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IMPACT OF THE VERTICAL POTSHELL DEFORMATION ON THE MHD CELL STABILITY BEHAVIOR OF A 500 KA ALUMINUM ELECTROLYSIS CELL

Marc Dupuis[1], Valdis Bojarevics[2] and Daniel Richard[3]

[1]GéniSim Inc.
3111 Alger St., Jonquière, Québec, Canada, G7S 2M9
marc.dupuis@genisim.com

[2]University of Greenwich, School of Computing and Mathematics
30 Park Row, London, SE10 9LS, UK
V.Bojarevics@gre.ac.uk

[3]Hatch
5 Place Ville Marie, Bureau 200, Montréal (Québec), Canada, H3B 2G2
DRichard@hatch.ca

Abstract

In previous publications [1,2], it was rationalized that a large vertical potshell deformation may have a negative impact on the operations of very high amperage cells.

The MHD-Valdis non-linear Magneto-Hydro-Dynamic model was therefore extended to take into account the displacement of the potshell. The MHD cell stability behavior of a 500 kA cell with a 17.3 meters long potshell was then studied.

Introduction

The work presented in this paper is part of a longer term collaboration efforts by the authors to investigate if there is a technical limit to the size of an aluminum electrolysis cell that can be designed, built and successfully operated.

The first and currently most popular argument is that there is a size limit dictated by the heat dissipation requirement hence the need for the AP50 technology to use an active heat exchanger system on the potshell in order to enhance the heat dissipation.

This issue was addressed in [3]. The demonstration is quite simple to make: because there is a size restriction on the cell width, having a bigger cell means having a longer cell. Already, length to width aspect ratio of modern high amperage cells is quite high so they proportionally do not dissipate much heat by their end walls. Very simple calculations can be made to demonstrate that a 300 kA cell operating at 15 kWh/kg would need higher heat fluxes to dissipate its internal heat than a 740 kA cell operating at 13.5 kWh/kg.

The second argument is that there is a size limit dictated by the MHD cell stability requirement. This issue was addressed in [1]. It is known that the modern high amperage cell operating at around 300 to 350 kA can comfortably be operated with asymmetric busbar network compensating for the effect of the return line located about 60 meters away. Furthermore, the Bz minimization requirement imposes that the great majority of the positive side busbars must go around the cell.

At 500 kA, the cell aspect ratio is such that it becomes both impractical and quite expensive to continue to run most of the positive side busbars around the cell. In order to avoid to have to do that, a compensation busbars network like the one presented in [4] is required.

While until further notice, it seems true that at around 500 kA, a compensation busbars network is required in order to address both the cell stability problem and the busbar cost minimization problem, it was claimed in [1] that it is possible to perfectly magnetically compensate cells of any length and hence of any amperage as results presented for a 500 kA and a 740 kA cell clearly demonstrate.

The third and last argument is that there is a size limit dictated by the cell mechanical design requirements. This argument is not often even raised, but as discussed in [2], it may well be the most serious argument.

It used to be that due to carbon lining swelling, the potshell badly deformed laterally. But modern high amperage cells using 100% graphitic or graphitized cathode blocks and strong orthotropic potshell do not deform much laterally due to carbon swelling they rather deform vertically due to their own thermal loading [1,2].

It can be observed (but it has not yet been formally presented in a paper) that this vertical deformation can have a negative impact on the cell operations. The aim of the present paper is to take the first step in trying to take into account impact of the vertical potshell deformation on the cell predicted operational behavior.

Fully coupled aspect of the problem

To start with, the vertical potshell deformation problem is a fully coupled thermo-electro-mechanical problem. The potshell deforms due to its thermal load and this thermal load is generated by the cell heat dissipation characteristics [2].

Unfortunately, for a cell in operation, it is not as "easy" to develop a fully coupled thermo-electro-mechanical model as it was possible to do for a cell in its preheat phase [5,6], relatively speaking of course!

The added difficulties are coming from the added presence of the liquid zone where a lot of extra physics take place. The main impact of the vertical potshell deformation is the generation of a drastically longitudinally varying metal pad thickness. This variation in the metal pad thickness have an impact on the local sludge accumulation in the two ends that will have an impact on the local electrical resistance above the cathode that will have an impact on the longitudinal collector bars current pickup. All this drastically affects the MHD cell stability characteristic of the cell.

