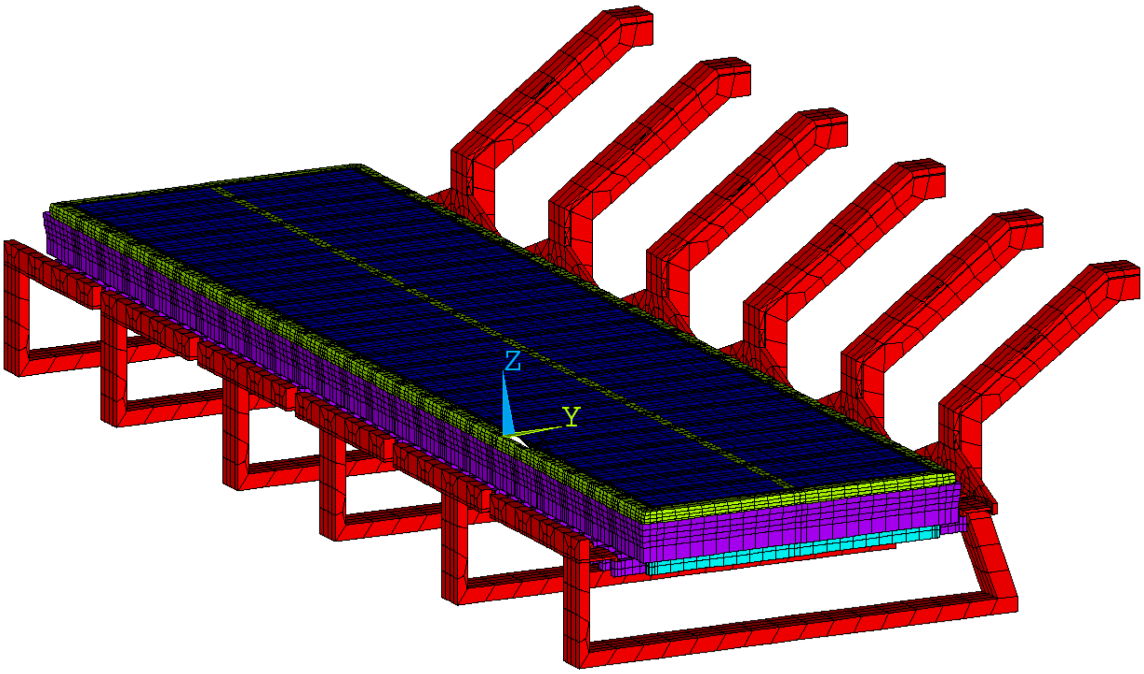

Figure 1: Full cell 3D ANSYS® based model mesh

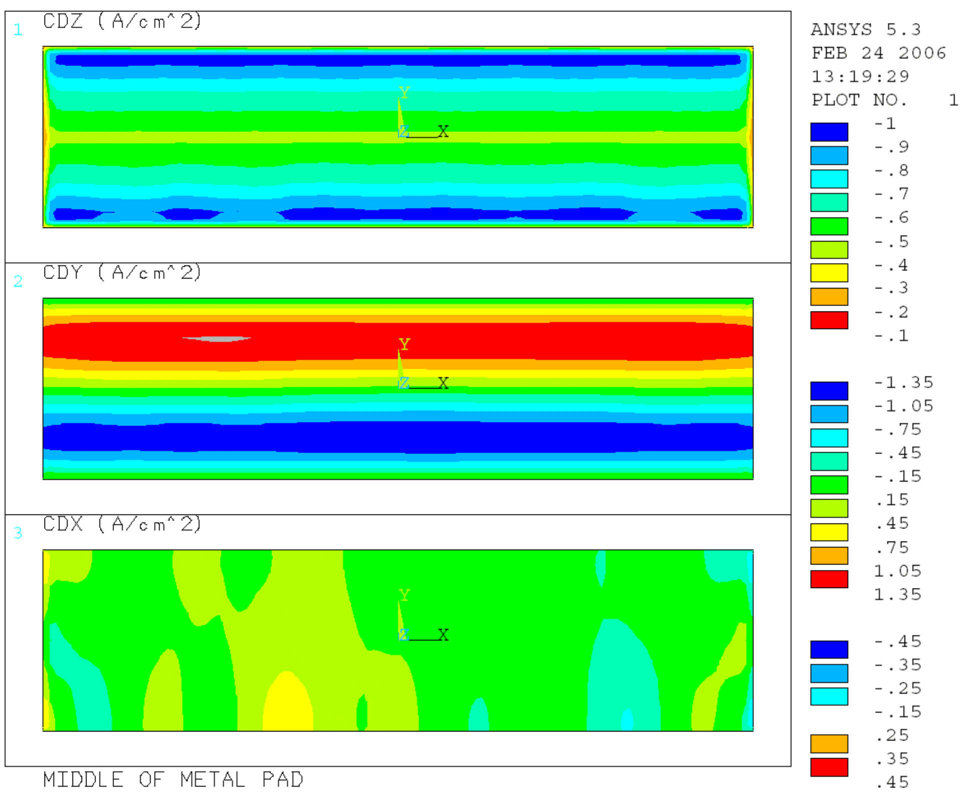

Figure 2: Full cell 3D model metal pad current density field solution

FULL CELL PARTIALLY 1D ANSYS® BASED MODEL

In order to illustrate the tradeoff between ease-of-use and efficiency on one side and the solution accuracy on the other side, a second ANSYS® based mostly electric only model was developed (see Figure 3). The second model is part 3D and part 1D mesh. The 1D mesh T/E busbar model part was presented in [8]. The 3D mesh electric only inside shell part is more generic than the previous model so it is easier to setup, but represents the real geometry a bit less accurately.

The simpler model took 7 minutes CPU time to compute the metal pad current density field presented in Figure 4. Even if 7 minutes CPU doesn't sound very long, repeating the calculation 4000 times in the context of a cell stability analysis would required 19.4 days of CPU time, which is a bit too long to be considered practical!

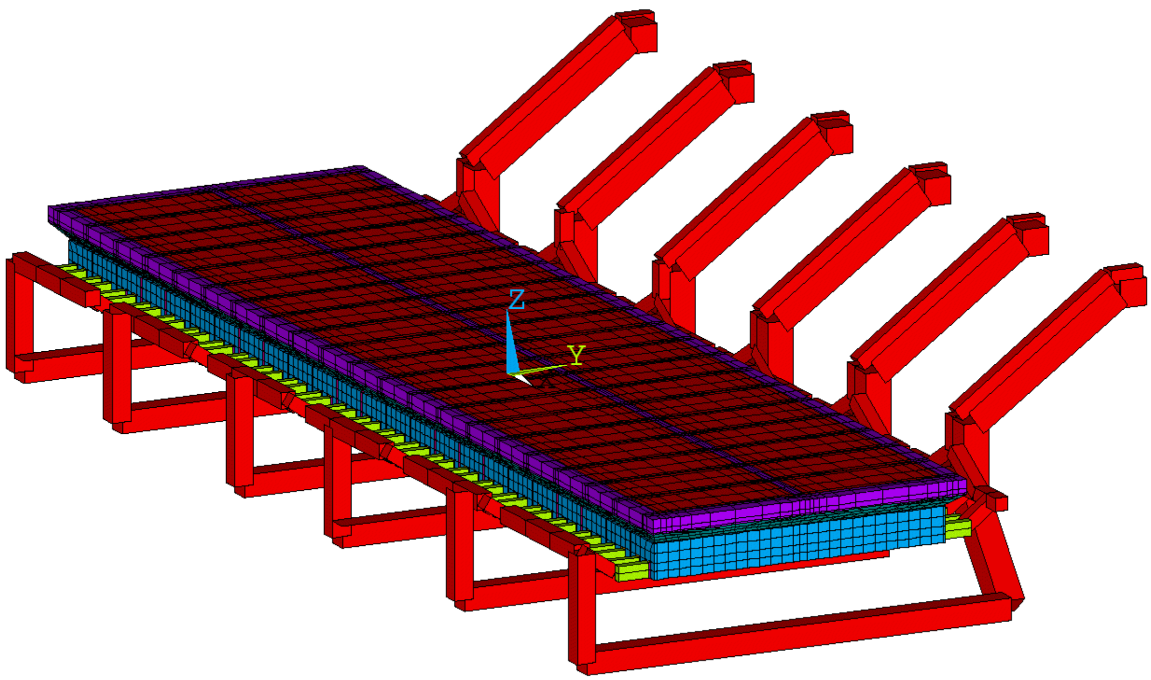

Figure 3: Full cell partially 1D ANSYS® based model mesh

MHD-VALDIS 1D MODEL

It is important to remember that not only the T/E model in MHD-Valdis must be able to solve accurately the cell busbar network current distribution and the metal pad current density field as the two previous models did, but it must also be able to solve the electric network of the full smelter as the solution of the full smelter electric network is required for the accurate solution of the magnetic field inside the metal pad.

