MHD Stability of End Cells

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Abstract

Despite the periodic arrangement of cells, aluminium smelters include several cells with different magnetic configuration due to their particular position in the potline. It might be cells at the entrance or exit of potrooms as well as cells before and after passageways or before and after stopped cells. Cells most affected are generally last cells at the exit of potrooms before the cross-over busbars. Their collector bars current distribution can be disturbed by the cross-over busbars, and the absence of neighbouring cell at the downstream side combined with the vicinity of the cross-over busbars results in a less uniform magnetic field in the metal pad. Such cells experience larger magnetic forces resulting in higher metal velocity and more frequent and higher amplitude waves at the metal surface. At equal cell voltage, it translates into higher instability, lower current efficiency (CE) and often shorter cell life. The present paper investigates the magnetohydrodynamic (MHD) stability of last and penultimate cells with respect to standard cells as a function of amperage. It also evaluates the effectiveness of curative measures such as larger metal height and anode-to-cathode distance (ACD), hollow cell and compensation loop. A stability analysis software computes the evolution of perturbations to the 3D stationary variables (electric potential, magnetic field, velocity and pressure) accounting for ledge shape and ferromagnetic materials. Quantitative results are obtained that characterize the level of MHD stability for each scenario. The importance of busbars design, and also of operating parameters on the performance of end cells can be highlighted.

Keywords: Aluminium electrolysis cell, Metal oscillation mode and cell stability diagram, Potroom ends and cross-over busbars, Magnetic compensation loop.

1. Introduction

The magnetic field in the metal pad is responsible for magnetic forces and consequently for metal velocity, metal upheaval and waves at the metal surface. The magnetic field results from external current (busbars, anodic assemblies, cathodic assemblies, neighbouring cells) as well as from internal currents including induced currents (which depend on the magnetic field). The magnetic field is particularly strong close to busbars which carry high currents. Technologies with higher amperage cells have enlarged cell dimensions and added risers and external conductors to keep current density inside the cell and maximum magnetic field values below a certain level. Modern smelters arrange cells side-by-side into long potlines with the objective of minimizing land use and external voltage but also of reducing the number of end cells. The influence of adjacent potroom and potlines can be mitigated by asymmetries in the busbars design around the cell and by compensation loops. Only a small number of cells have a significantly different magnetic configuration, and these are cells at the entrance or exit of potrooms as well as cells before and after passageways or before and after stopped cells. In this paper, we focus on last cells at the exit of potrooms since their performance suffers the most.

As mentioned earlier, last cells are not only negatively affected by their magnetic configuration but also by their current distribution on the cathodic side. The busbars resistance network until an equipotential point before the cross-over busbars must be such that the collector bars current distribution is similar to the one of standard cells. In such case, the presence or not of a "hollow cell" – defined here as the area at the end of the potroom, with no cell, where the arrangement of the busbars mimics the spatial distribution of the current paths of a neighbouring cell – and the distance to the cross-over busbars will further determine how different the magnetic configuration of the last cell is in comparison to a standard cell.

To quantify the MHD stability of different cells across a potroom with various operating parameters, a specialized software analyses the evolution of perturbations to the stationary field variables that are: electric potential, magnetic field, velocity and pressure [1]. The frequency and growth factor of each oscillation mode are computed (see Figure 1), and the maximum growth factor defines the stability level. Oscillation modes (waves) with positive growth factors are more likely to grow over time whereas oscillation modes with negative growth factors will be damped over time.

