

Stabilizing Aluminium Reduction Cells by Oscillating Currents in Magnetic Compensation Loops

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Abstract

It was observed in a numerical study reported in [1] and [2] that the MHD stability of aluminium reduction cells can be increased by oscillating the current of the potline. A smelter performing this kind of potline current modulation would have modulated power demand that could be problematic for the power grid operation. For that reason, the effect of oscillating the currents in magnetic compensation loops on the cell stability keeping the potline current constant was studied. The same stabilizing effect is observed. Performing this current oscillation in magnetic compensation loops would reduce the modulated demand of the smelter. The smelter modulated demand would be reduced to zero if superconductor busbars are used to build those magnetic compensation loops.

Keywords: Aluminium reduction cells, Modeling and simulation, Magneto hydrodynamics, Cell Stability, Oscillating currents

1. Introduction

The idea of oscillating the potline current in order to increase the stability of the cells is originating from Prof. Douglas Kelley and his research group at Rochester University [1] and [2]. That idea was inspired by the physics of the Kapitza's pendulum [3]. The Kapitza's pendulum is a reversed rigid pendulum that has an unstable rest position at zero degree of inclination. Yet that position becomes stable when the pendulum is oscillating vertically. Reference [4] presents a stability analysis of the system identifying zone of stability in function of both the amplitude and the frequency of that vertical oscillation.

In order to theoretically investigate the idea of increasing the stability of an aluminium reduction cell by oscillating the current of the potline, the concept was tested on the "Davidson's mobile" [5]. The Davidson's mobile displayed in Figure 1 is a simple imaginary system that behaves very similarly to an aluminium reduction cell. Depending on the values of the different parameters like B_z , J_0 and h_0 , the system can be stable or unstable.

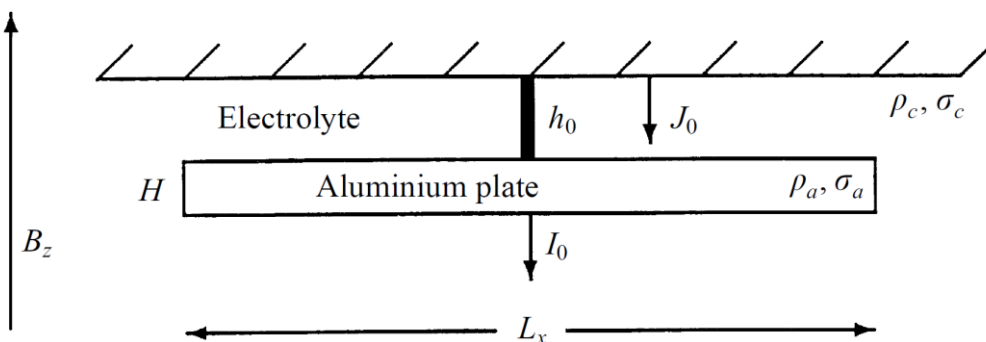


Figure 1. Davidson's mobile, Figure 4 of [5].

In a stability analysis very similar to the one presented in [4], it was demonstrated in [6] that oscillating the current J_0 increases the stability of the system depending of the selected amplitude and frequency of the oscillation.

As a next step, the MHD cell stability code MHD-Valdis was modified to incorporate the option to oscillate the potline current during the transient simulation of the interface wave evolution. Unfortunately, it is not possible to do a thorough investigation of the system stability situation for all possible combinations of the current oscillation amplitude and frequency as investigating a single combination requires an overnight run on the computer. Yet, as reported in [1] and [2], for the selected 180 kA TRIMET cell located in Hamburg, a 22 % potline current amplitude oscillation at 0.04545 Hz frequency or 22 s. period, increases the cell stability. As explained in [1] and [2], the stabilization is achieved by exciting a combined (4, 0) (0, 2) standing wave which is preventing the less stable combined (2, 0) (0, 1) (1, 1) rotating wave to grow.

Performing that 22 % current oscillation on the potline would produce about a 36 % power demand oscillation for that potline which in that case constitutes two third of the smelter consuming about 210 MW when operating at 180 kA. Even if the rectifiers could be adapted to deliver that 22 % current oscillation at 0.04545 Hz to the potline, the power grid would probably not appreciate the associated smelter continuous power demand oscillation at that frequency.

For that practical reason, it was decided to investigate another way to achieve the same stabilizing effect. One can speculate that oscillating the magnetic field B_z instead of the current in the Davidson's mobile system would produce the same stabilizing effect. This could be mathematically demonstrated, but that step was bypassed here. Instead, the MHD-Valdis code was again modified for this time add the option to oscillate the current in external magnetic compensation loops during the transient simulation of the interface wave evolution to be able to investigate if that oscillation would also increase the cell stability.

2. Addition of Two Magnetic Compensation Loops to the TRIMET 180 kA Cell

The Hamburg smelter was built by Reynolds Aluminum company using its P-19, side by side, end risers, side broken, 145 kA prebaked cell technology designed in the 60s. The smelter started its operation in 1974. About 20 years later, the busbar layout was retrofitted by VAW from four end risers to two end risers and two side risers. As presented in Figure 2 from [7], this change very significantly improved the cell stability by reducing the B_z intensity by close to 60 %. After this change plus the introduction of poor man point feeders and a longer anode, it became possible to increase the cell amperage to 180 kA.