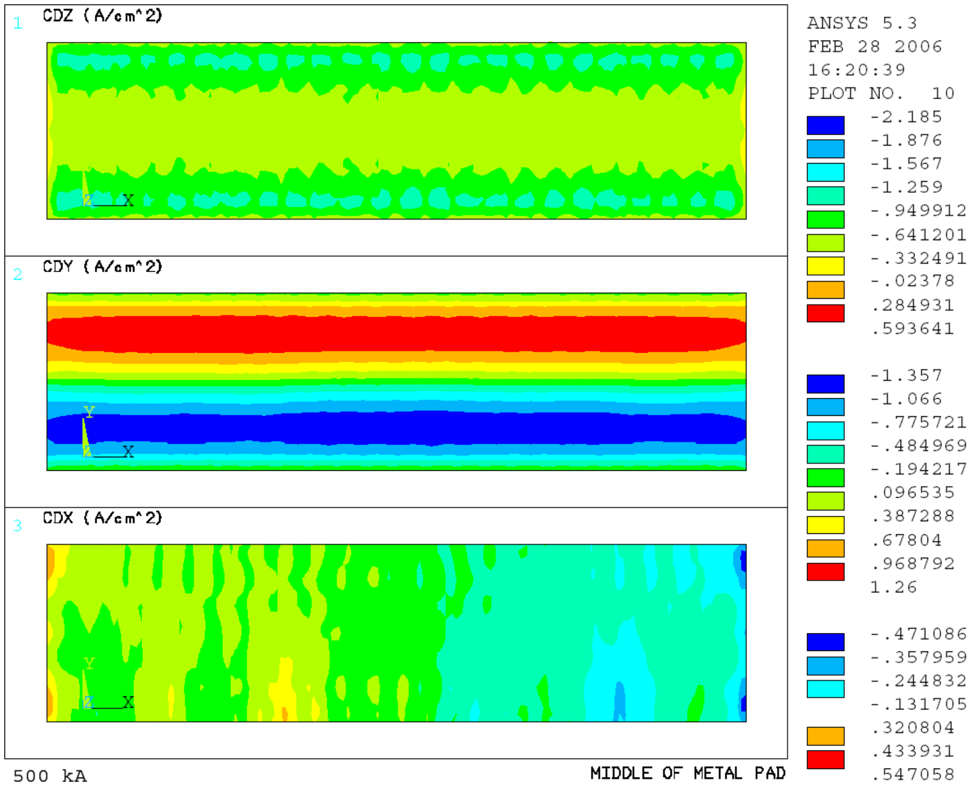

Figure 4: Full cell partial 1D model metal pad current density field solution

Furthermore, in the context of a cell stability analysis, it is important to solve for the neighbor cells electrical network perturbation due to the bath-metal interface wave evolution of the cell under study as this will have an impact on the magnetic field perturbation. For this reason, the 1D electrical network solved by MHD-Valdis represents several cells in the neighbourhood of the test cell (see Figure 5).

That main electrical network is complemented by additional, electrically connected sub-network that computes the current density field of the cathode block by solving the cathode block collector bar connection and the collector bar current pickup, and another continuous domain to compute the current field in the two liquid zones. It is important to notice that the solution presented in Figure 6 has been computed in only a few CPU seconds.

By comparing Figures 2, 4 and 6, we can see that MHD-Valdis is computing much faster than the two ANSYS® based models a very similar metal pad current density field. When comparing those three figures, it is important to point out that for the two ANSYS® based models, CDZ (A/cm^2) is the vertical component of the current density in the middle plane of the metal pad while for MHD-Valdis, JB (A/m^2) is the vertical component of the current density at bottom of the metal pad i.e. the surface of the cathode blocks.

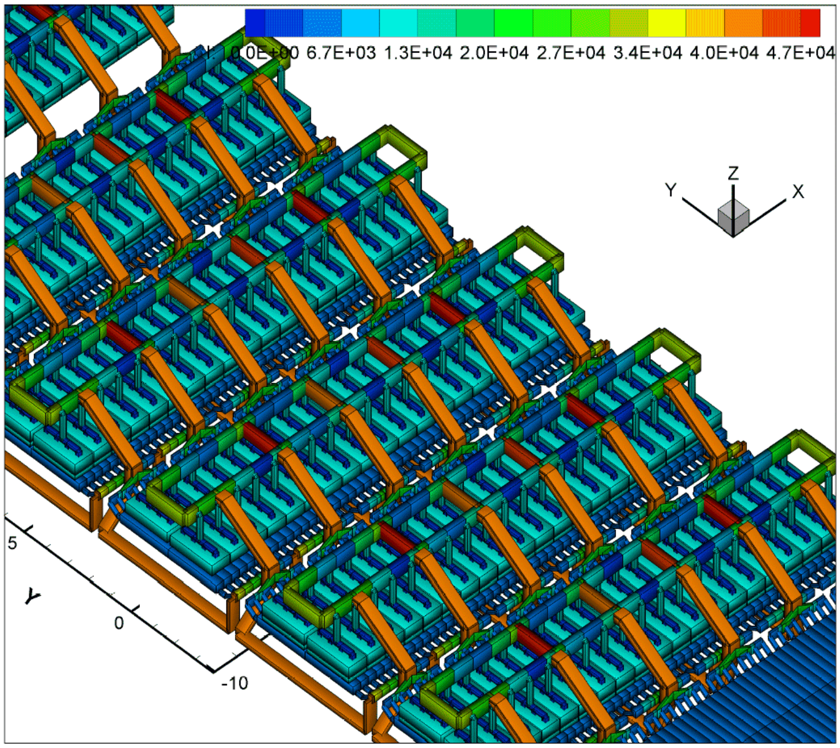

Figure 5: MHD-Valdis electric network model mesh

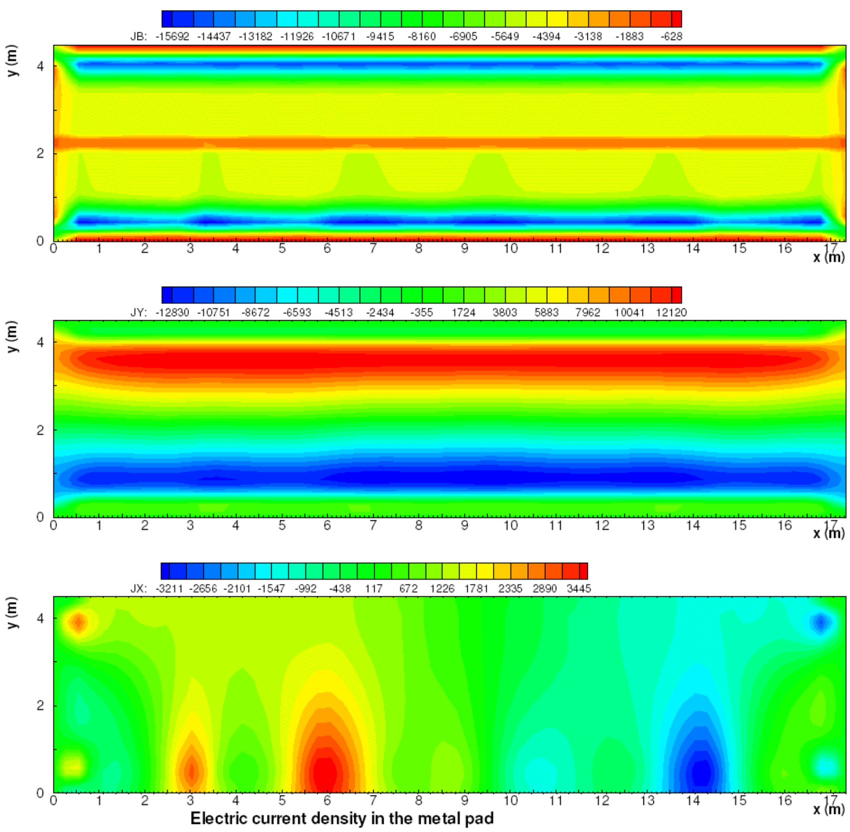

Figure 6: MHD-Valdis model metal pad current density field solution: J_z at bottom, J_y and J_x depth average.

