INFLUENCE OF THE CATHODE SURFACE GEOMETRY ON THE METAL PAD CURRENT DENSITY

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Keywords: Modeling, MHD, cell stability, irregular cathode surface, current density

Abstract

In the recent years, the Chinese aluminum industry has started to extensively use irregular top surface cathode blocks in its new cell designs. The increase popularity of these new type of cell designs in China is explained by the fact that they can be operated at a much lower cell voltage.

The cell voltage can be reduced because irregular top cathode surface designs seem to increase the MHD cell stability which allows the cell to be operated at a reduced ACD. No satisfactory explanation as to why the usage of irregular top cathode surface promotes MHD cell stability has been presented up to now.

The present work concentrates on the influence of the cathode surface geometry on the metal pad current density as potential cause of the change in the MHD cell stability behavior.

Introduction

A typical cell retrofit story involving the replacement of a standard flat top surface cathode design by an irregular top surface cathode design has been presented in [1]. Figure 1 below, a reproduction of Figure 5 presented in [1], is showing an example of geometry of the irregular cathode block surface. This is not the only design used, since references [2, 3] present alternative irregular top surface cathode designs.

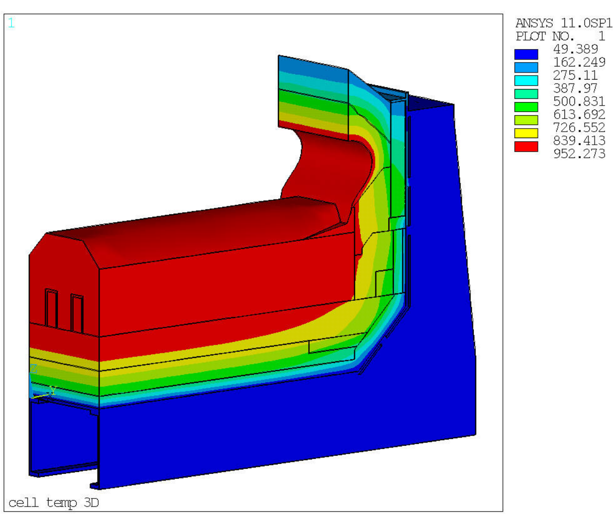


Figure 1. Example of irregular top surface cathode design

For the retrofit study presented in [1] using the irregular top surface cathode design presented in Figure 1, the cell voltage was reduced from 4.17 V to 3.85 V which is a reduction of 320 mV. Out of that 320 mV reduction, 274 mV came from a reduction of the cell ACD (see Table 7 of [1]), clearly indicating that the new cell design increased the cell stability as compared to the previous one.

Yet, the cell stability analysis based on MHD-Valdis code presented in [4] predicted that adding such transversal ridges, while keeping the same metal level, hence, reducing the metal volume, will decrease the cell stability. At best, if the metal volume is kept constant, the presence of those transversal ridges is predicted to have a negligible impact on the cell stability.

The discrepancy between the cell stability analysis and the observations was not addressed in [4]. It is important to notice that for standard flat top surface cathode design the MHD-Valdis code was observed to be quite reliable in [5], so clearly, more research work was required.

Study of the Impact of Cathode Surface Geometry on the Cathode Surface Current Density

The local variation of the thickness of carbon above the collector bar(s) has, among other parameters, an impact on the current density field on the cathode surface and hence the current density field in the metal pad. This effect was recognized as a key to the prediction of the acceleration of the erosion rate of the cathode reported in [6].

Yet this effect was not considered when the option to define the geometry of the top cathode was added to the MHD-Valdis code in order to produce the cell stability analysis presented in [7]. This was the case simply because the deformation of the top cathode surface like the one presented in Figure 2 (Figure 8 of [7]), was caused by the global deformation of the cell. Obviously, as can be seen in Figure 3 (Figure 9 of [8]), the global deformation of the cell due to the cathode panel swelling do affect the geometry of the cathode surface but is not affecting the thickness of the carbon above the collector bar(s), and hence is not affecting the current density field on the top cathode surface.

