# Performing MHD cell stability sensitivity analysis using MHD-Valdis

**M. Dupuis, GeniSim, and V. Bojarevics, University of Greenwich**

**When designing aluminium reduction cell technology or retrofitting an existing one, there are two critical cell design aspects that must be addressed. One of them is the cell energy balance, the second one is the Magneto-Hydro-Dynamic or MHD cell stability. The second aspect is simpler than it looks: one wants the cell to be a very bad resonator of perturbations; when you bang it, you want the resonating noise to die quickly. The physics of that MHD noise resonance in an aluminium reduction cell is now well understood and can be reproduced numerically in mathematical models that can then be used as design tools. MHD-Valdis is such a mathematical model. It is commercially available to the whole aluminium industry, to be used as an efficient cell design tool for improving the cell busbar design in particular. The article below presents key aspects of the behaviour of the MHD-Valdis code to demonstrate its ability to reproduce the MHD behaviour of an aluminium reduction cell.**

The authors have already published many technical papers on the development and usage of MHD-Valdis, including in this magazine [1-8]. This article does not present the theoretical equations used by the code implemented in MHD-Valdis to reproduce the physics of the MHD cell stability, nor does it use the code to design a new cell or retrofit an existing cell. Instead we will present the results of many sensitivity analysis of different parameters affecting (or not) the cell stability.

The list of parameters we will cover in this article is not exhaustive, but it is significant. We have examined four parameters: Firstly, CF, the 2D shallow water CFD formulation empirical friction coefficient, which is a critical user input for absolute cell stability predictions. Secondly, the cell internal cavity aspect ratio r=Lx/Ly, which, in idealized or simplified purely theoretical cases, is shown to significantly affect the cell stability. Is this the case in an industrial configuration, where full electric current is computed and the turbulent friction is accounted? Thirdly, the anode cathode distance, which is known to greatly affect the cell stability, and is the most important factor to improve the cell power efficiency. Finally, the metal pad thickness, also known to affect the cell stability. Sensitivity analyses allows us to quantify such effects.

## Presentation of the industrial case used to carry out those sensitivity analyses

In order to carry out these sensitivity analyses, the authors selected the same cell technology created to present their TMS 2020 paper [9]. The paper, soon to be published, presents the retrofit study of a generic cell design inspired from published Chinese cell technologies. The busbar is specifically adapted from the published GY420 cell busbar [10], more details will be presented in [9]. Fig. 1 presents the MHD-Valdis model setup of that generic 420 kA Chinese cell technology. The steady state solution of the base case will be presented first. For this base case, the key parameter setups are the following: the friction coefficient CF=0.06; the internal cell cavity aspect ratio r=4.64; the anode cathode distance ACD=4.5 cm; and the metal pad thickness 20 cm.

The steady state results are presented in the following figures: Fig. 2 presents the current density in the middle of the metal pad, Fig. 3 presents the vertical component of the magnetic field BZ, also in the middle of the metal pad. (Actually the magnetic field for the stability is computed also on the top and bottom of the metal pad), Fig. 4