10 CM METAL PAD CASE

In order to test the versatility of MHD-Valdis metal pad current density field solver, two additional configurations, in addition to the base case presented above, are being presented. In the first variation case, the metal pad thickness is reduced from 20 cm down to 10 cm. The resulting metal pad current density field solutions for the 3D ANSYS® model, the partial 1D ANSYS® model and the MHD-Valdis model are presented respectively in Figures 7, 8 and 9.

Reducing by half the height of the metal pad simply doubles the intensity of the horizontal component of the current density field. As expected, all the three models are correctly making that prediction. As we will see below, increasing the intensity of the horizontal component of the metal pad current density field has a significant impact on the MHD cell stability.

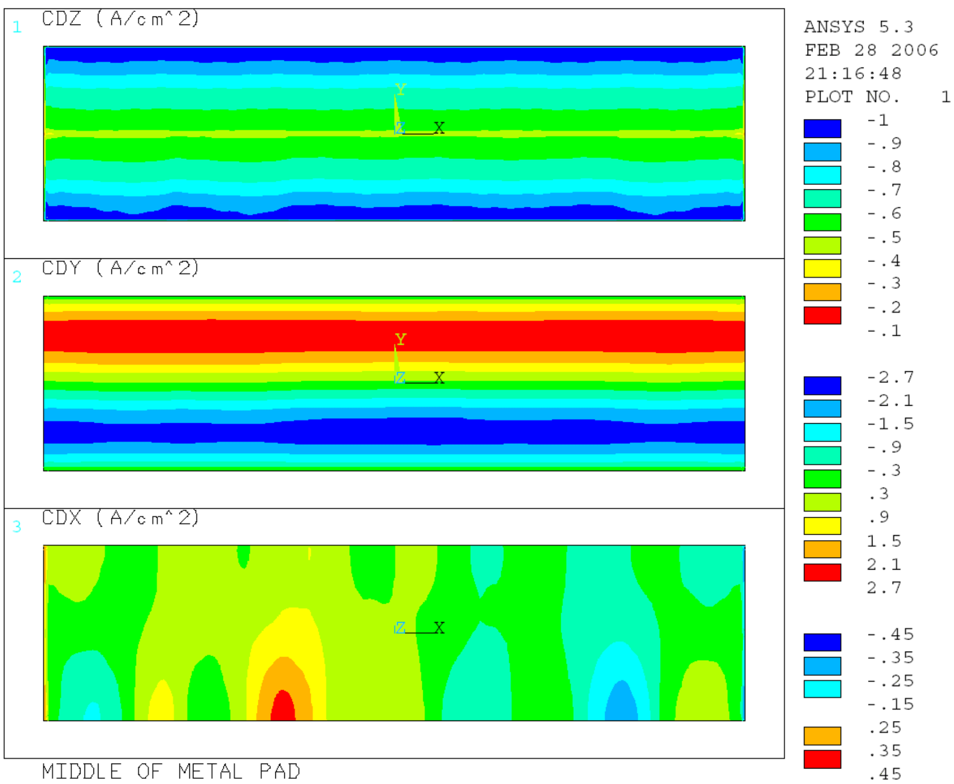

Figure 7: Full cell 3D model metal pad current density field solution

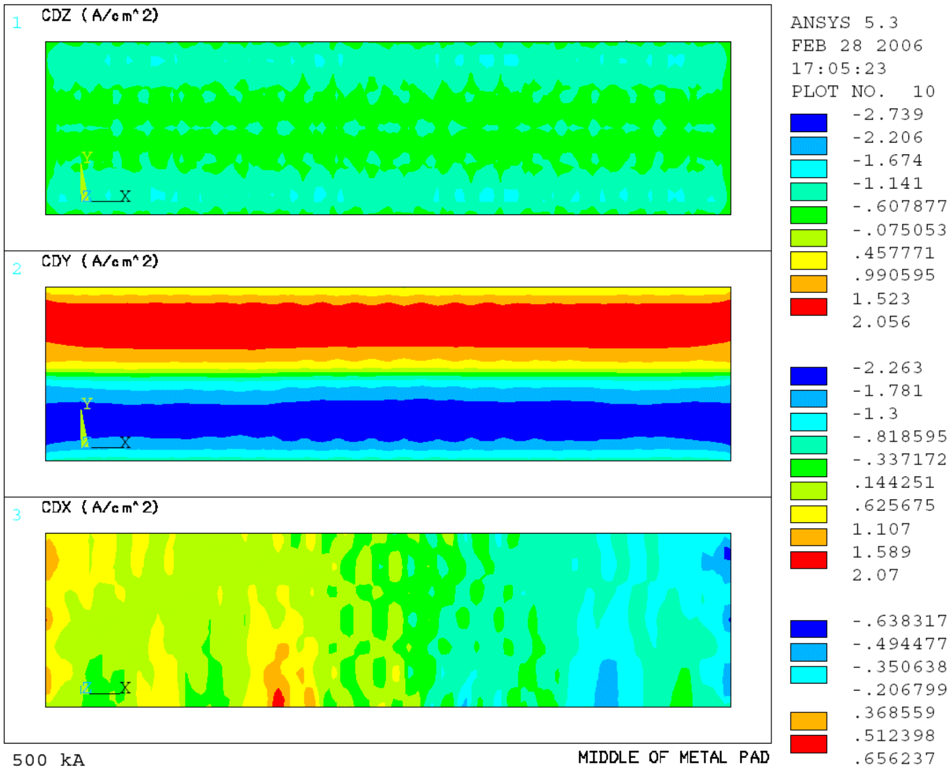

Figure 8: Full cell partial 1D model metal pad current density field solution

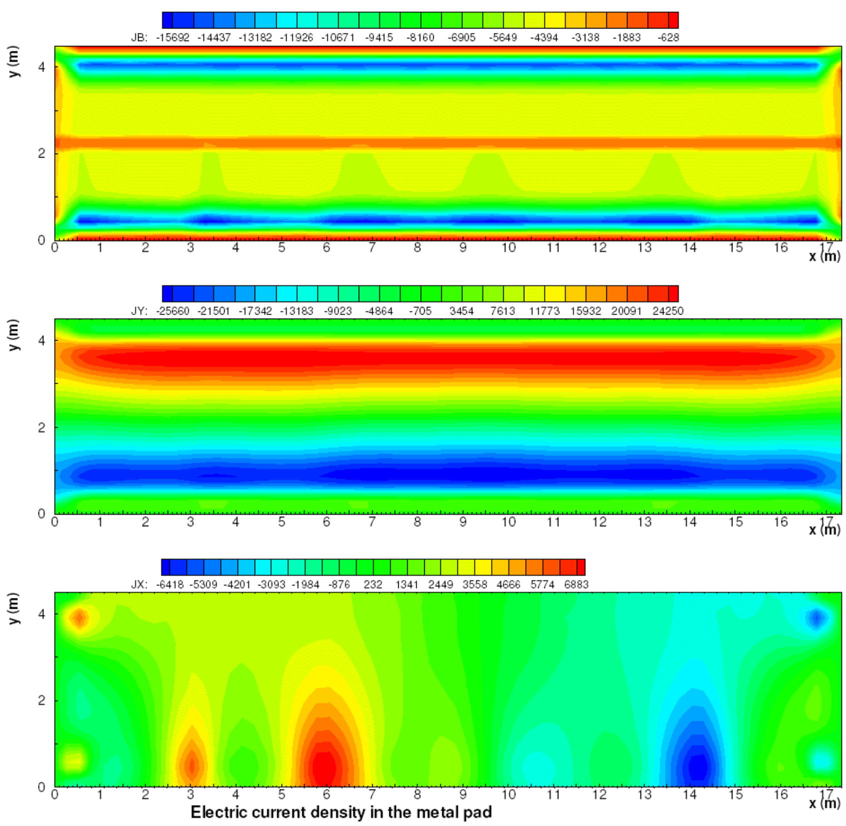

Figure 9: MHD-Valdis model metal pad current density field solution

10 CM LEDGE THICKNESS

In the second variation case, the side and end ledge toe thickness is increased from 4 cm to 10 cm. The resulting metal pad current density field solutions for the 3D ANSYS® model, the partial 1D ANSYS® model and the MHD-Valdis model are presented respectively in Figures 10, 11 and 12.