Since the usage of an irregular top surface cathode design do affect the local variation of the thickness of carbon above the collector bar(s), this variation must be considered in the calculation of the cathode surface current density. Since no study has been presented yet on that specific subject, this section is presenting the result of such a study using a full cell side slice thermo-electric 300 kA cell model.

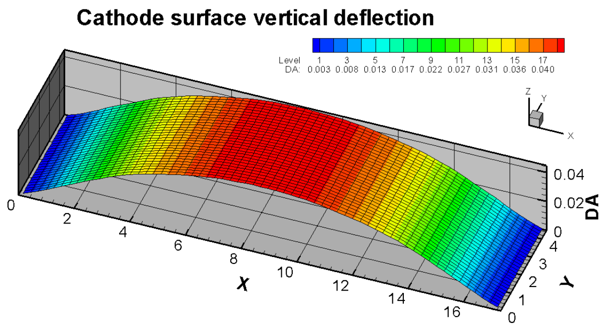
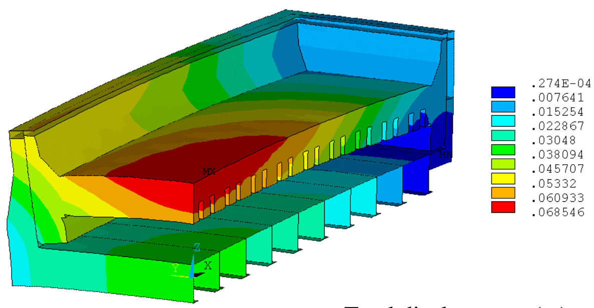


Figure 2. Metal pad bottom profile input for an impact of cell deformation cell stability study



Total displacement (m)

Figure 3. Cathode panel displacement results from thermo-mechanical potshell and lining modeling

Study of the Impact of Longitudinal Ridges

Figure 4 presents the first model geometry case with four longitudinal ridges. This is similar to the geometry presented in Figure 5 of [2].

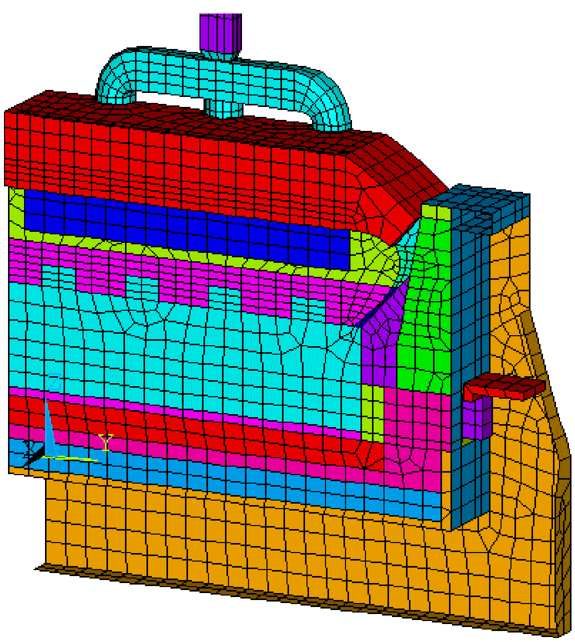


Figure 4. Full cell side slice thermo-electric model geometry with four longitudinal ridges

Since the cathode carbon material is far more resistive than the metal, the current has no incentive to enter into those ridges in order to reach the collector bar. This is indeed what the full cell side slice thermo-electric model solution is indicating. See Figure 5 for the cathode top surface current density solution.