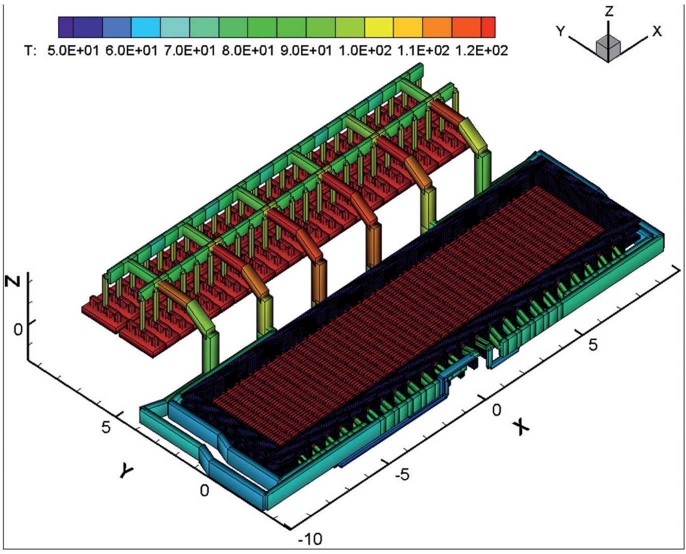

Fig. 1: MHD-Valdis model setup of a generic 420 kA Chinese cell technology

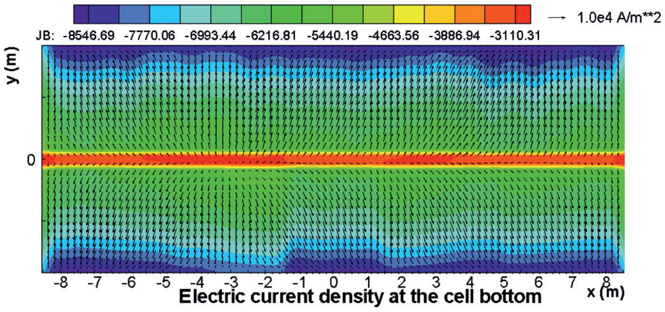

Fig. 2: Current density, in the middle of the metal pad (vectors), on the cathode surface (colours)

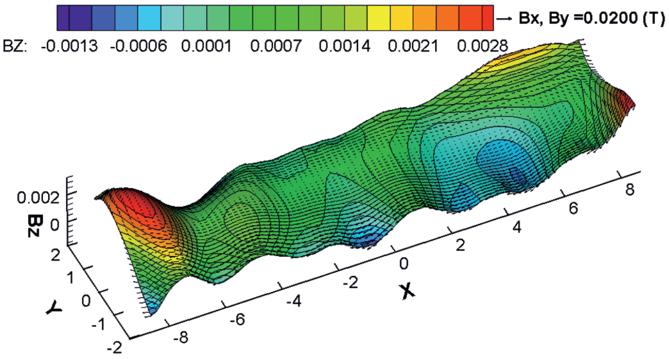

Fig. 3: Vertical component of the magnetic field BZ in the middle of the metal pad

presents the depth averaged metal flow, and finally Fig. 5 presents the position of the bath-metal interface. All those results give insight to what happens in the cell, but they do not provide any direct predictions on the cell stability, as cell noise resonance is a dynamic phenomenon. To predict whether a cell busbar and lining design combination is a good or bad voltage noise resonator or amplifier, a dynamic analysis must be carried out. The specific formulation of MHD-Valdis allows us to carry out this dynamic analysis in a reasonable amount of CPU time. Fig. 6 presents the result of a typical MHD-Valdis cell stability analysis, where the obtained bath-metal interface growth rate has been calculated. In the presented case, the growth rate is negative, as it is rather a damping rate. That perturbation growth rate can be used as both a relative and an absolute criterion of cell stability. A positive growth rate (growing wave amplitude) means an unstable cell at the specified operating conditions, a negative growth rate signifies a stable cell, and a zero or very close to zero growth rate means a cell at the stability threshold or critical stability limit. First, we must calibrate the empirical friction coefficient so that the model output matches the observed cell stability behaviour. Then the model cell stability prediction can be treated as an absolute criterion. In the absence of such a calibration, the criterion is only relative: this case is more or less stable than another case.