In the absence of a complex CFD component, it is not possible to model that complete interaction, but as a first step, it is possible to take into account some effects of the vertical potshell deformation in the MHD cell stability model.

Weakly coupled mechanical and MHD models

As demonstrated in [7], the metal pad horizontal current density has a strong influence on the MHD cell stability and the intensity of that horizontal current density is directly proportional to the metal pad thickness. With a vertically deformed potshell, there is a strong longitudinal variation of that horizontal current density even for the "static" bath/metal interface configuration.

A new version of MHD-Valdis cell stability model has been developed to take into account the longitudinal deformation of the cathode block surface as computed by the mechanical model [2] and hence take into account the strongly varying metal pad thickness and corresponding horizontal current density on the non-linear MHD cell stability analysis.

500 kA demonstration cell

The computed vertical potshell deformation for the base case (no cooling fins and no forced convection) 500 kA demonstration cell is presented in Figure 9 of [2]. There is about a 2.25 cm difference between the maximum potshell floor surface elevation at the center of the cell and the minimum elevation at the two ends.

In the present work, it is assumed that the relative vertical displacement of the cathode block top surface is identical to the computed relative vertical displacement of the potshell floor and that the vertical cathode block surface displacement is uniform along the width of the cell because there is no data available at this time to justify to do otherwise. Yet, it is important to notice that this is not a limitation of the new MHD-Valdis model extension that could accept any types of X-Y variable vertical surface topology, like a cathode surface erosion profile for example.

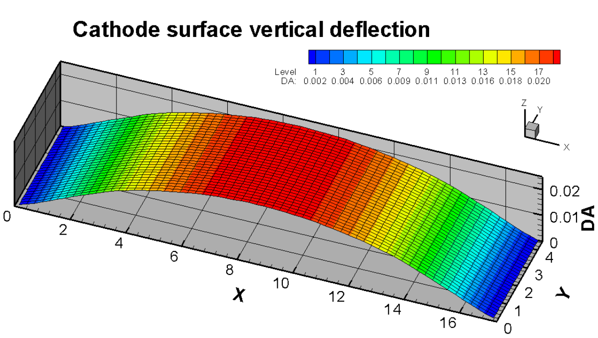

Figure 1. Metal pad bottom profile input

Figure 1 presents the metal pad bottom that has been input to the extended MHD-Valdis model based on the base case vertical displacement presented in Figure 9 of [2].

Before comparing the bath/metal interface oscillation evolution before and after considering the new bottom profile input, it is worth specifying that the 500 kA busbar design used in the present work is the one presented in Figure 1 of [8]. The base case 4.5 cm ACD, 20 cm metal pad thickness and flat bottom profile bath/metal interface oscillation evolution is presented in Figure 2. This type of oscillation evolution is characteristic of a stable cell prediction. The figure compares the results obtained with the updated MHD-Valdis model version using a flat bottom input with the results obtained using the previous MHD-Valdis version [8]. They are of course virtually identical.

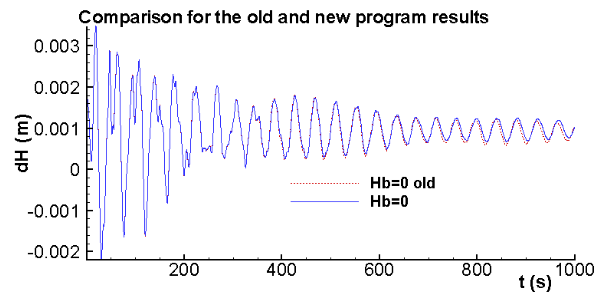

Figure 2. The comparison of the MHD-VALDIS results before and after the variable bottom upgrade.

Figure 3 compares the bath/metal interface oscillation evolution of the same base case with flat bottom profile with the one predicted when using the bottom profile presented in Figure 1. Figure 4 compares the Fourier power spectra of the two interface waves presented in Figure 3. Results indicate that the latter case is predicted to be less stable than the base case.