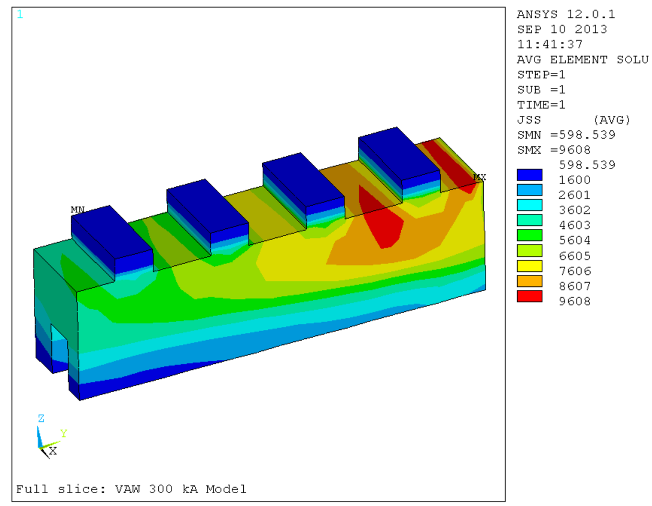


Figure 5. Current density in the cathode block in A/m^2

The resulting current density in the metal pad is presented in Figure 6, this time using a vector representation in order to distinguish between the horizontal and vertical components of the current density.

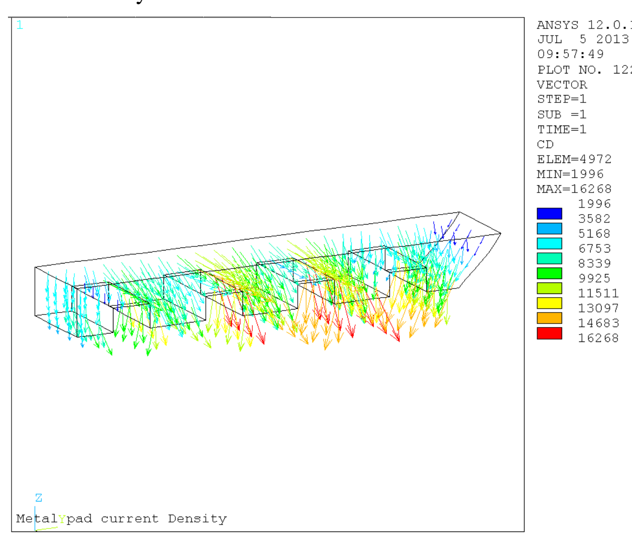


Figure 6. Current density in the metal pad in A/m^2

As it is the horizontal component of the current density that is promoting cell instability, it is pertinent to compare the horizontal current density in the middle of the metal pad with and without those four longitudinal ridges (keeping the same metal level). As can be seen in Figure 7, the four longitudinal ridges are adding local gradient of current density as the current has to go around those ridges in order to enter the cathode block in the lower flat sections between them.

The next step would be to analyse the impact of that change on the cell stability by using a cell stability analysis code like MHD-Valdis, but unfortunately the required version of the code was still under development when this study was carried out.

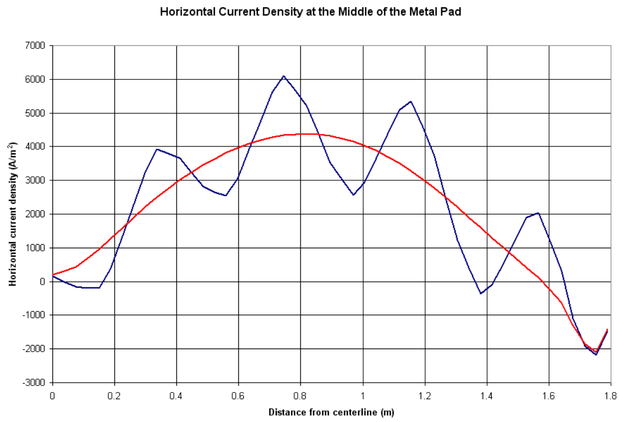


Figure 7. Comparison of the current density in the metal pad, with and without ridges, in A/m^2

