Analysing the Dynamic Stabilization of Aluminium Electrolysis Cells

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Abstract

It was demonstrated in [1], by using the MHD-Valdis code to perform non-linear transient cell stability analysis, that it is possible to stabilize an aluminium electrolysis cell by alternating the potline current. This stabilization effect is highly dependent on the cell operating parameters, such as anode-to-cathode distance (ACD) and cell dimensions, and the alternating current amplitude and frequency. Later it was demonstrated in [2], still using the MHD-Valdis code that it is also possible to stabilize an aluminium electrolysis cell by alternating the current in magnetic field compensation busbar loops only.

A very large number of combinations of parameters exist, and it would be ideal to find the optimal combination for the most efficient stabilization. However, each simulated combination of alternating current and cell parameters requires an overnight run, limiting the number of analysed combinations in a week per example to only a few. Having a reduced model where it would be possible to explore the stability of the cell of a great number of combinations very quickly would be of great benefit in reducing the total number of MHD-Valdis simulations that we need to run to find the optimum combination. For example, a detailed frequency vs amplitude stability map was produced in [3, 4] using a frictionless mechanical pendulum model.

However, the pendulum model did not exhibit stability and instability at realistic cell parameters. This limits the map's usefulness in identifying parameter combinations of interest to investigate using the MHD-Valdis model for a real cell. A damped mechanical mobile model [5, 6], that more closely mimics behaviour an actual aluminium reduction cell to investigate the cell stability was developed to address that limitation.

In the present work, both the damped mechanical mobile model and MHD-Valdis code are used to further investigate the frequency vs amplitude stability map of dynamic stabilization by alternating the current in magnetic field compensation busbar loops.

Keywords: Magnetohydrodynamic instability, Aluminium cell modelling.

1. Introduction

Magneto-Hydro-Dynamic (MHD) cell stability is a complex phenomenon that involves electric energy transfer into mechanical energy through a mechanism of resonance. Peter Davidson developed his pendulum mechanical model to illustrate that mechanism of resonance [7].

Urata explained the wave mechanism in [8], the main ingredient for rotating wave amplification is a longitudinal gradient of the vertical component of the magnetic field (x component of gradient of Bz). The second ingredient is the magnitude of the horizontal components of the metal pad current density in both the longitudinal and transversal directions (Jx and Jy).

To optimize MHD cell stability, the busbar network layout is designed in order to minimize overall Bz component. The busbar network is also balanced in order to minizine Jx and the cathode assembly is designed in order to minimize Jy. In old cell designs, external magnetic field compensation busbar loops can be added to minimize Bz without modifying the existing busbar or in new cell designs rely on external compensation busbar loops in order to minimize busbar network weight, hence the busbar cost.

In [1] a totally new way to increase MHD cell stability was proposed: alternating potline current. By alternating the potline current, a new wave is generated that is interfering with the growth of the naturally occurring rotating wave; in reference [4] this effect is called anti-resonance. It was demonstrated in [1] using MHD-Valdis code that anti-resonance by alternating the potline current is increasing cell stability. In [2], it was also demonstrated that anti-resonance by alternating the current in compensation busbar loops is increasing cell stability. In [3], the Davidson frictionless pendulum model was extended to demonstrate analytically that anti-resonance by alternating the model current density parameter (potline current) is working. A frequency/amplitude map was produced. That mathematical work on Davidson pendulum model was reproduced and extended in [4].

The problem with the Davidson frictionless pendulum model is that even if its behaviour is analogous to real cells, the stability threshold is very different from real cells, so the stability map produced is not useful to indicate what would be the most efficient frequency/amplitude combination for those real cells. Unfortunately, direct usage of MHD-Valdis to investigate a real cell frequency/amplitude stability map is very CPU time consuming so for this reason, it is not very practical.

For those reasons, a damped mechanical mobile model was developed [5, 6]. That new mechanical model once calibrated instantaneously provides a wave damping rate very similar to the one that can be calculated after an MHD-Valdis overnight run. The variation of ACD and potline current stability map of conventional cell operation was quickly obtained using that mechanical model. The present work is an extension of the work presented in [2] and [6].

2. Third Calibration of the Damped Mechanical Mobile Model

In [5] a first calibration of the mobile model was presented. That first calibration led to a first prediction of the damping rate for a change of ACD that was looking promising but was not so close to the wave damping rate obtained by MHD-Valdis. For that reason, in [6], a second calibration was performed that led to the production of damping rate very close to those obtained by MHD-Valdis as presented in figure 11 of [6].

The two model parameters that are adjusted to match one damping rate prediction of MHD-Valdis are n, the relative position of the centre of mass of the mobile aluminium plate and ζ, the plate motion damping coefficient. There is a multitude of combinations of those two parameters that leads to the reproduction of a single damping rate obtained from MHD-Valdis, but in fact the two parameters can be used to reproduce two MHD-Valdis results. Table 1 compare the results obtained with the 2nd and 3rd calibration with the ones obtained with MHD-Valdis. The calibrated results are displayed in bold. Obviously, it is possible to calibrate using any combination of two results obtained by MHD-Valdis. The new results are not that different from those presented in figures 4 and 5 of [6] which is a good thing. The hope is that this new calibration method could be use systematically for other cell designs in the future.

The results of the damped mobile model are obtained using a MATLAB App developed by Ibrahim Mohammad. Figure 1 presents the results obtained for the second calibration point. The model setup parameters are entered and by pressing "Solve" the damping rate is calculated and

According to the damped mobile model, the maximum stabilization effect is obtained using the maximum alternating line current amplitude possible at 2x (twice) the natural plate oscillation frequency.

While using MHD-Valdis to investigate the frequency/amplitude stability map of alternating the current in compensation busbar loops, it was observed that 2x the naturally occurring rotating wave frequency is more efficient than 3x frequency and that 4x frequency is essentially not responding.

While using MHD-Valdis to investigate the frequency/amplitude stability map of alternating the current in compensation busbar loops around the optimum static compensation current, it was observed that 10 kA amplitude is more efficient than 20 kA amplitude.

For the static compensation at 30 kA, the last stable results were obtained at 3.1 cm ACD. For mixed compensation using 2x or 0.04926 Hz frequency, 10 kA amplitude with a minimum of 25 kA and a maximum of 35 kA alternating current, stable results were obtained down to 2.9 cm ACD.

So, static compensation alone has a huge stabilization impact as the critical ACD was reduced from 4.3 cm to 3.1 cm. By adding dynamic compensation, the ACD can be further reduced to at least 2.9 cm.

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9. References

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