Despite that major improvement of the B_z , the presence of the two remaining end risers still generates enough B_z to force operation at about 4.3 cm anode-cathode distance (ACD) in order to keep the cell stable. This is confirmed by the cell stability study presented in Figure 3. It would be possible to do much better these days as per example the retrofit of the SM-17SE into the SY-235 by SAMI [8]. But that would require again a major retrofit of the busbar network. Alternatively, it is possible to reduce the B_z intensity by adding two external magnetic compensation loops.

This option was tested using the same TRIMET 180 kA MHD-Valdis model developed in [9] and used in [1] and [2]. Figure 4 presents the B_z obtained using the base case MHD-Valdis model without magnetic compensation loops. The results are quite similar but not identical to those obtained in [7], but it was recently discovered that the pot row to pot row distance used to develop the model in [9] and used for this study was not accurate. In any case, the work presented here is just a theoretical exercise. Figure 5 is presenting the busbar network after the addition of the two magnetic compensation loops. Figures 6a shows the modified B_z when 20 kA is circulating into

each of them is the same direction as the potline, while Figure 6b shows the modified B_z when 40 kA is circulating into each loop.

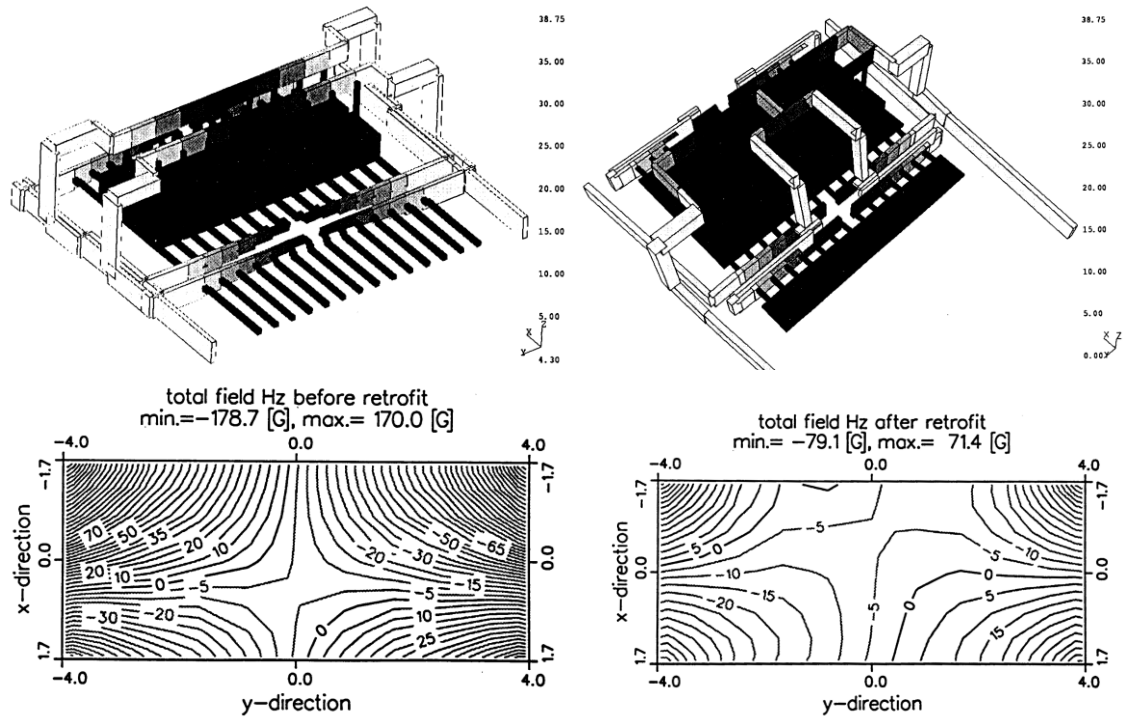


Figure 2. Left: original P-19 busbar. Right: VAW busbar retrofit, from [7].

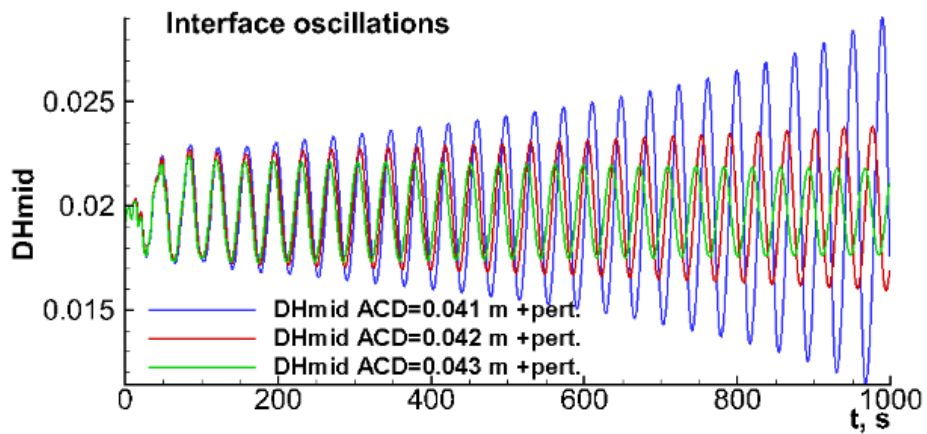


Figure 3. TRIMET 180 kA cell stability study.