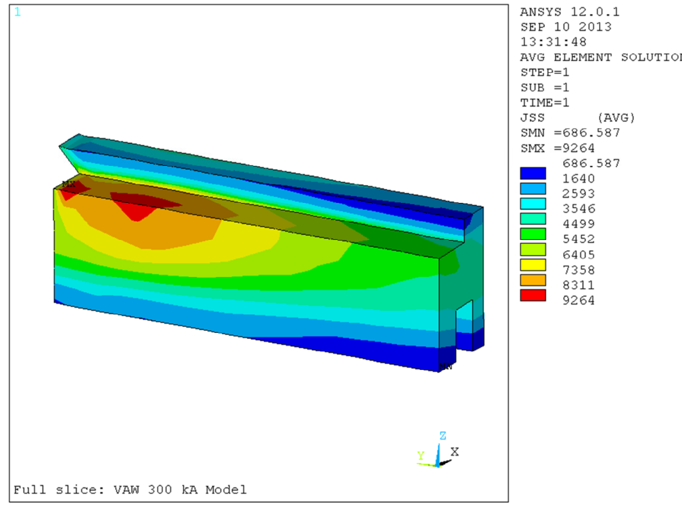


Figure 9. Current density in the cathode block in A/m^2

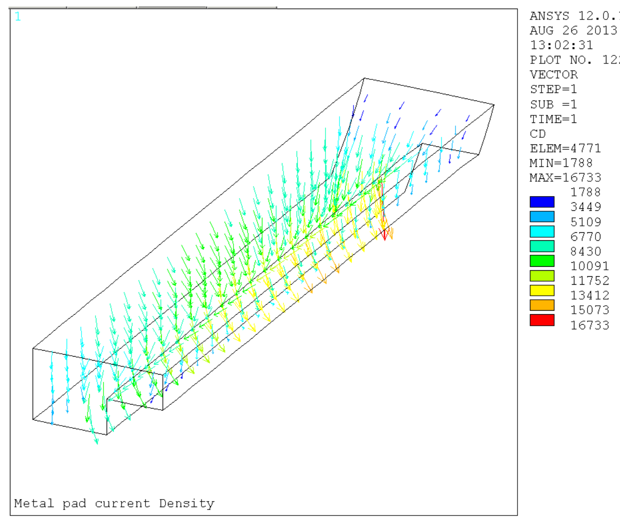


Figure 10. Current density in the metal pad in A/m^2

Study of the Impact of Transversal Ridges

The second case studied is the case of the addition of transversal ridges like the ones presented in Figure 4 of [2]. Figure 8 presents the model temperature solution with the transversal ridge. That geometry is not that different from the geometry presented in Figure 1.

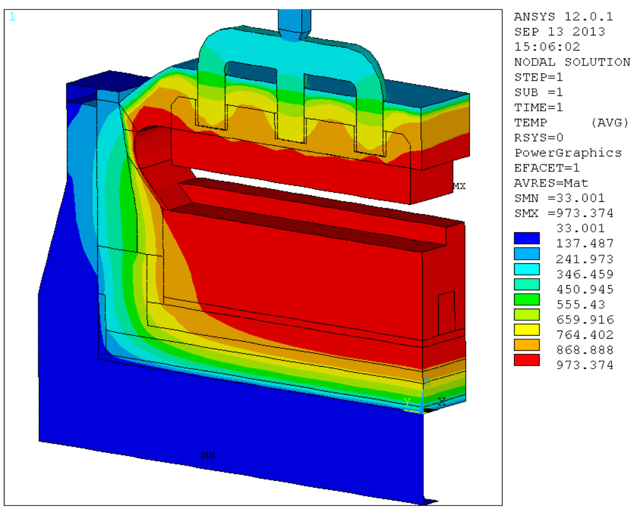


Figure 8. Full cell side slice thermo-electric model thermal solution with a transversal ridge

Figure 9 shows that, as for the previous case, the cathode top surface current density is quite affected by the presence of the ridge.

Figure 10 shows the resulting current density in the metal pad. This time the ridge introduces a horizontal current density component in the third dimension (the X direction in the model).

Again, the next step is to analyse the impact of that change on the cell stability by using a cell stability analysis code like MHD-Valdis, and again required version of the code was still under development at the time this study was carried out.

But for this very specific case, the flexibility of the available code is permitting the user to build and hence analyse this case. That work is presented in the next section.