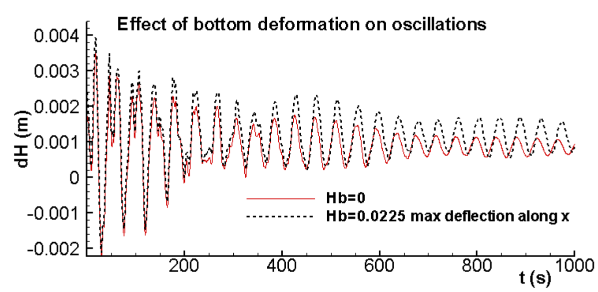

Figure 3. The comparison of the MHD-VALDIS results with and without up to 2.25 cm of vertical displacement.

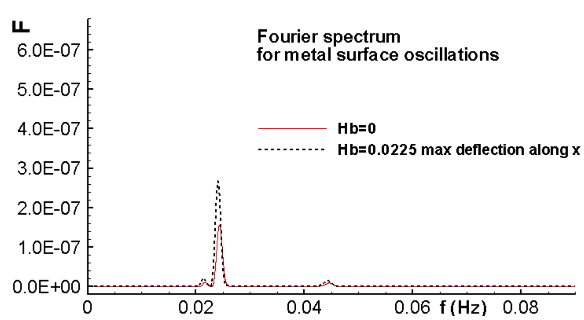

Figure 4. Effect of the vertical displacement (max 2.25 cm) on the interface wave Fourier power spectra.

The difference in cell stability is significant but not excessive because a 2.25 cm middle cathode surface upward displacement is not affecting too much the intensity of the horizontal current density when the metal pad thickness in on average 20 cm deep as we can see by comparing Figures 5 and 6 presenting the intensity of the lateral (Y) horizontal metal pad current density initially calculated using a flat bath/metal interface for both the flat bottom profile and the deflected one.

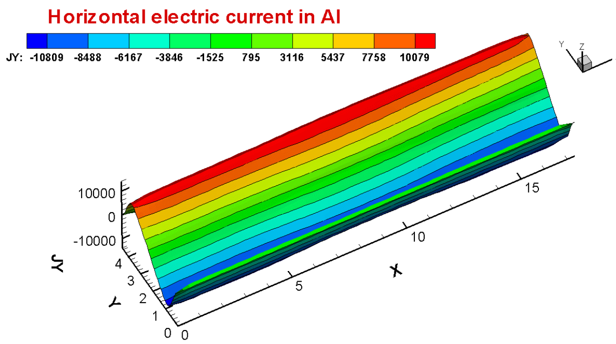

Figure 5. Lateral (Y) horizontal metal pad current density initially calculated using a flat bath/metal interface and a flat bottom profile.

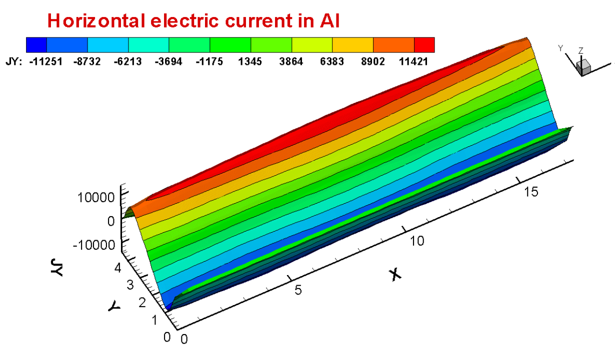

Figure 6. Lateral (Y) horizontal metal pad current density initially calculated using a flat bath/metal interface and a deflected (2.25 cm max) bottom profile.

As argued in [2], it is very likely that the magnitude of the maximum relative vertical displacement will be more than 2.25 cm for an AP potshell design as those potshells have stiffer upper side wall than the potshell design modeled in [2]. For that reason, a second metal pad bottom profile, this time with a 4.5 cm maximum displacement (see figure 7) has also been modeled.

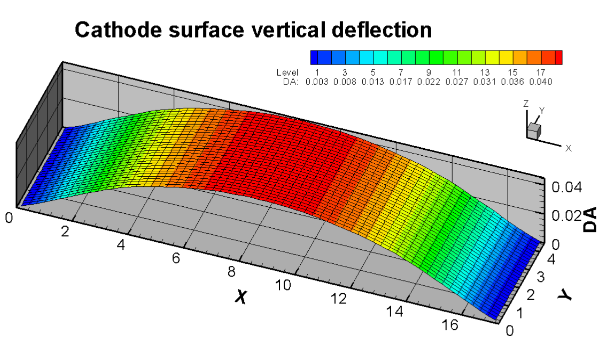

Figure 7. Metal pad bottom profile input

Figure 8 presents the corresponding intensity of the lateral (Y) horizontal metal pad current density calculated using a flat bath/metal interface.