The impact of increasing the ledge toe thickness from 4 cm to 10 cm is a bit less obvious to distinguish. It is clear that the presence of extra ledge insulation on the top of the cathode surface creates a local perturbation close to the ledge toe position. That local perturbation is more or less well captured depending on the accuracy of the geometry representation in the model. On the global scale, all three models correctly predict a slight reduction of the intensity of the lateral horizontal current density (JY) field. As the collectors bars are rodded up to the edge of the cathode blocks, up to a certain point having more ledge toe thickness can be a good thing. Only carrying up the cell stability analysis will indicate if the cell will be more or less stable after this change of ledge toe thickness.

It would have been interesting to analyze the impact of having even more ledge toe thickness, unfortunately topology limitations in the 3D ANSYS® based model, are preventing us to run the model with more ledge toe thickness.

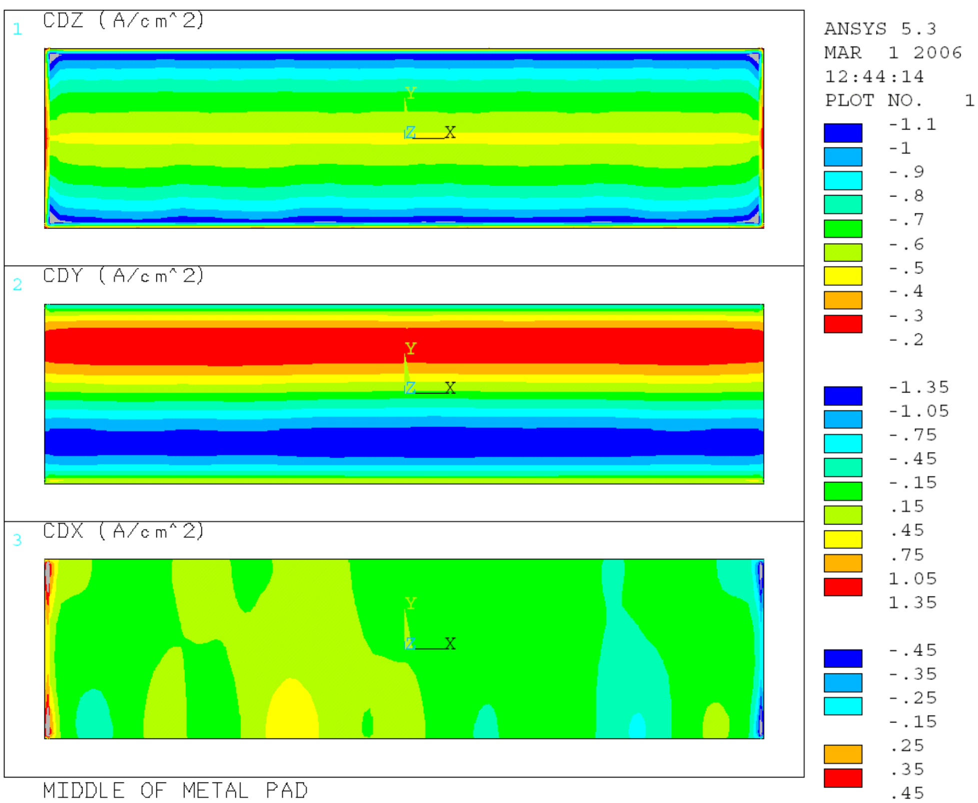

Figure 10: Full cell 3D model metal pad current density field solution

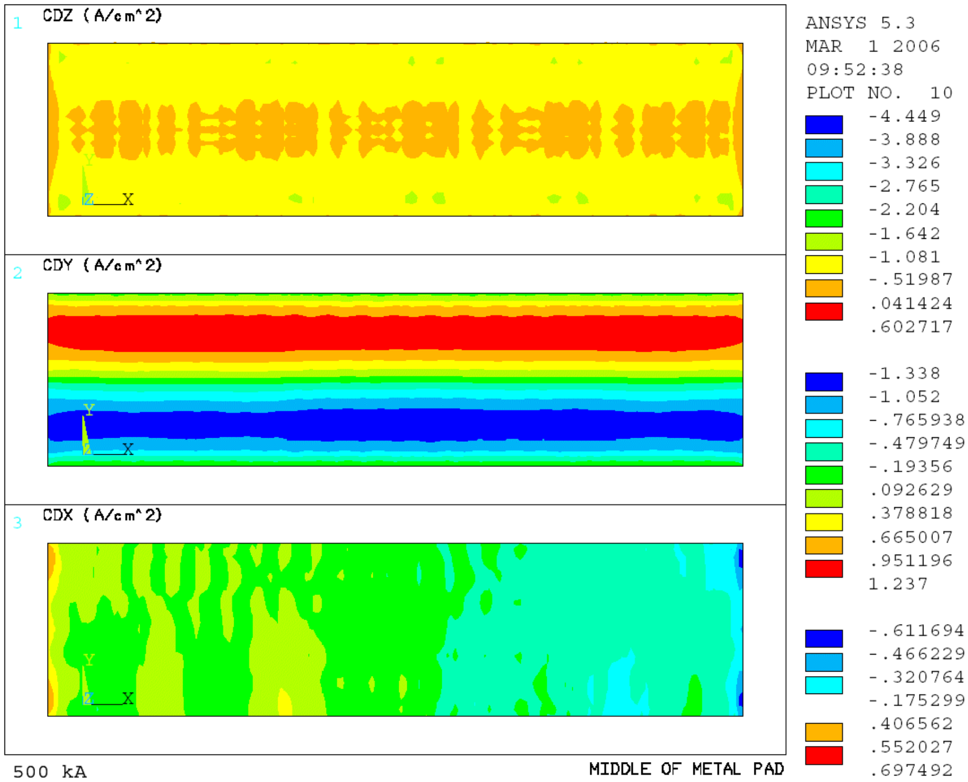

Figure 11: Full cell partial 1D model metal pad current density field solution

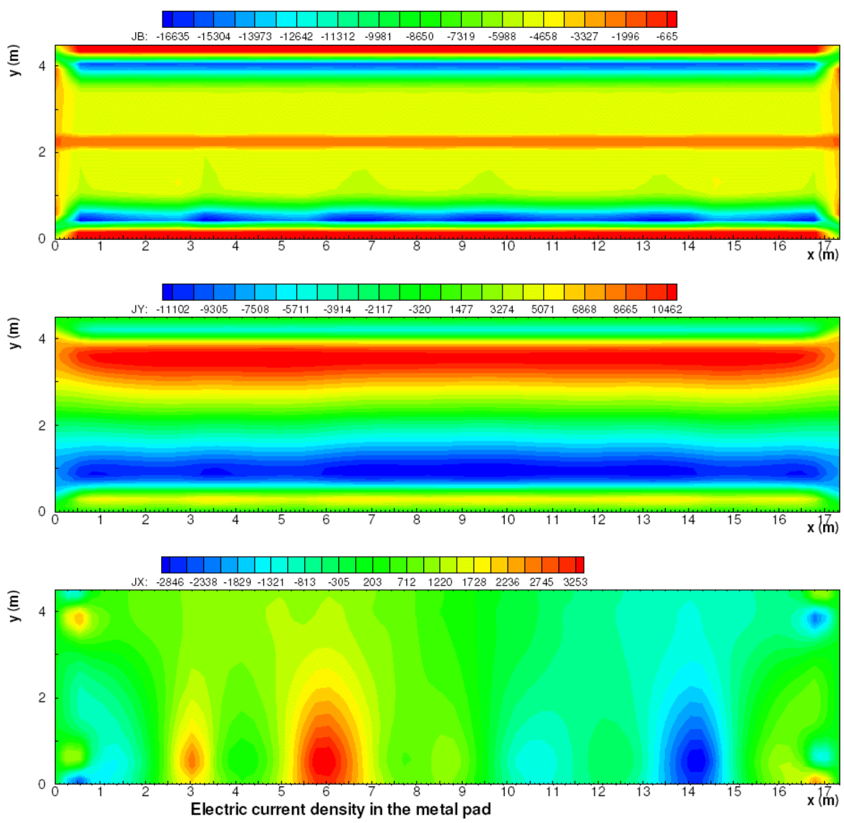

Figure 12: MHD-Valdis model metal pad current density field solution

INFLUENCE OF THE METAL PAD CURRENT DENSITY FIELD ON THE MHD CELL STABILITY