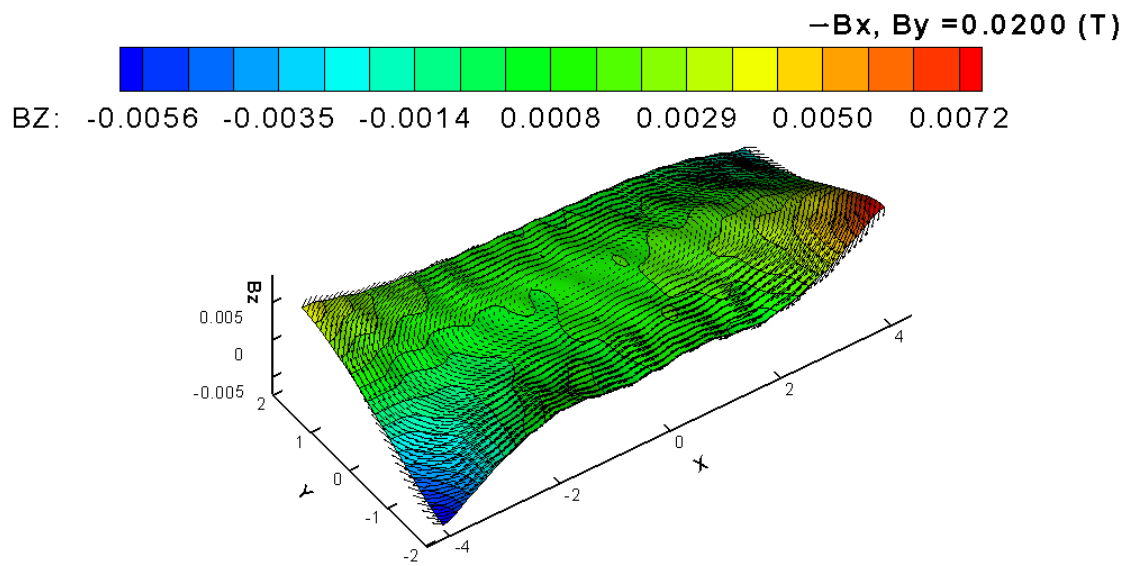


Figure 4. B_z calculated by the MHD-Valdis model of the TRIMET 180 kA cell.

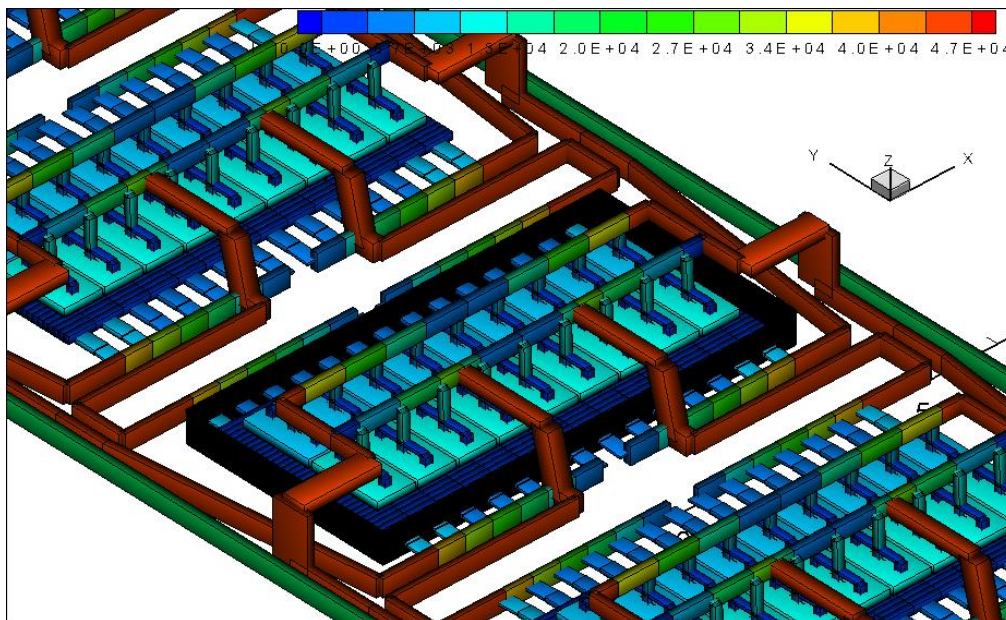


Figure 5. TRIMET 180 kA cell busbar layout with the addition of the two magnetic compensation loops.