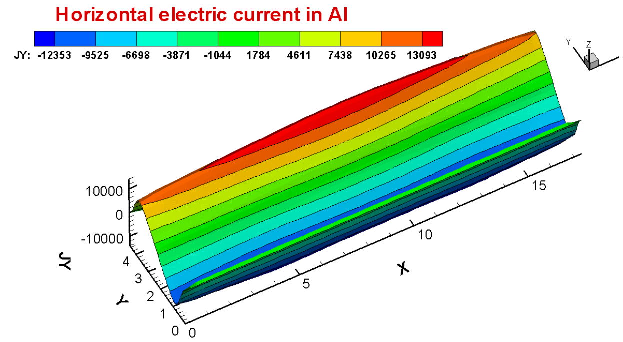

Figure 8. Lateral (Y) horizontal metal pad current density initially calculated using a flat bath/metal interface and a deflected (4.5 cm max) bottom profile.

Figure 9 compares the bath/metal interface oscillation evolution of the flat bottom base case with the one predicted when using the bottom profile presented in Figure 7. Finally, Figure 10 compares the Fourier power spectra of the two interface waves presented in Figure 9.

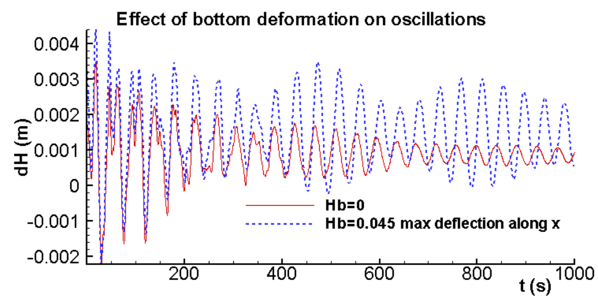

Figure 9. The comparison of the MHD-VALDIS results with and without up to 4.5 cm of vertical displacement.

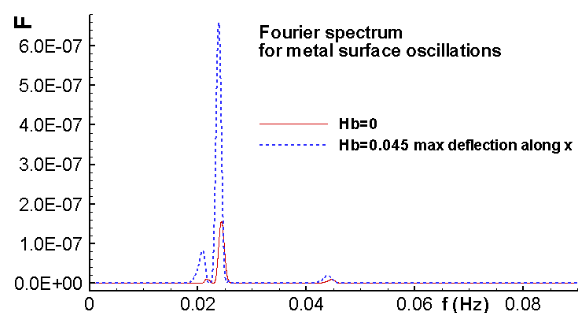

Figure 10. Effect of the vertical displacement (max 4.5 cm) on the interface wave Fourier power spectra.

This time, the cell stability is predicted to have been very significantly decreased. It is quite obvious that with 4.5 cm maximum bottom displacement and 20 cm average metal pad thickness, we are getting very close to the cell instability threshold clearly indicating that an excessive vertical potshell displacement can render a cell with a good busbar design unstable.

In that context, one can consider the importance of using counter measures like forced air cooling on the potshell walls in order to prevent such an excessive vertical potshell displacement, for example on the AP50 potshell.

Conclusions

MHD-Valdis non-linear cell stability analysis software was successfully updated to be able to take into account the impact of having a non perfectly horizontal cathode surface.

For the 500 kA demonstration cell, the non-linear cell stability analysis results show that vertical potshell displacement and hence the cathode block top surface displacement do affect the cell stability in a negative way.

This preliminary study suggests that with a 20 cm average metal pad thickness, a 17 meters long 500 kA cell, that was predicted to be relatively stable with a flat bottom metal pad, is getting very close to the cell instability threshold when the metal pad has a 4.5 cm maximum vertical bottom displacement.

In that context, one can judge of the importance of using counter measures like forced air cooling on the potshell walls in order to prevent such an excessive vertical potshell displacement, for example, on the AP50 potshell [2].

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