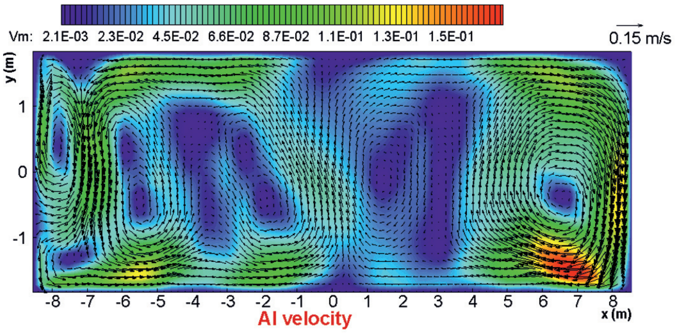

**Fig. 4: Depth averaged metal flow**

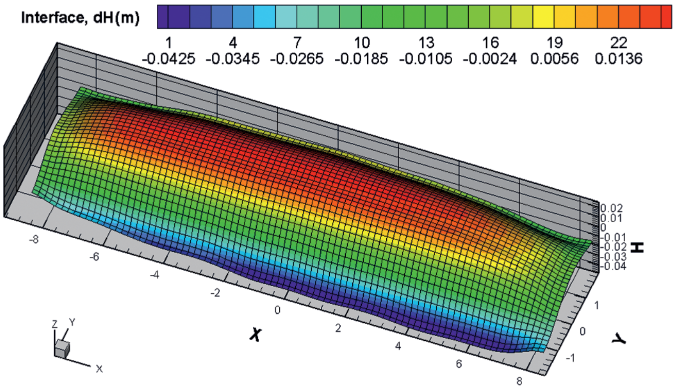

**Fig. 5: Position of the bath-metal interface**

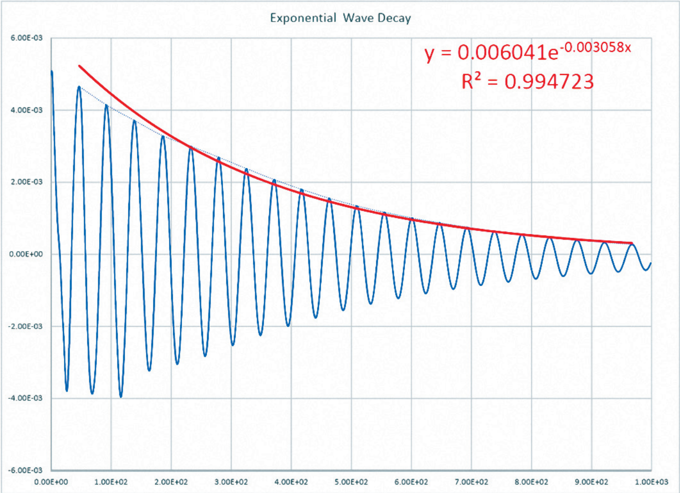

**Fig. 6: Typical MHD-Valdis cell stability analysis, where the obtained bath-metal interface growth rate has been fitted**

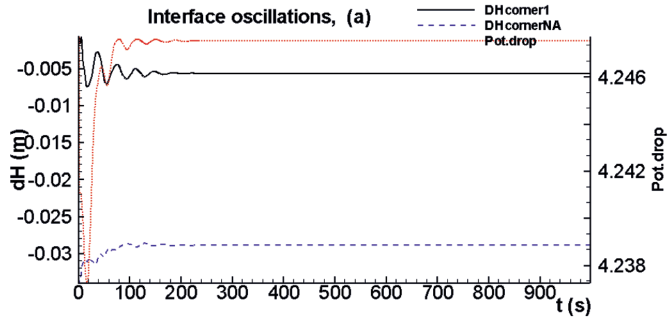

**Fig. 7: Results of the very stable generic 420 kA cell technology base case stability analysis at CF=0.06**

Fig. 7 presents the results of the base case stability analysis. Assuming that the CF was calibrated, this is a prediction for a very stable cell when running at the selected operating parameters, and not suffering from any operational problems, like bad quality anodes creating dusting problems, or alumina quality problems creating slugging issues, etc. We can also analyse the impact of anode change, but this is not presented for this basic cell stability analysis.

## Sensitivity to CF, the friction coefficient

The first sensitivity analysis is not on a cell operational parameter or a cell design parameter, it is on CF, the friction coefficient, the critical shallow water model setup parameter. That friction coefficient parameter appears in the shallow water formulation when the 3D flow equations are depth averaged so as to obtain the 2D shallow water formulation. This simplified 2D formulation gets rid of the vertical gradient of the flow as well as the associated viscous boundary layers at solid surfaces in the vertical direction. In the case on an aluminium reduction cell, those are the top of cathode surface and the bottom of anode surfaces.

The shallow water CFD formulation was developed to model the flow of rivers, lakes or tidal flows in coastal regions. In particular, studies have been made to estimate the proper friction coefficient to be used for those cases. Reference [11] presents a summary of many such studies. CF as low as 0.011 is reported for the Yellow River, while CF as high as 0.101 is reported for the Karun River during the dry period. So, a range of values covers a full order of magnitude.