In order to illustrate the impact of the change of intensity of the horizontal current in the metal pad on the cell stability, the same three cases will be analyzed again with MHD-Valdis but this time using the busbar design inspired from the Pechiney 1987 patent [9] (see Figure 13). That busbar design is producing a more stable cell than the one available in our 3D ANSYS® based 500 kA demonstration model, so it is better suited for this comparative cell stability study.

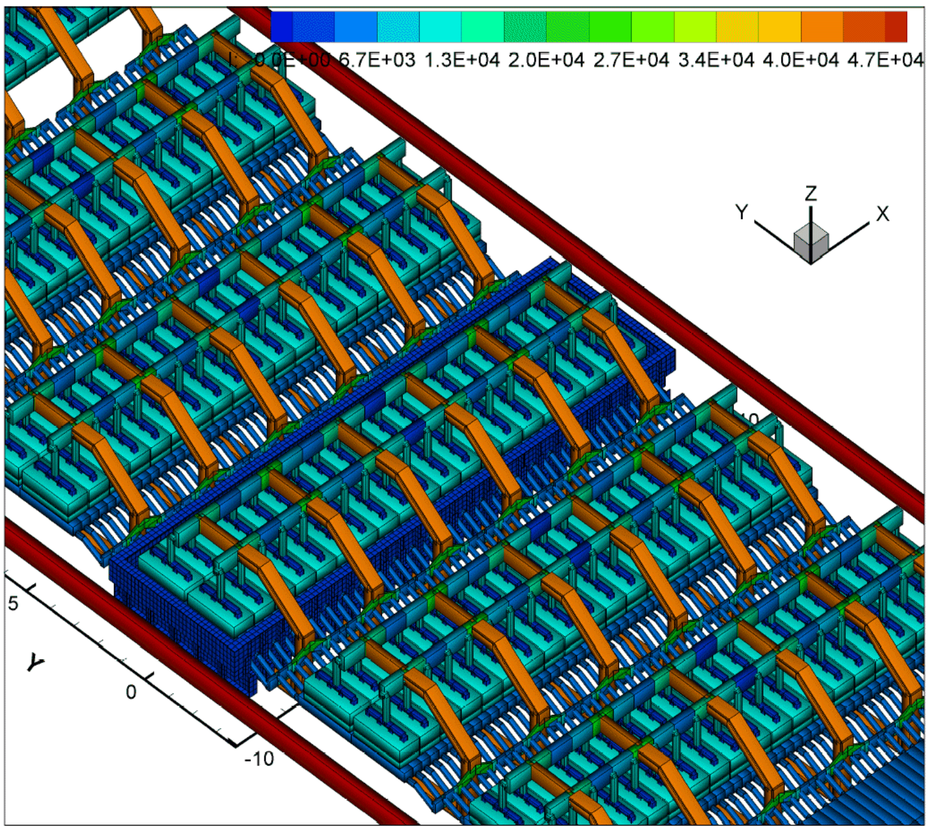

Figure 13: MHD-Valdis electric network model mesh with compensation loop

A very similar stability analysis study of this 500 kA demonstration cell design with that busbar configuration has already been presented in [10]. The only difference being that the metal level in the previous study was setup to 25 cm while it is set to 20 cm in the present case. The ledge toe thickness is set to 4 cm, very close to the anode shadow, as it was in the previous study.

Figure 14 presents the obtained initial metal pad current density field. The intensity of the cell longitudinal component (JX) is slightly different from the one presented in Figure 6 because the busbar network is better balanced in the present case.

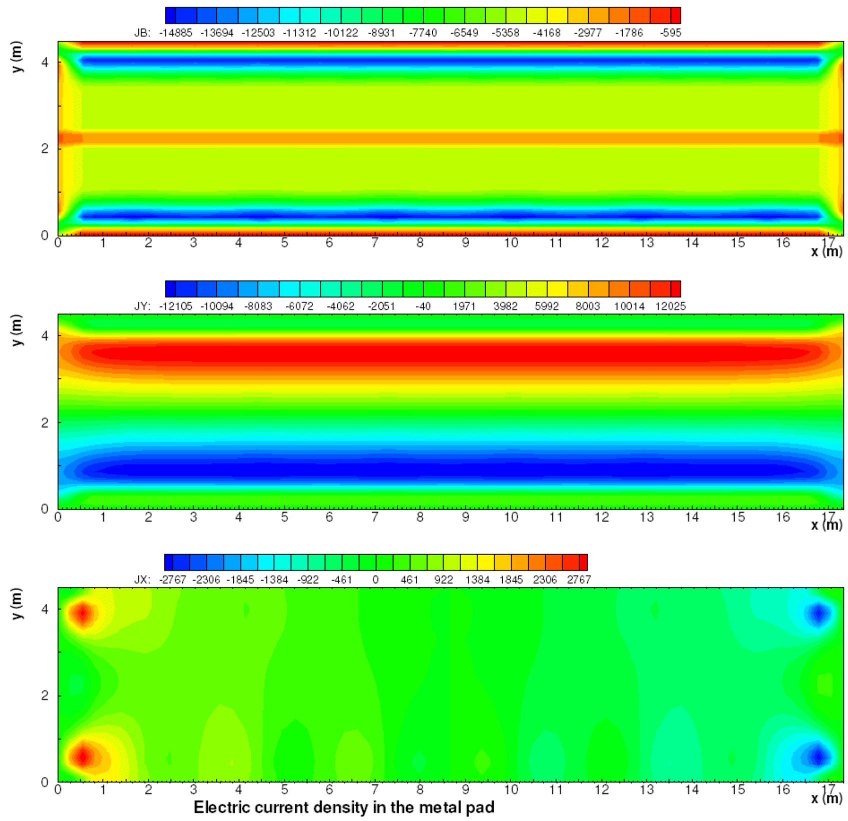

Figure 14: MHD-Valdis model metal pad current density field solution

Figure 15 presents the obtained initial metal pad magnetic field. With the help of the compensation busbar, the intensity of the vertical (BZ) component is quite low as required to ensure the cell MHD stability.