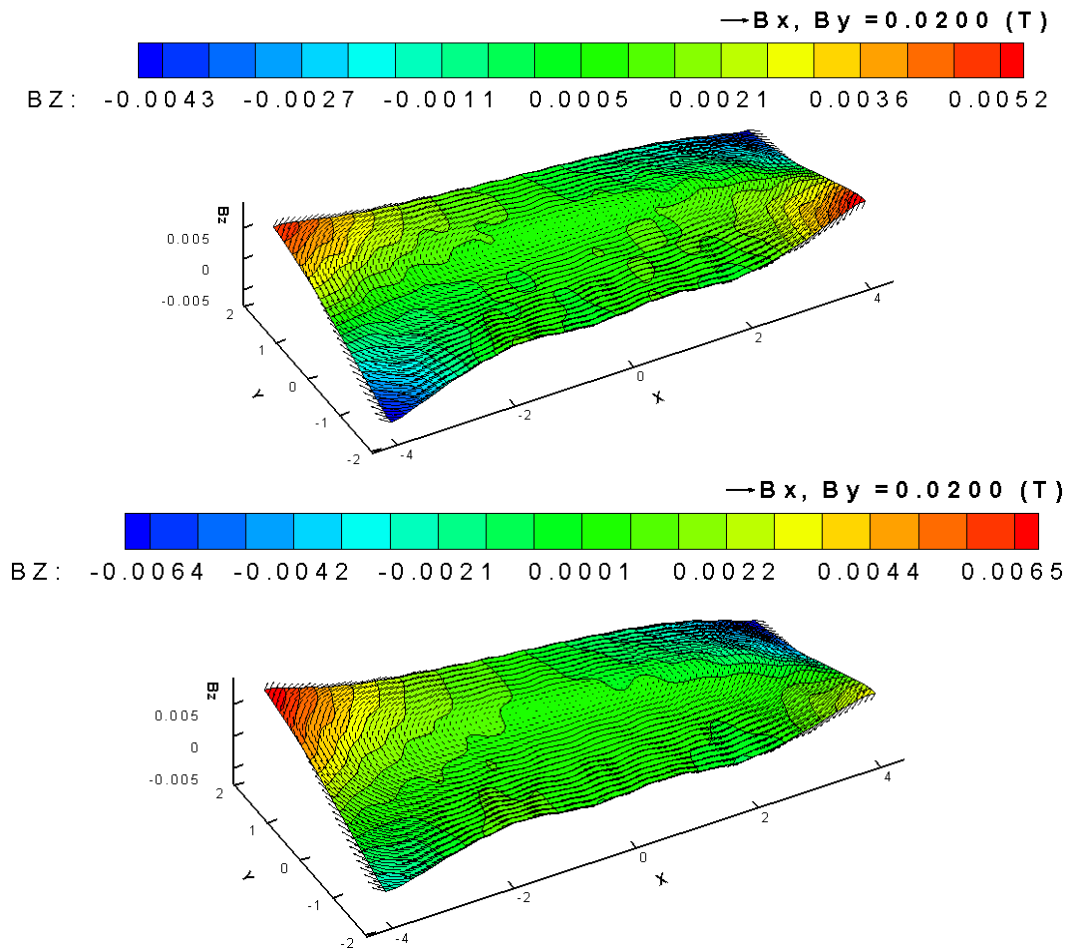


Figure 6. Modified B_z . Top: when 20 kA is circulating in both magnetic compensation loops. Bottom: when 40 kA is circulating in both compensation loops.

So, passing 20 kA into each magnetic compensation loop improves the B_z and hence the cell stability but passing 40 kA brings the situation back to when there is no compensation but this time in the two downstream corners instead of the two upstream corners.

3. Testing the Impact of Oscillating the Current in Magnetic Compensation Loops on the Cell Stability

In order to separate the stabilizing effect of improving the static B_z by passing a constant current and oscillating the current in those magnetic compensation loops, tests were done first by alternating the current so that the average current is zero.

For the first test presented here, the current in the two magnetic compensation loops is oscillating from +40 kA to -40 kA at a frequency of 0.0493 Hz and the ACD is set to 4.1 cm so the cell would be unstable without that magnetic field oscillation. Figure 7 presents the results obtained, where we can see the oscillation of the current in the magnetic compensation loops, the resulting oscillation of the B_z in the cell and finally the oscillation of one point on the bath/metal interface. The Fourier spectrum analysis indicates that the interface is purely oscillating at the excitation frequency with no sign of the naturally occurring rotating wave that would be unstable at that value of ACD.