The present sensitivity study covers about half of that range by presenting results at values of CF of 0.015, 0.03, 0.045 and 0.06. Fig. 8 presents some of the obtained results. We have already seen that at CF=0.06, the cell is predicted to be extremely stable. On the opposite side of the range, at CF=0.015, the cell is predicted to be about critically stable, probably on the unstable side with a positive growth rate. A longer transient analysis would show more reliably whether the growth rate is positive or not, but this is not a critical item of information in the context of this sensitivity study.

It is the responsibility of the MHD-Valdis model user to evaluate the proper CF value to use for his particular cell design studies. He must do this by carrying an ACD squeeze test [12]. The ACD squeeze test lets us identify the ACD cell stability threshold. We can then adjust the CF for MHD-Valdis stability analysis to predict critical stability at the same value of ACD. In the past, the authors were using CF=0.045 to carry out their demonstration analysis, due to absence of validation data. Now partial access to some validation data led the authors to use CF=0.06 to carry out the present demonstration analyses and the retrofit study presented in [9].

Yet, this CF value cannot be considered by any means universal or generally valid for any cell design and operating conditions. It is up to the user of the MHD-Valdis model to establish the best value of CF to use for his own cell design. Irregular cathode designs [13-15], for example, are intended to increase the cathode surface drag. Some other types of surface irregularities are meant to decrease surface drag [16]. Unfortunately, when using the shallow water formulation, any cathode design change that affects the cathode surface drag must be evaluated experimentally, and then accounted for in the model by adjusting the value of CF.

## Sensitivity to r, the cell aspect ratio

As far as MHD cell instabilities are concerned, it might be useful to think of cell cavities as if they were resonance chambers in a musical instrument. Depending on the cell aspect ratio, some rotating waves will be amplified and some other will not. In [17] Urata considered a combined (2,0) and (0,1) rotating waves for small cells, while Davidson [18] considered of combined (3,0) and (0,1) rotating waves for more recent, higher amperage cells which have a bigger length to width aspect ratio r. Clearly, the mode of rotating wave that will be amplified depends on the cell cavity aspect ratio.

Typical theoretical studies like the one presented in [19] predict that some cell cavity aspect ratios are preferable to others to avoid cell instabilities. That study makes too many theoretical abstractions to be useful for cell designers. The present work presents a sensitivity analysis of the parameter r, the cell cavity aspect ratio for three values of r: 4, 4.64 and 5 (practically attainable for the existing cell). Since the goal of the study is the sensitivity to the cell aspect ratio r, we aim to keep all other conditions, like the metal pad current density and magnetic field, unchanged. The range of r values is very limited due to the present cell busbar and potshell design. Even with that very limited range, it was impossible to keep all the other conditions totally unchanged.

Fig. 9 presents the results obtained. CF=0.015 was selected to help highlight the change in the cell stability. Very little change in cell stability can be observed, even very close to the cell stability threshold. The results indicate that the cell stability increases very slightly when the cell cavity ratio goes from 4 to 5. Yet, considering that other cell conditions were not kept perfectly unchanged, this observation may not be significant. What is significant is the observation that the cell aspect ratio has little impact on the cell MHD stability, at least in the tested range.

## Sensitivity to the ACD, the anode to cathode distance

Demonstrating cell stability sensitivity to the anode cathode distance (ACD) is quite fundamental. Fig. 10 presents the results obtained for the following values of ACD: 2.5, 3.0, 3.5, 4.0 and 4.5 cm. There is no big surprise to report, except that when using CF=0.06, the tested cell design is predicted to be critically stable around 2.5 cm of ACD in otherwise perfect operating conditions. Yet, considering recent publications like [20], even that is not a surprising result.

ACD is the critical parameter for both the MHD cell stability and the cell thermal balance. ACD squeeze tests often reveal an ACD cell stability limit far below the cell thermal ACD limit (where the cell would become too 'cold' to operate well). We need another type of modelling tool to study this thermal ACD reduction limitation, but this is not the topic of the present article.