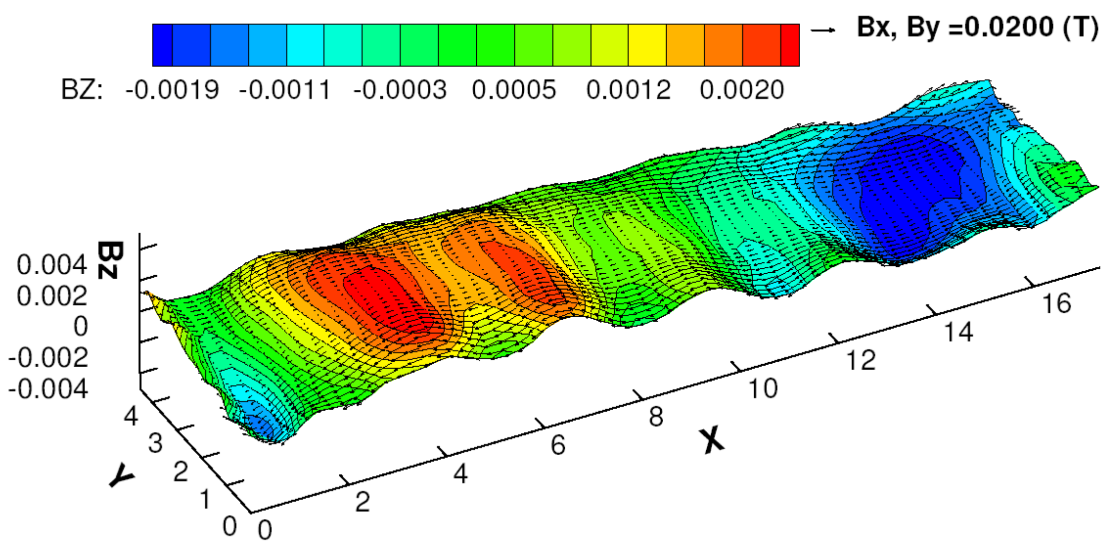

Figure 15: MHD-Valdis model metal pad magnetic field solution

The liquid metal pad and cell voltage oscillation, and the Fourier power spectra of the non-linear cell stability analysis results are presented in Figure 16. At 20 cm of metal pad thickness, the results indicate that at best, the cell will only be marginally stable due to the intensity of the lateral (JY) current density field. Figure 17 presents the obtained bath-metal interface wave pattern.

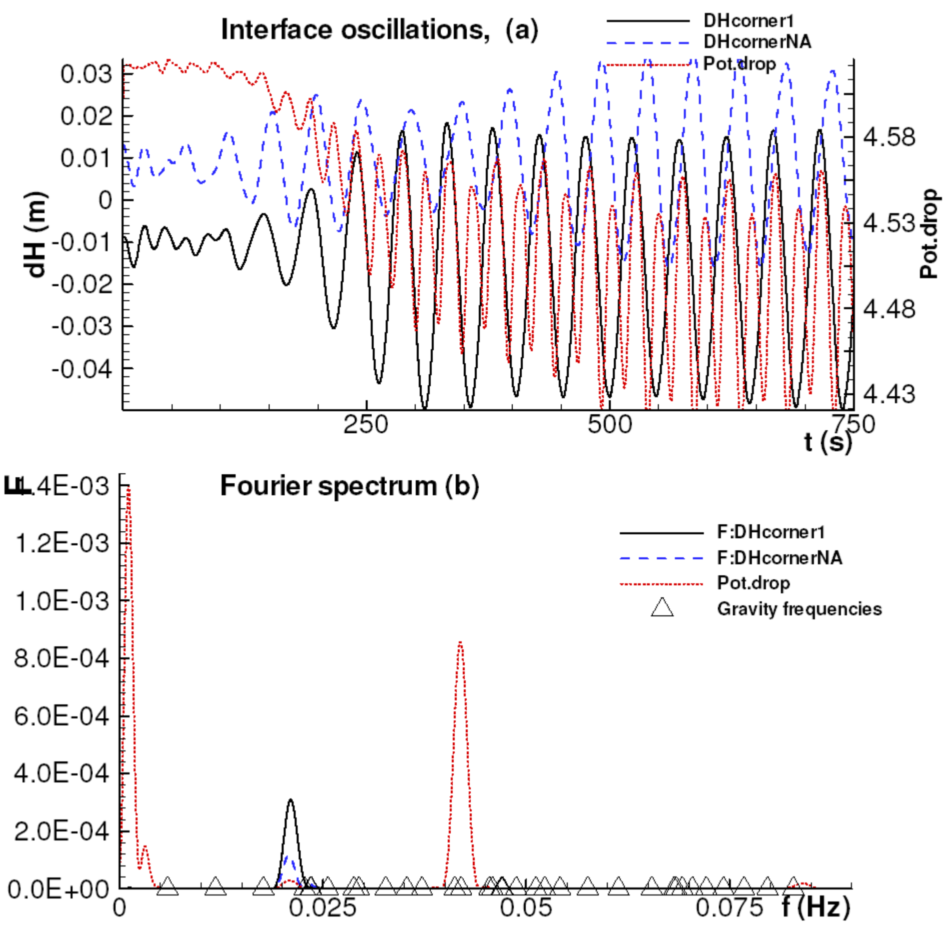

Figure 16: MHD-Valdis model liquid metal pad and cell voltage oscillation

10 CM METAL PAD CASE

Figure 18 shows the metal pad current density field when the metal pad thickness is reduced to only 10 cm. The resulting metal pad and cell voltage oscillation, and the Fourier power spectra of the non-linear cell stability analysis results are presented in Figure 19. As we can see, at 10 cm of metal pad thickness, the horizontal current intensity doubled and as a result, the cell is predicted to be completely unstable.