Study of the Impact of Cathode Surface Geometry on the Cell Stability

500 kA Flat Cathode Surface Base Case Model

The base case of that cell stability comparison study is the 500 kA cell design presented in Figure 1 of [9]. The "classical" asymmetric busbar layout is presented in Figure 11.

The current density on the top surface of the cathode and at the middle of the metal pad is presented in Figure 12. Since the busbar network is perfectly balanced and the ledge toe position has been optimized, there is essentially no horizontal current in the longitudinal direction (JX) in the solution.

Since the magnitude of the vertical component of the magnetic field (BZ) is key to the cell stability, that solution is presented in Figure 13. Finally the evolution of the interface position during the transient analysis is presented in Figure 14, from which that cell design is predicted to be stable.

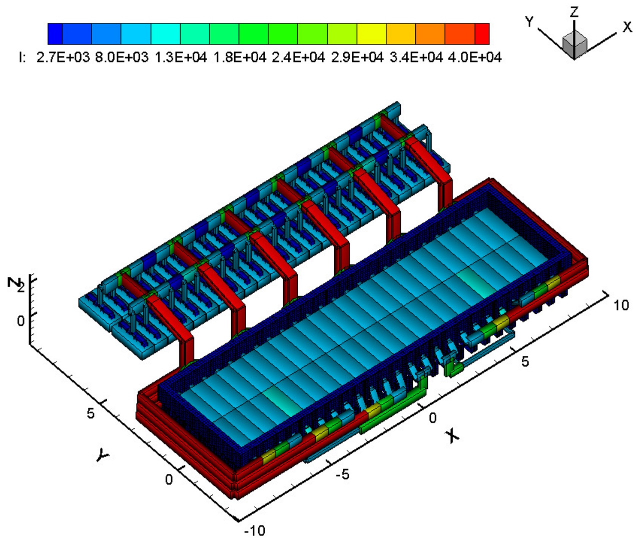


Figure 11. Geometry of the 500 kA base case model showing the current intensity solution in each conductor in A

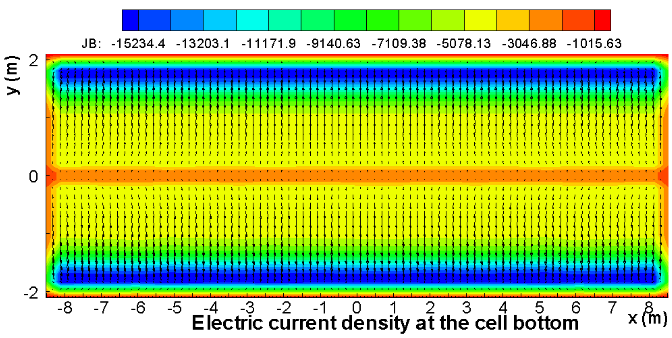


Figure 12. Current density solution on the top surface of the cathode in A/m^2

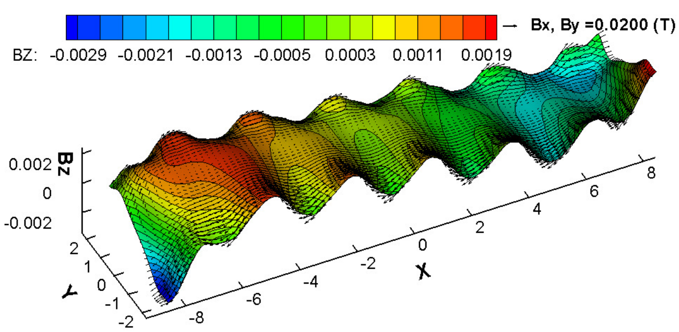


Figure 13. Vertical component of the magnetic field solution in the middle of the metal pad in T

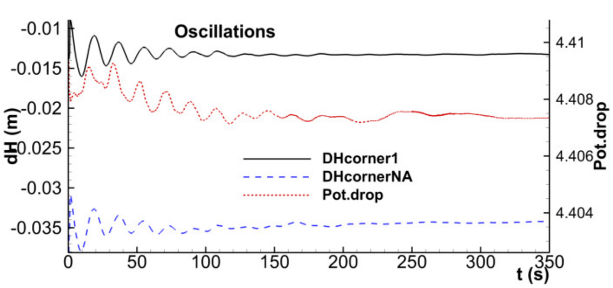


Figure 14. Evolution of the interface position (m)