## Sensitivity to the metal pad thickness

Cell stability is also known to be sensitive to metal pad thickness. Fig. 11 presents the results obtained for the following values of metal pad thickness: 15, 20, 25 and 30 cm. We selected CF=0.06 and ACD=3.0 were selected to perform that first metal pad thickness sensitivity analysis. As can be seen in Fig. 11, adding metal pad thickness increases significantly the cell stability due to the decrease in

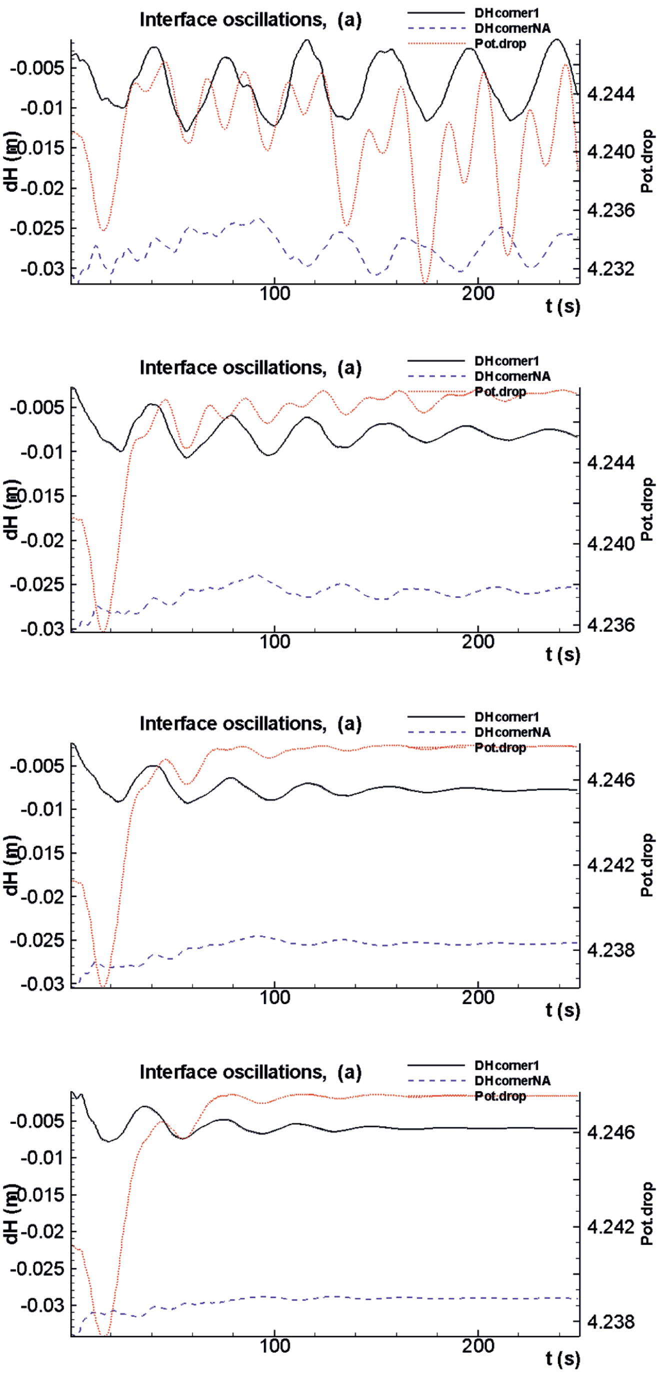

**Fig. 8: The friction coefficient effect on the generic 420 kA cell technology stability analysis at CF=0.015, 0.03, 0.045 and 0.06**

the horizontal current density. This cell is predicted to be very stable at CF=0.06, ACD=3.0 and 30 cm of metal pad thickness.

This observation opens the door to attempts to achieve cell stability at even lower values of ACD. Fig. 12 presents the results obtained for metal pad thicknesses of 25 and 30 cm at only 2.0 cm of ACD, still using CF=0.06. The result of that unusual test shows that the generic Chinese 420 kA cell is about critically stable at 2.0 cm of ACD and 30 cm of metal pad thickness. Clearly, its thermal design will prevent continuous operating at such a low ACD and high metal pad thickness, because reducing the ACD reduces the cell internal heat generation, and increasing the metal pad thickness increases the cell heat dissipation. Such operating conditions would completely freeze up the cell when using the lining design presented in [9]. This clearly demonstrates that in the present case, the reduction of the cell energy consumption is limited more by the cell thermal lining design than by the cell busbar design.