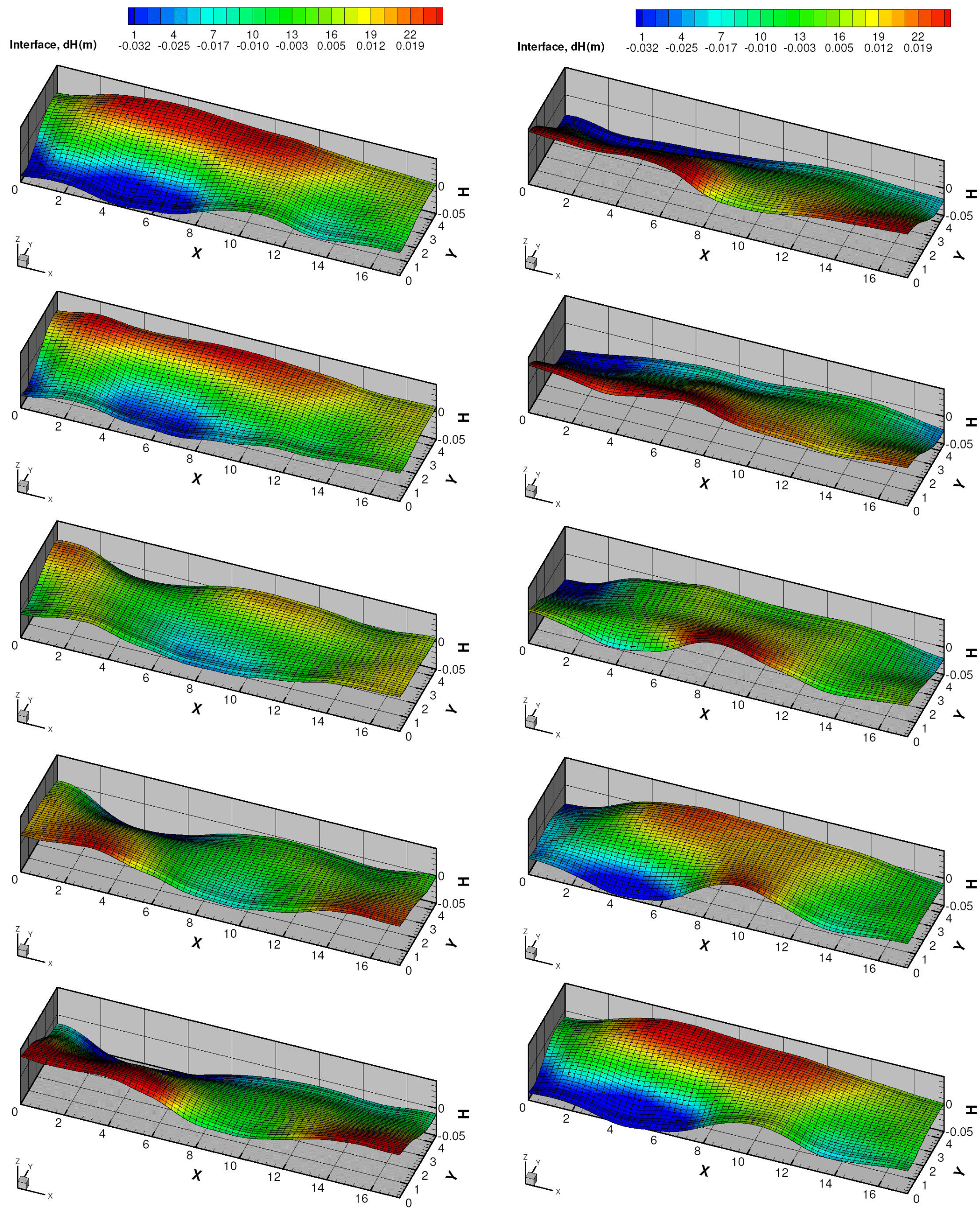

Figure 17: MHD-Valdis model bath-metal interface wave pattern

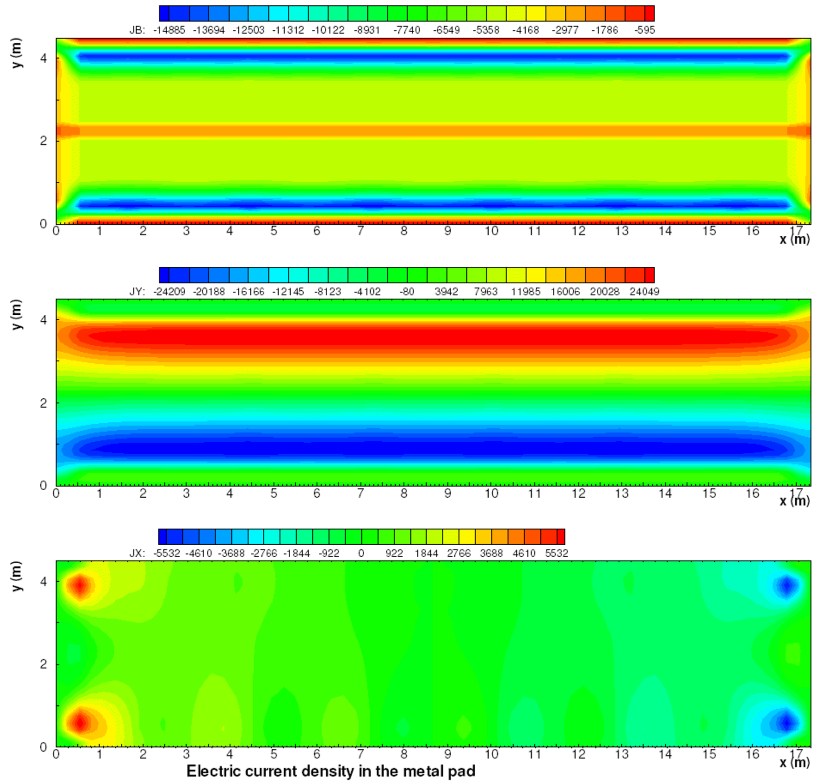

Figure 18: MHD-Valdis model metal pad current density field solution

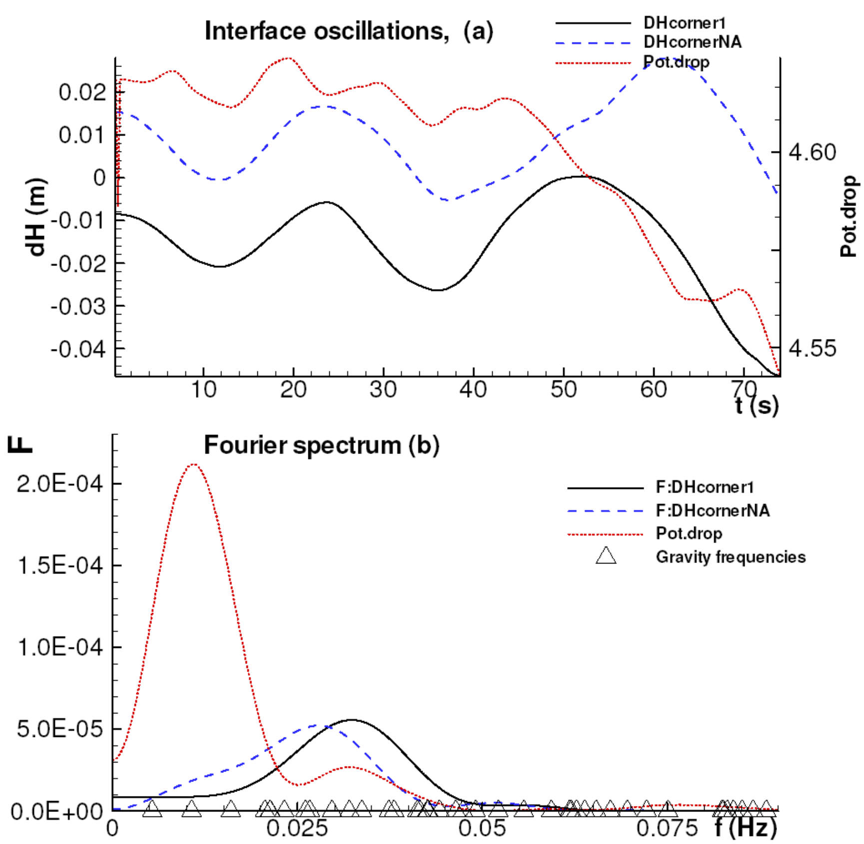

Figure 19: MHD-Valdis model liquid metal pad and cell voltage oscillation

10 AND 20 CM LEDGE THICKNESS

Figure 20 shows the metal pad current density field when the ledge thickness is increased to 10 cm. The resulting metal pad and cell voltage oscillation and Fourier power spectra of the non-linear cell stability analysis results are presented in Figure 21.

In order to save some CPU time, the non-linear stability analysis was carried out only up to 250 seconds instead of 1000 seconds for the base case analysis. For that reason, it is not so easy to compare the results obtained. Nevertheless, it seems that by increasing the ledge thickness from 4 cm to 10 cm, the cell is predicted to be a bit more stable which is consistent with the slight decrease of the intensity of the horizontal current in the metal pad. It is interesting to notice that in modern cell design, such a reduction of horizontal current intensity and cell stability improvement is achieved by not rodding the collector bar up to the edge of the cathode block.

Yet, as we can see in Figures 22 and 23, this tendency is reversing fast as the case with 20 cm ledge thickness is predicted to be less stable than the case with 10 cm ledge thickness.