<u>500 kA with Transversal Ridges Case Model</u>

As in the previous study [4], the geometry of the top cathode surface must be entered in MHD-Valdis' BOTTOM input file. This ensures that the code will account for that geometry in the calculation of the metal pad current density and the subsequent CFD solution of the metal flow.

But in the available version at the time of this study, this doesn't ensure that the geometry of the top cathode surface is affecting the current density on that top cathode surface. Fortunately, in that specific case, it is possible to ensure that by taking advantage of the code user input flexibility.

The procedure to follow to achieve that is:

1. Replace each double bars block in the model by 3 single bar block
2. Change the flex to network busbar connections accordingly in MHD-Valdis' BUSNET input file
3. Manually disconnect all the flexes of the middle block, (so block 2,5,8 etc) in MHD-Valdis' BARSIN input file
4. Run MHD-Valdis with the option to use input from BARSIN activated

Figure 15 presents the cell geometry obtained by following this procedure. Figure 16 presents the current density solution obtained following this cell geometry setup. This solution is only an approximation of the correct solution as no current at all can enter in the ridges.

Figure 17 presents the resulting magnetic field that is also affected. Finally, Figure 18 presents the resulting transient cell stability results using the same metal pad depth and the same ledge toe position.

As for the cell stability study presented in [4], the cell with transverse ridges is predicted to be less stable than the base case cell with flat bottom when keeping the same metal depth, hence, decreasing the metal volume.

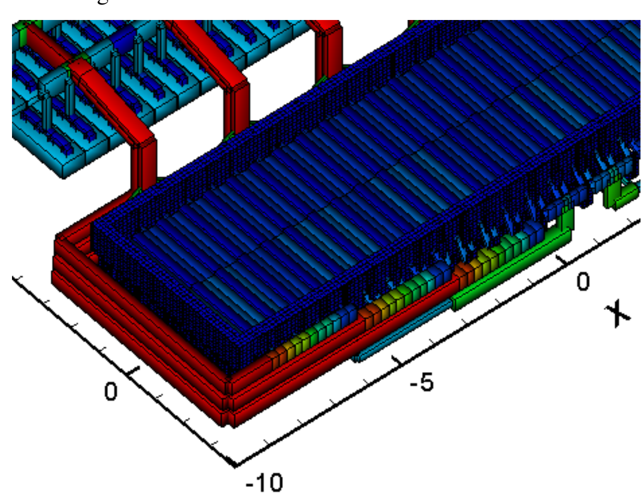


Figure 15a. Geometry of the 500 kA with transversal ridges case model (BARSIN and BUSNET files)

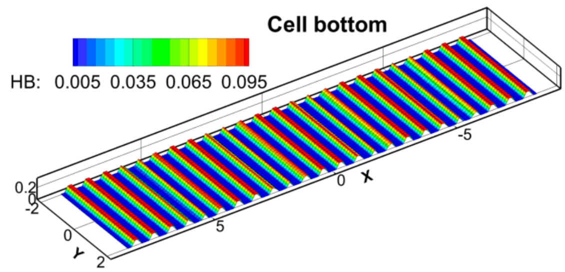


Figure 15b. Geometry of the 500 kA with transversal ridges case model (BOTTOM file)