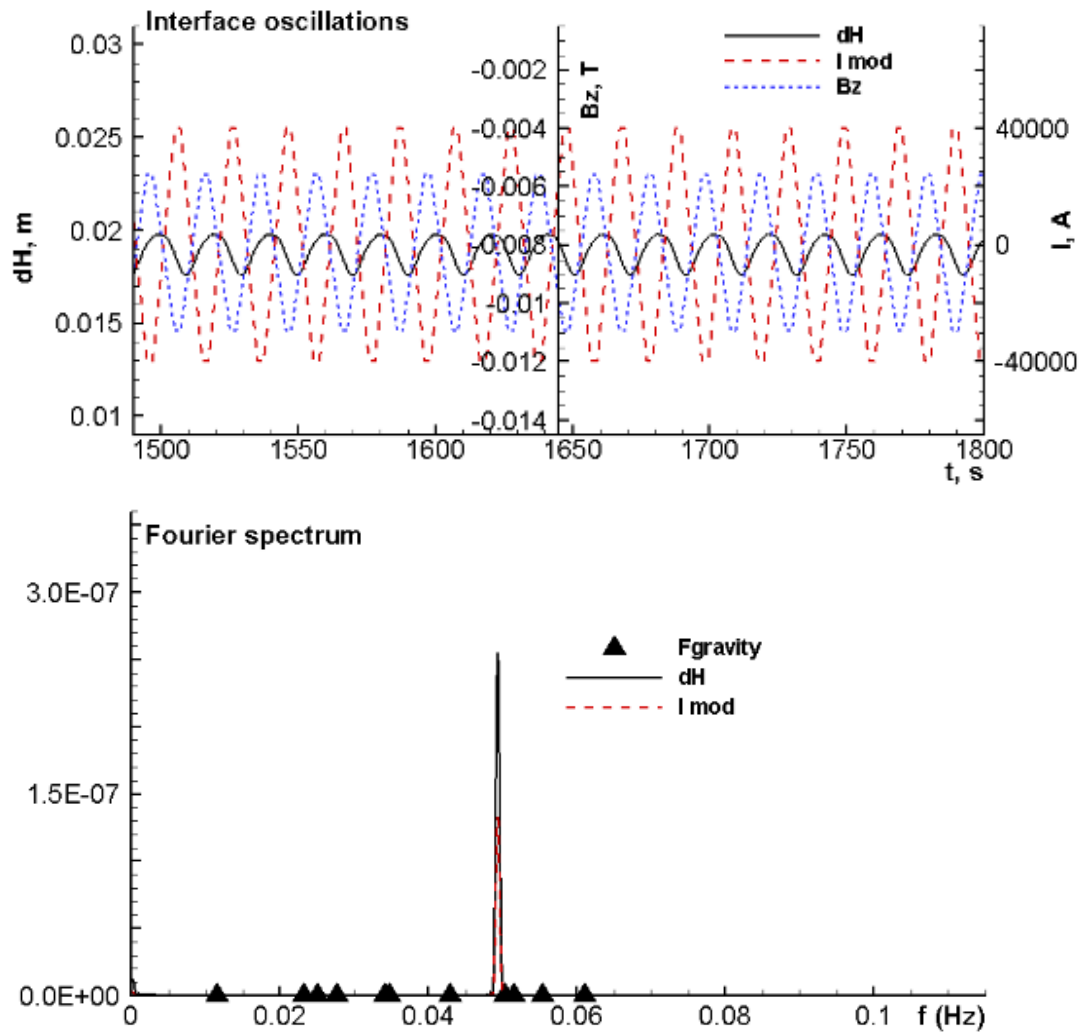


Figure 7. Results of oscillating the current in the two magnetic compensation loops from +40 kA to -40 kA at 0.0493 Hz frequency at 4.1 cm ACD.

For the second test, the current in the two magnetic compensation loops is oscillating from +30 kA to -30 kA at a frequency of 0.0493 Hz and the ACD is set to 4.1 cm so the cell would be unstable without that magnetic field oscillation. Figure 8 presents the results obtained. Note that the cell is still stable despite this reduction of the oscillation amplitude. Notice that even if the interface is still oscillating at the excitation frequency, that oscillation is more complex.

For the third test, the current in the two magnetic compensation loops is oscillating from +40 kA to -40 kA at a frequency of 0.0555 Hz and the ACD is set to 4.0 cm so the cell would be very unstable without that magnetic field oscillation. Figure 9 presents the results obtained showing that the cell is still stable at that reduced ACD at that excitation frequency.

An even higher excitation frequency was tested without success, clearly those tests are just scratching the surface of the possibilities. There are certainly some combinations of amplitude and frequency that are working better than others to stabilize the cell. The fact that each test requires an overnight run certainly makes the process of identifying the optimum combination a very slow process, so that was not really attempted in the current work.

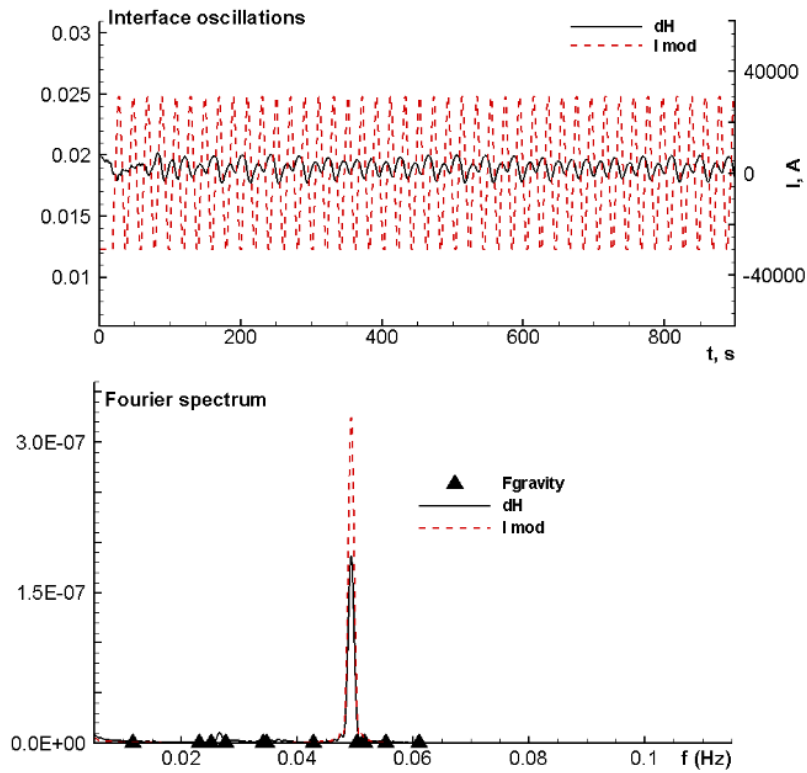


Figure 8. Results of oscillating the current in the two magnetic compensation loops from +30 kA to -30 kA at 0.0493 Hz frequency at 4.1 cm ACD.