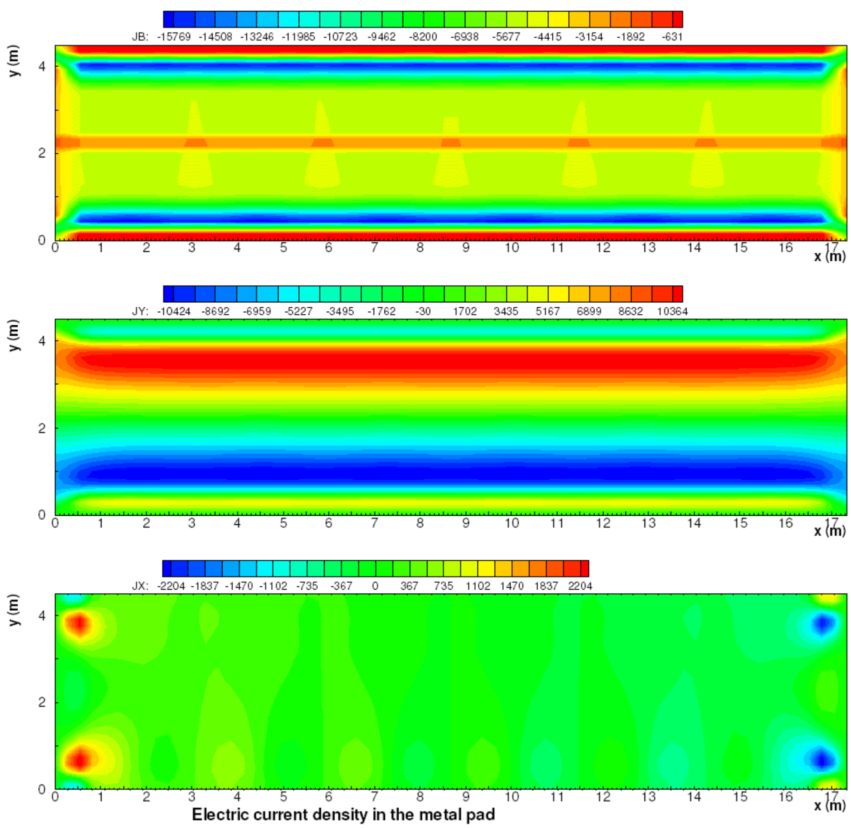

Figure 20: MHD-Valdis model metal pad current density field solution

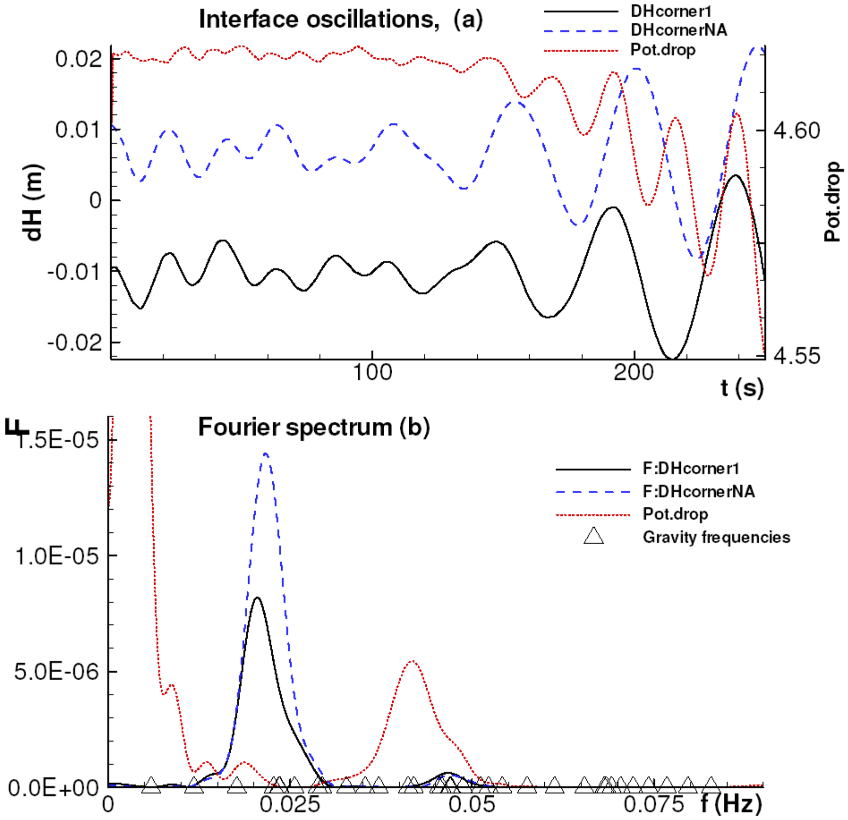

Figure 21: MHD-Valdis model liquid metal pad and cell voltage oscillation

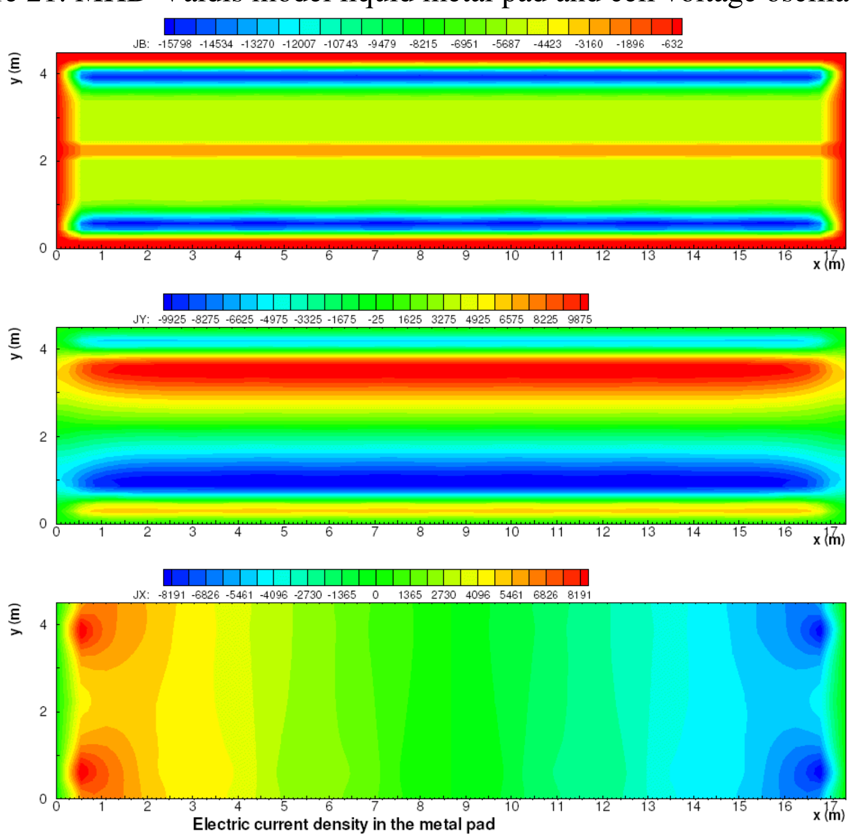

Figure 22: MHD-Valdis model metal pad current density field solution

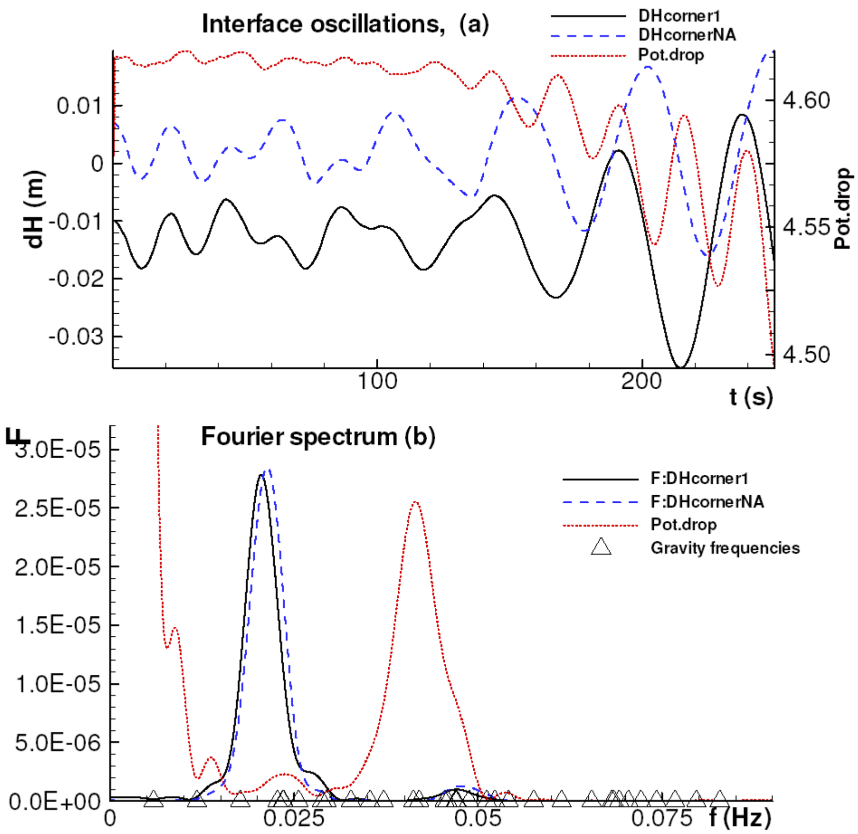

Figure 23: MHD-Valdis model liquid metal pad and cell voltage oscillation

CONCLUSIONS

It has been demonstrated that, despite the fact that it is solving the metal pad current density field in only a few CPU seconds, MHD-Valdis is obtaining very similar metal pad current density results as those obtained by much more detailed but much more CPU demanding ANSYS® models.

The negative impact of horizontal current in the metal pad on the cell stability is highlighted in both the metal pad thickness and the ledge thickness change examples.

Those extra examples of practical applications in addition to the ones presented previously in [1,4,7,8] continue to demonstrate the usefulness and convenience of using MHD-Valdis as MHD non-linear cell stability analysis tool to carry out a new cell design study or a cell retrofit study.

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