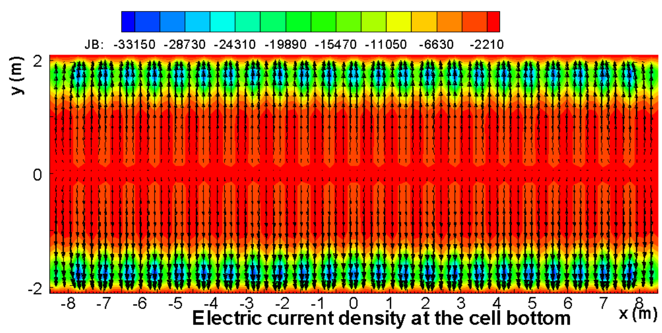


Figure 16. Current density solution on the top surface of the cathode in A/m^2

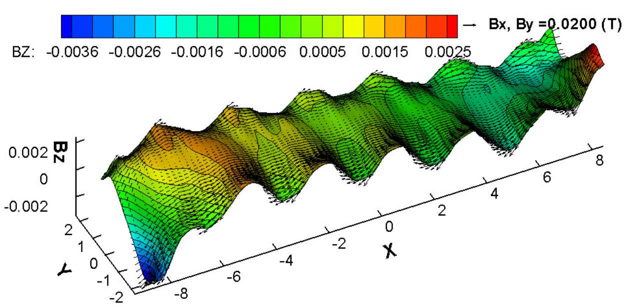


Figure 17. Vertical component of the magnetic field solution in the middle of the metal pad in T

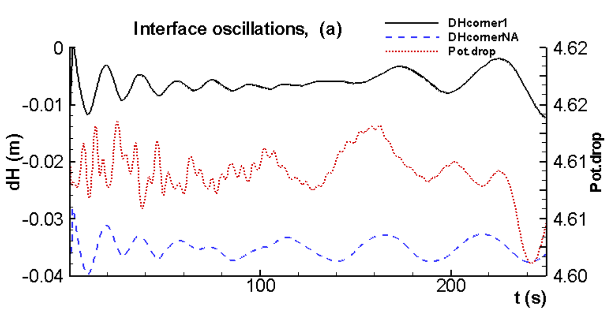


Figure 18. Evolution of the interface position (m)

500 kA Base Case Model with Less Metal and More Ledge

This leaves intact the discrepancy between the cell stability analysis results and the observations in China. If this time, it is assumed that the model represents in totality the effect of adding transversal ridges on the cell stability and that effect is negative or in the best case, where the metal volume is conserved [4], neutral, something else must be responsible for the observed gain of cell stability.

In Figure 19 (Figure 4 of [1]), it can be seen that before the retrofit, the ledge toe is extending a lot on the flat cathode surface. This is no longer the case in Figure 1 after the retrofit. It is well known that ledge toe extension under the anode shadow is bad for the cell stability. In order to illustrate that, the base case flat cathode surface model will be rerun this time to more accurately represent the conditions of operation of cells in China before the retrofit.

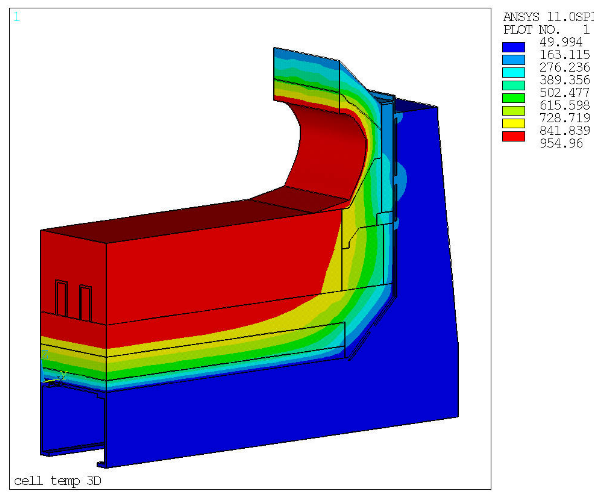


Figure 19. Typical ledge toe extension in cells prior to retrofitted cathode with ridges in China

Compared to the base case model, this case has 5 cm less metal and about 20 cm more ledge toe extension. The resulting current density solution is presented in Figure 20.