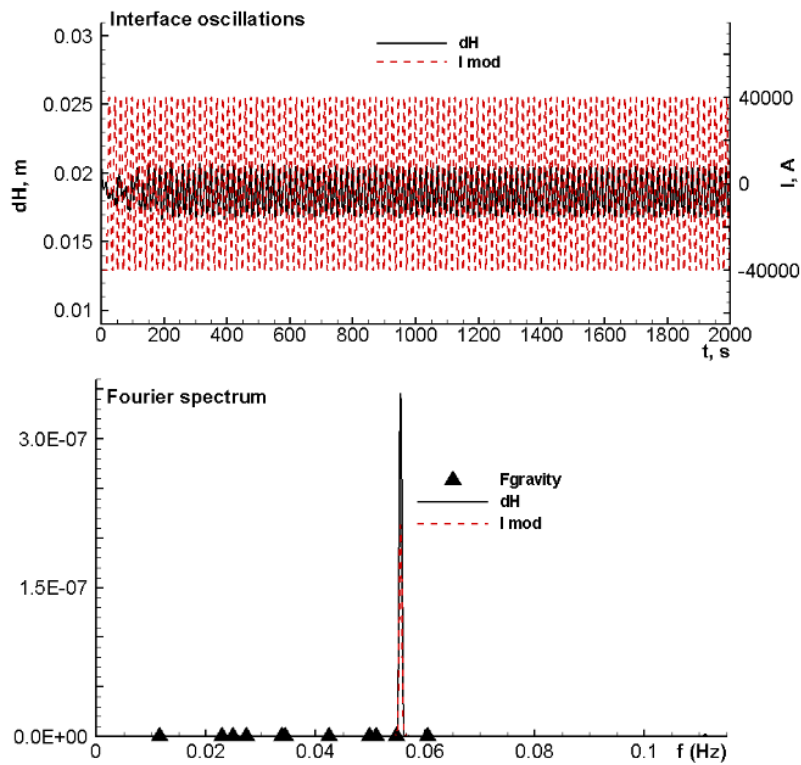


Figure 9. Results of oscillating the current in the two magnetic compensation loops from +40 kA to -40 kA at 0.0555 Hz frequency at 4.0 cm ACD.

4. Testing Combining the Static and Dynamic Compensation on the Cell Stability

Of course, in the case of oscillating the current in magnetic compensation loops, there is a third parameter that was up to now set to zero, on the purpose of not to confuse things. It was seen above for the TRIMET 180 kA cell case that a regular static compensation improved the cell stability.

As a final test, a combined static and dynamic compensation is now presented, the current in the two magnetic compensation loops is oscillating from 0 kA to -20 kA (negative is the potline direction) at a frequency of 0.04545 Hz and the ACD is set to 4.1 cm. It is not possible to know if the cell would be stable or unstable without the dynamic compensation without also running a case with only static compensation at -10 kA. Figure 10 presents the results obtained. It may notice that the cell is getting extremely quiet despite the oscillation of the magnetic field.

Clearly many more runs would be required to find the optimum compensation scheme in terms of average compensation current and amplitude and frequency of the compensation current oscillation.

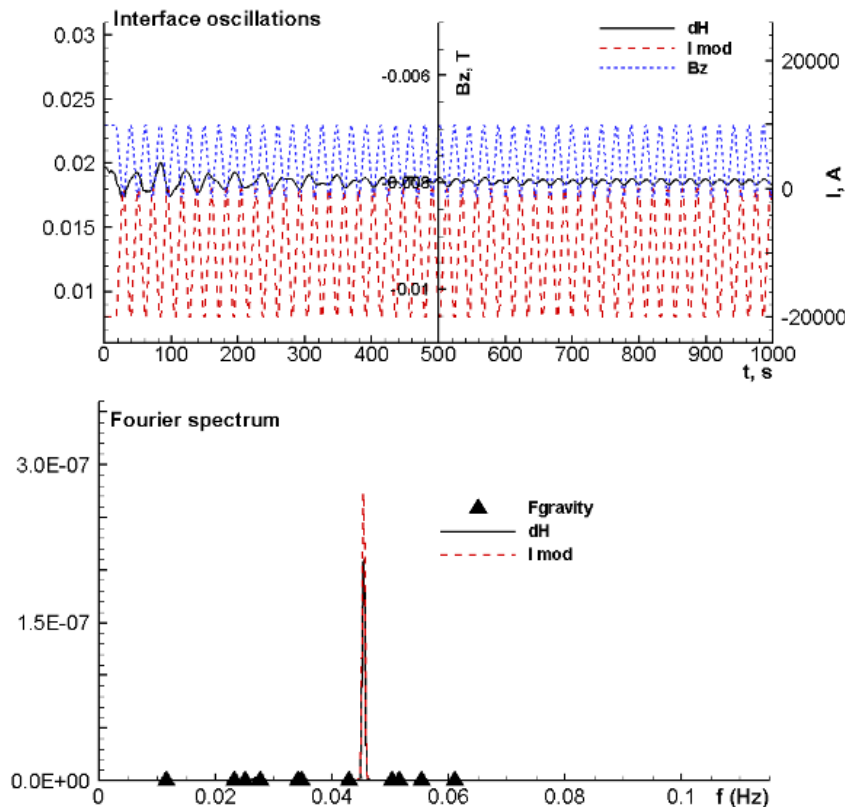


Figure 10. Results of oscillating the current in the two magnetic compensation loops from 0 kA to -20 kA at 0.04545 Hz frequency at 4.1 cm ACD.

5. Using Superconductors to Build the Two Magnetic Compensation Loops

In [10] and [11], a superconductor busbar system is presented for potential usage at the TRIMET Hamburg smelter. Figure 11 from [11] is presenting on the left a 20 kA superconductor with the surrounding piping required to keep the superconductor operating at 70 K and on the right the comparison between the section of that superconductor and the section of the aluminium busbar it is substituting.