## Conclusions

Several sensitivity studies have been presented here. The first one highlights the importance of properly selecting CF, the shallow water formulation friction coefficient, so as to properly predict the cell stability threshold. The authors strongly recommend MHD-Valdis users to perform ACD squeeze tests to identify the ACD value where the cells become unstable, and then to adjust the value of CF in order for the code to reproduce that behaviour correctly.

The second sensitivity study investigates how the cell internal cavity aspect ratio r influences the cell stability. The results obtained

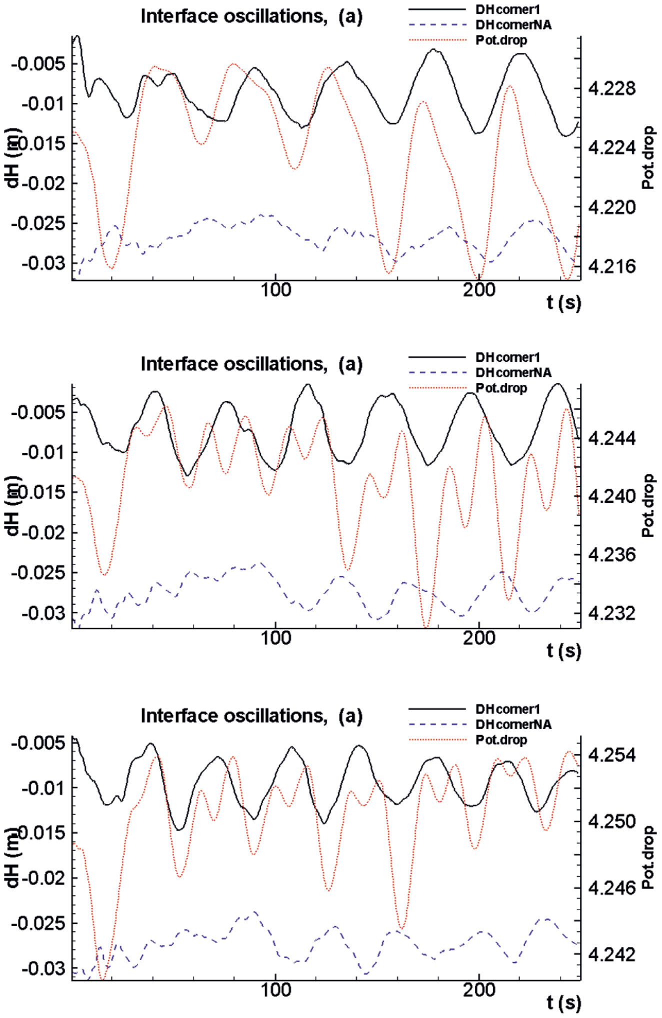

Fig. 9: The dependence on the cell aspect ratio in the generic 420 kA cell technology stability analysis at r=4, 4.64 and 5, CF=0.015