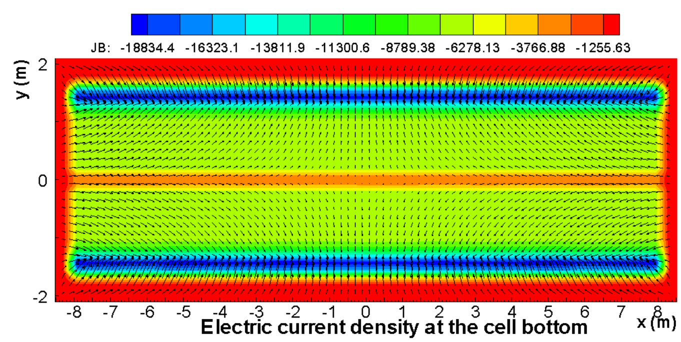


Figure 20. Current density solution on the top surface of the cathode in A/m^2

The excessive ledge toe extension introduces a lot of extra horizontal current particularly increasing the JX in the end of the cell where none were present in the base case with optimum ledge toe position. Figure 21 presents the corresponding magnetic field solution. Finally, Figure 22 presents the obtained transient cell stability results.

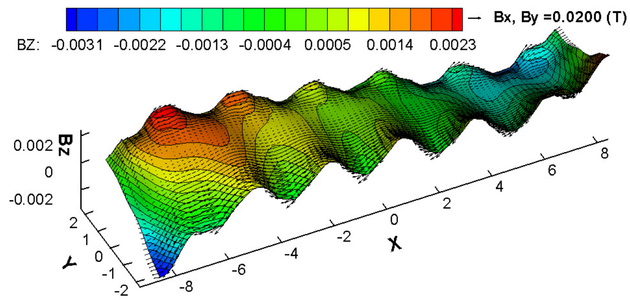


Figure 21. Vertical component of the magnetic field solution in the middle of the metal pad in T

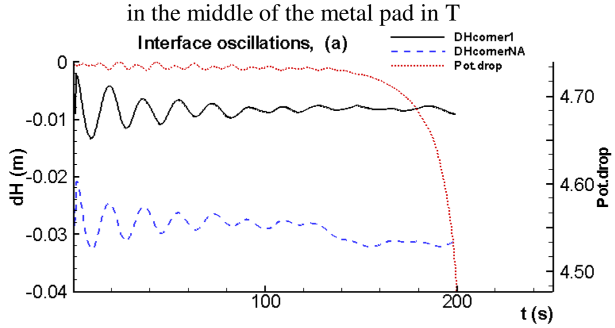


Figure 22. Evolution of the interface position (m)

In a short time after the beginning of the simulation, the bath-metal deforms and touches the anode, stopping the simulation so that configuration is predicted to be unstable.

Thus clearly, despite the fact that on their own, the introduction of ridges on the surface of the cathode has a negative or at best neutral impact on the cell stability, it appears that the improvement of the ledge toe position between Figure 19 and 1 is the main reason responsible for the gain of cell stability observed in the industrial cells in China.

Conclusions

In the first part of the paper, it was demonstrated that ridges on cathode surface affect the top cathode surface current density. This influences the metal pad current density in two ways, the first one by locally changing the depth of metal and the second way by affecting the top cathode surface current density.

Depth of the metal variation is taken into account in the available version of MHD-Valdis at the time this study was carried out by providing the geometry of that top cathode surface in the BOTTOM input file.

Changed to the cathode surface current density is not automatically taken into account in the available version of MHD-Valdis but for the specific case of transversal ridges, it has been taken into account by performing the appropriate adjustments to the MHD-Valdis input files.

The cell stability analysis that was performed for a cell with transversal ridges on its cathode surface taking into account the two ways those ridges affect the metal pad current density. The conclusion of the study is that those ridges decrease the cell stability if the metal height is kept the same (less metal volume).

A new version of the program (see the accompanying paper in this volume) not available when the present study was carried out is accounting for the effect and is bringing very similar general conclusions.

Since the new results confirm the results of the previous study [4], the discrepancy between the cell stability analysis and the observations still needed to be explained.

The last part of the paper addresses this by suggesting that it is the improvement of the ledge toe position that improved the observed cell stability not the impact of the ridges on the metal pad current density or the metal pad flow pattern.

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