According to [10], the energy requirement of operating a superconductor busbar is about 26 % of the energy requirement of operating the regular aluminium busbar it is replacing while the voltage drop is only about 3 %. The great majority of the energy requirement is spent on the operation of the cooling system required to maintain the 70 K busbar operating temperature.

This means that oscillating the current in superconductor magnetic compensation loops would have very little impact on the smelter power demand making that current oscillation more manageable by the power grid.



Figure 11. 20 kA superconductor busbar from [11].

6. Speculation on the Impact of Dynamic Compensation on the Cell Current Efficiency

Assuming that dynamic compensation permits to reduce the ACD by 2 mm or more as the preliminary modeling work indicates and that performing that dynamic compensation in superconductor magnetic compensation loops is not detrimental to the power grid, doing that dynamic modulation could look like an interesting option to reduce cell energy consumption assuming that performing that dynamic compensation has no negative impact on the process.

Dynamic compensation actively produces a constant bath-metal interface fluctuation at the oscillation frequency that has to be higher than the naturally occurring rotating wave frequency. That fluctuation of the interface does produce as for regular rotating waves, a fluctuation of the cell voltage usually called “cell noise”. The level of the cell noise generated depends on the amplitude of the bath-metal interface fluctuation, itself depending on the amplitude of the dynamic compensation. Preliminary modeling results indicate that to be efficient, the amplitude of the dynamic compensation must be significant.

So, there is a risk that dynamic compensation would be detrimental to the cell current efficiency. Short of actually trying it in prototypes, one can only speculate on that impact. The code MHD-Valdis do predict cell noise associated with performing dynamic compensation but not in normal operation. When modeling normal operation, the perturbation imposed at the beginning of the dynamic simulation is either damping down to zero in the case of a stable cell or amplifying to short-circuit the anode in the case of an unstable cell, so the code is not predicting permanent noise production except for critically stable cells. This means that the cell noise produced by

dynamic compensation cannot be compared with regular cell noise produced by only using modeling results.

Yet, the cell noise produced by dynamic compensation in MHD-Valdis can be compared with noise observed in real cells, keeping in mind that there is no bubble noise component in MHD-Valdis generated cell noise. There are several ways to express cell noise, a popular definition is the standard deviation of the cell voltage. Figure 12 presents the cell noise predicted by MHD-Valdis for the second case with oscillation between +30 kA to -30 kA. It is about 5.4 mV which is in the range of cell noise for very stable cell. The cell noise can reach about 40 mV for very noisy cells as can be seen in Figure 13 from [12]. Gary Tarcy is using a different definition of noise, a Max-Min of the cell pseudo-resistance, for its current efficiency model [13].

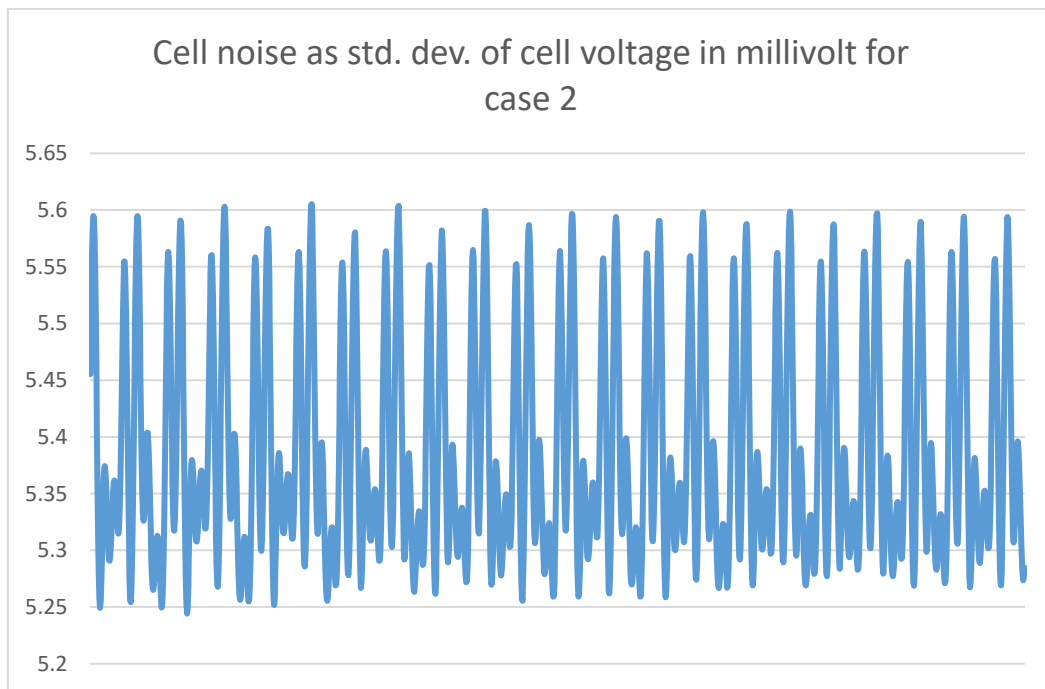
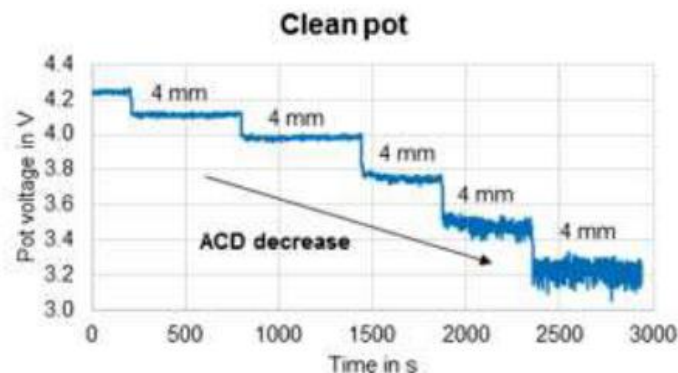


Figure 12. Cell noise (std. dev. of cell voltage) generated by oscillating the current in the two magnetic compensation loops from +30 kA to -30 kA at 0.0493 Hz frequency at 4.1 cm ACD.