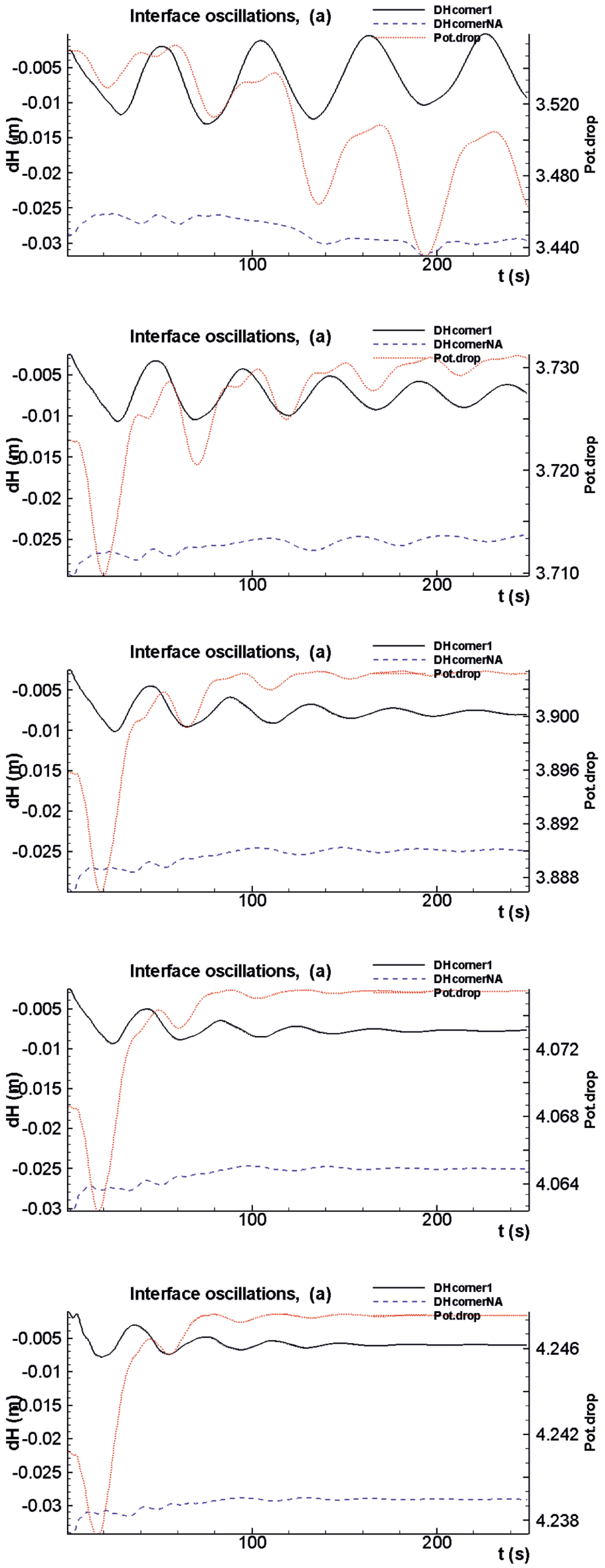

Fig. 10: The dependence on the interpolar distance for the generic 420 kA cell technology stability at ACD=2.5, 3.0, 3.5, 4.0 and 4.5 cm, CF=0.06

seem to indicate that the aspect ratio has little influence on the cell stability, at least within the relatively short range tested. A more extensive study would be required in order to obtain more general results.

The last two sensitivity studies demonstrate the expected influence of the ACD and the metal pad thickness on the cell stability. They also demonstrate that the tested cell is predicted to be stable well below 4.0 cm of ACD when CF=0.06 is selected. In fact, the tested cell is predicted to be at its stability threshold at 2.0 cm of ACD and 30 cm of metal pad thickness. Clearly, it is the thermal, and not the MHD cell stability, that prevents the reduction of the ACD in this Chinese technology inspired 420 kA cell.