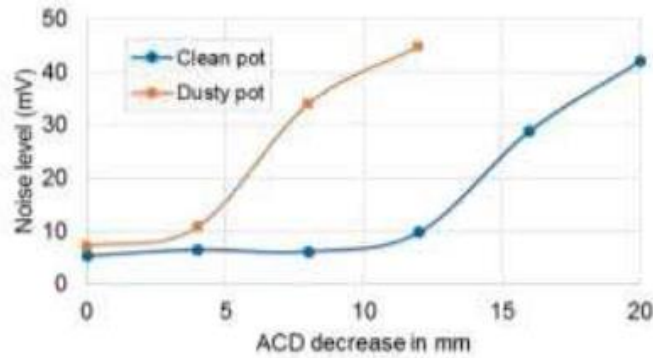


Figure 13. Measured noise level increase (bottom) during an ACD squeeze test (top), from [12].

Figure 14 is presenting the cell noise of the second case according to Gary Tarcy’s noise definition, it is about 0.1015 micro-ohm. The noise coefficient in Tarcy’s model is -1, so a noise level of 0.1 micro-ohm is subtracting 0.1 % of current efficiency in his model. According to that model, going from quiet to very noisy operation (i.e. from 4 to 40 mV of std. dev. or from 0.1 to 1.0 micro-ohm Max-Min) is decreasing the current efficiency by about 0.9 %.

Since dynamic compensation is replacing the noise generated by the regular rotating wave by noise generated by a standing wave at about the same noise intensity level, it can be speculated at this stage that performing dynamic compensation will not have a significant negative impact on the cell current efficiency.

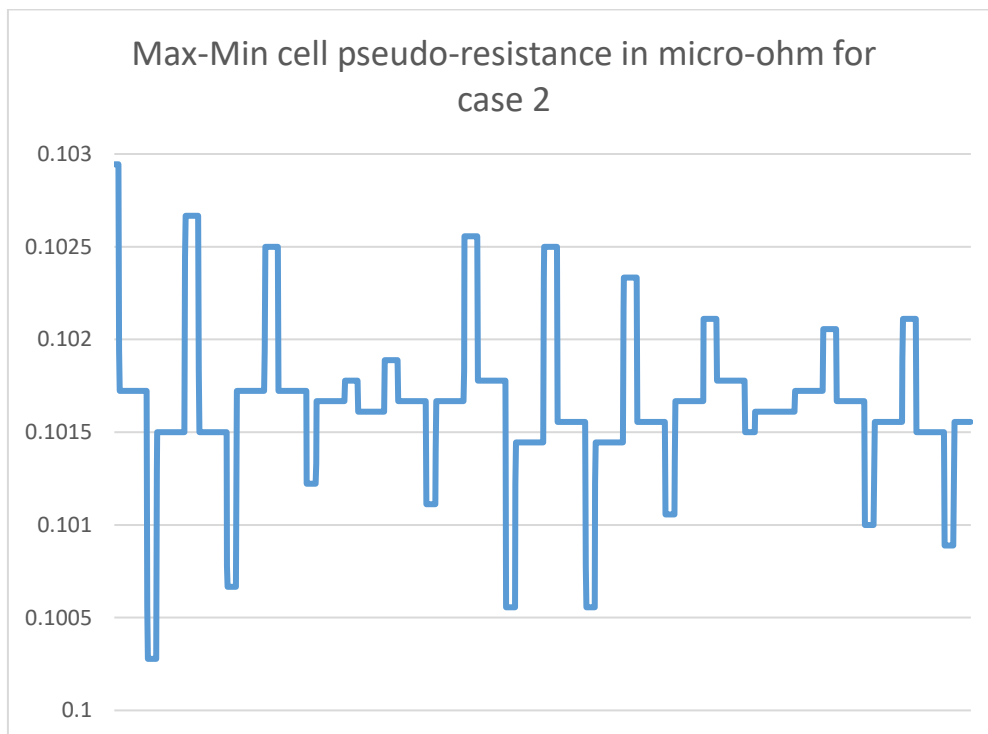


Figure 14. Cell noise (Max-Min of cell pseudo-resistance) generated by oscillating the current in the two magnetic compensation loops from +30 kA to – 30 kA at 0.0493 Hz frequency at 4.1 cm ACD.

7. Conclusions

It has been demonstrated that oscillating the current in compensation busbar, i.e., performing dynamic magnetic compensation, is also stabilizing the cell. The effect is cumulative over static magnetic compensation, so performing dynamic compensation over the optimum static compensation will further stabilize the cell, permitting further reduction of the ACD.

Performing dynamic compensation using superconductor busbar magnetic compensation loops should only have a marginal impact on a smelter dynamic power demand.

It is speculated that performing dynamic compensation should not significantly affect the cell current efficiency. Only industrial trials will permit to verify if that speculation is true or not.

8. References

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