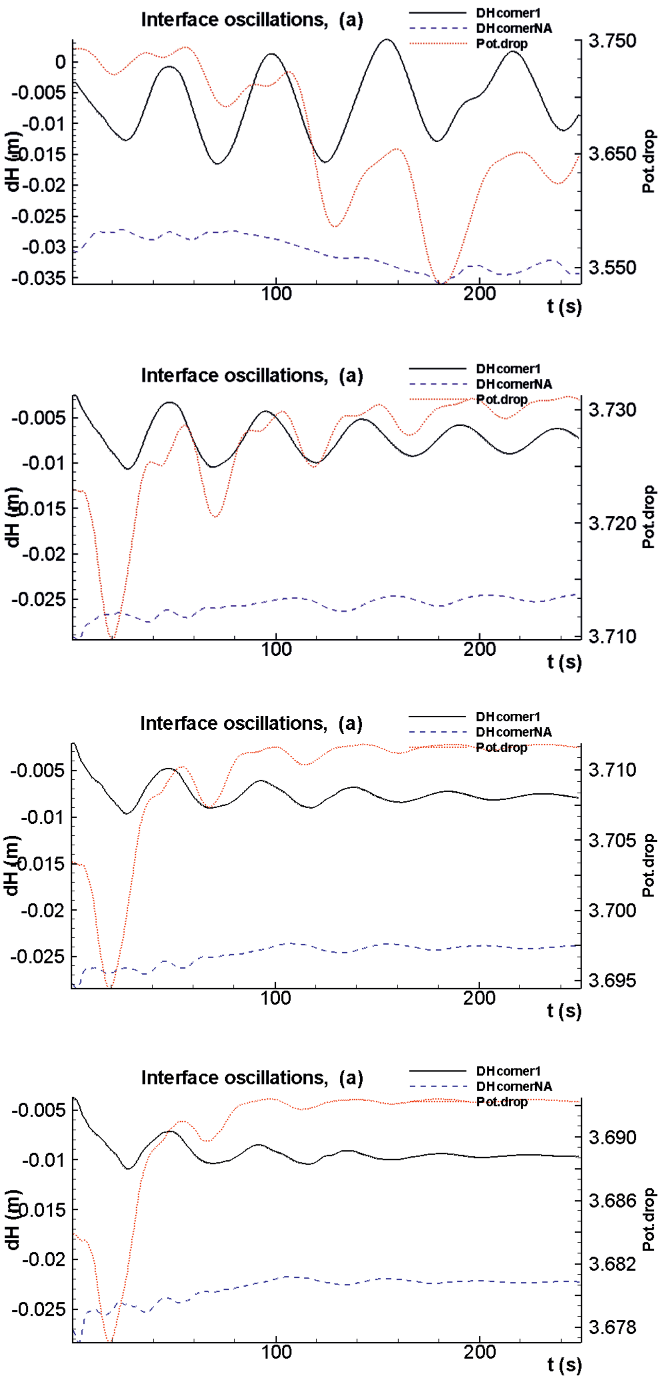

**Fig. 11: Dependence on the metal pad thickness for the generic 420 kA cell technology stability analysis at $H_{met}$=15, 20, 25 and 30 cm, CF=0.06 and ACD=3.0 cm**

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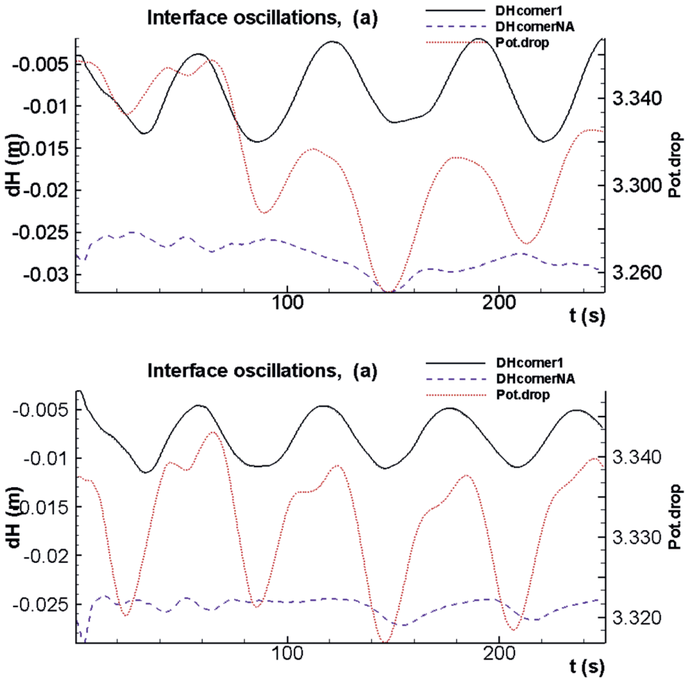

**Fig. 12: Dependence on the metal pad thickness for the generic 420 kA cell technology stability analysis at $H_{met}$=25 and 30 cm, CF=0.06 and ACD=2.0**

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## Authors

Dr. Marc Dupuis is a consultant specialized in the applications of mathematical modelling 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 with the retrofit of many existing cell technologies.

Dr. Valdis Bojarevics is an internationally recognized specialist in the field of computational magneto-hydro-dynamics (MHD), especially in developing original computational models for a wide range of practical applications, and supporting physical experiments in the electro-metallurgical industry. Dr. Bojarevics has been invited to several internationally leading research centres for collaborative work: 1991 and 1992 Ecole Federale de Lausanne (Switzerland), 1993 Madylam laboratory, Grenoble (France), 1993-1995 Reynolds Metals Research Centre (Alabama, USA). In 1995 Dr. Bojarevics was invited to join the Computational Modelling Group at the University of Greenwich, UK. He is currently a professor at the University of Greenwich.