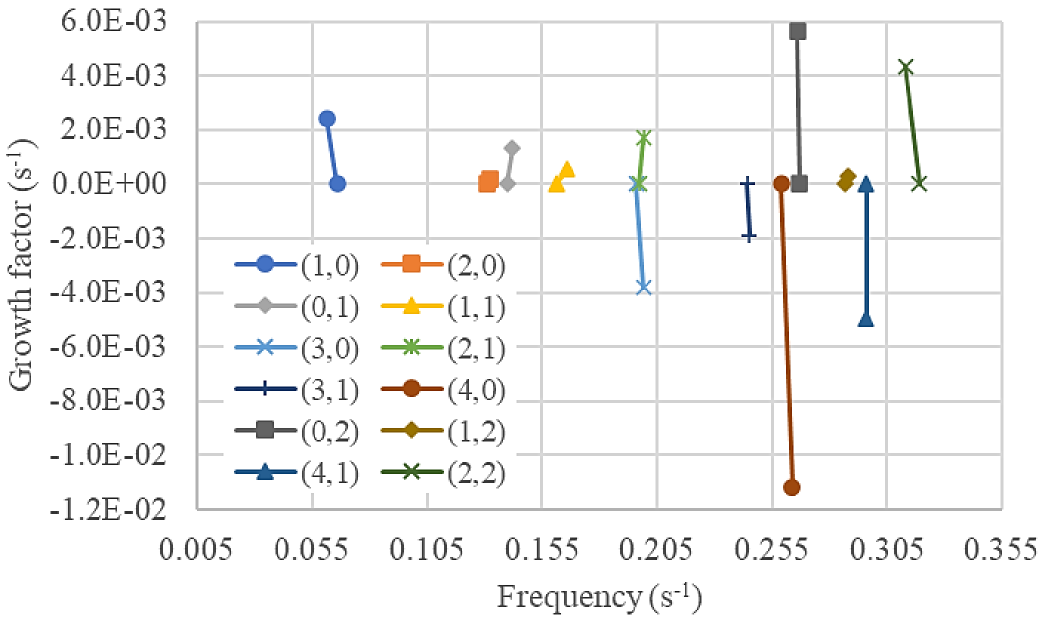


Figure 1. Stability diagram for a standard cell.
Legend for each curve where the oscillation mode is noted (Nx,Ny):
Nx =number of waves in the x-direction, Ny = number of waves in the y-direction.
For each 2-point curve, the point on the 0-growing factor line is the oscillating mode resulting from the gravity force only; the other point is the same mode with the MHD forces in addition.

Alternative models based on the shallow layer approximation were used to characterize the MHD stability of irregular and disturbed cells. In [2], the time evolution of cell voltage and metal height is computed for different scenarios.

2. Model and Scenarios

The study is performed on one potline with side-by-side cells. Electrically conducting materials of the studied cell (accounting for the ledge shape), as well as ferromagnetic materials are modelled in full 3D whereas busbars, neighbouring cells and adjacent potroom are modelled in filiform 3D (see Figure 2).

The stability of a standard cell, of the 2nd last (penultimate) cell and of the last cell are computed. For both standard and last cells, the stability is also computed with increased metal height (+4 cm) and +18 kW internal heat generation (corresponding to an additional +3 mm of the ACD) to achieve the same ledge shape. Both larger metal height and higher ACD help at stabilizing the cell since they respectively reduce horizontal currents in the metal pad and make the current distribution less sensitive to waves at the metal surface. The impact on stability of the standard cell and the last cell when these cells are subjected to a 10 kA current increase at constant ledge shape (+5 kW internal heat generation, -6 mm ACD) is evaluated. This is computed for both the standard cell and the last cell (with the presence of hollow cell and without compensation loop) to find out if the stability of the last cell is more sensitive to current increase. Finally, the impact of curative measures that are: a hollow cell at the exit of the potroom and a compensation loop are evaluated for the last cell. In one case, the hollow cell is removed, bringing the cross-over busbars closer to the last cell and in another case, a compensation loop with optimal amperage is added.

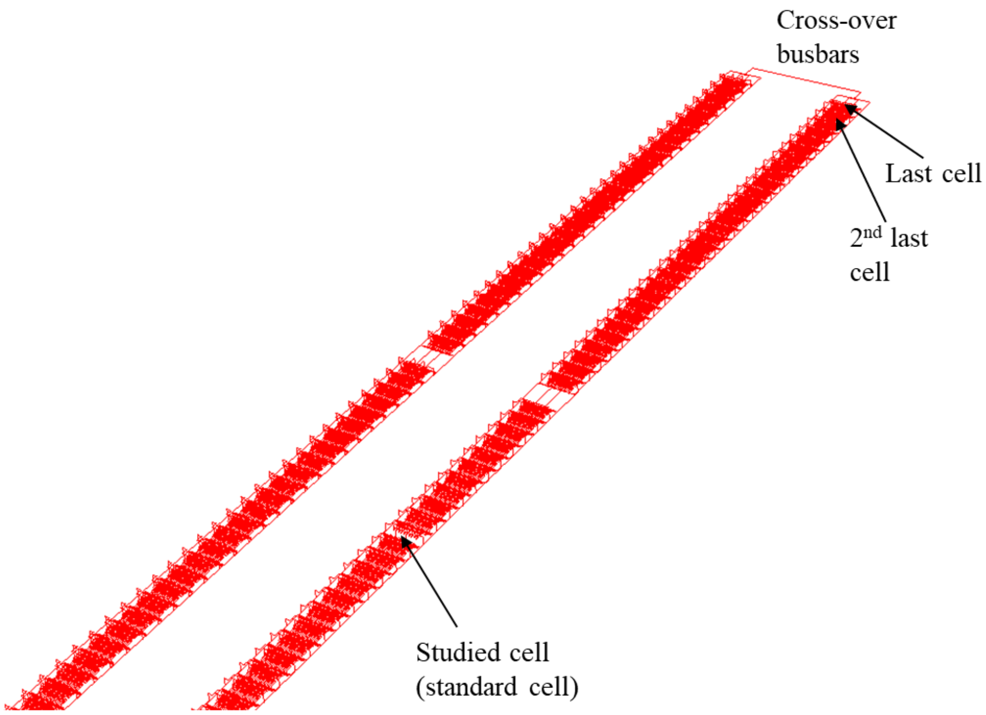


Figure 2. Filiform 3D model of busbars, neighbouring cells and adjacent potroom.

The variation in internal heat generation (i.e., ACD) to achieve the same ledge with a different metal height or amperage is obtained by stationary thermoelectric-magneto-hydrodynamic (TE-MHD) calculations of a different cell model including all cell materials and full 3D neighbouring cells (see Figure 3) [3]. Metal velocity field of the standard cell and of the last cell are shown to highlight the correlation between stability analysis and MHD stationary field variables.

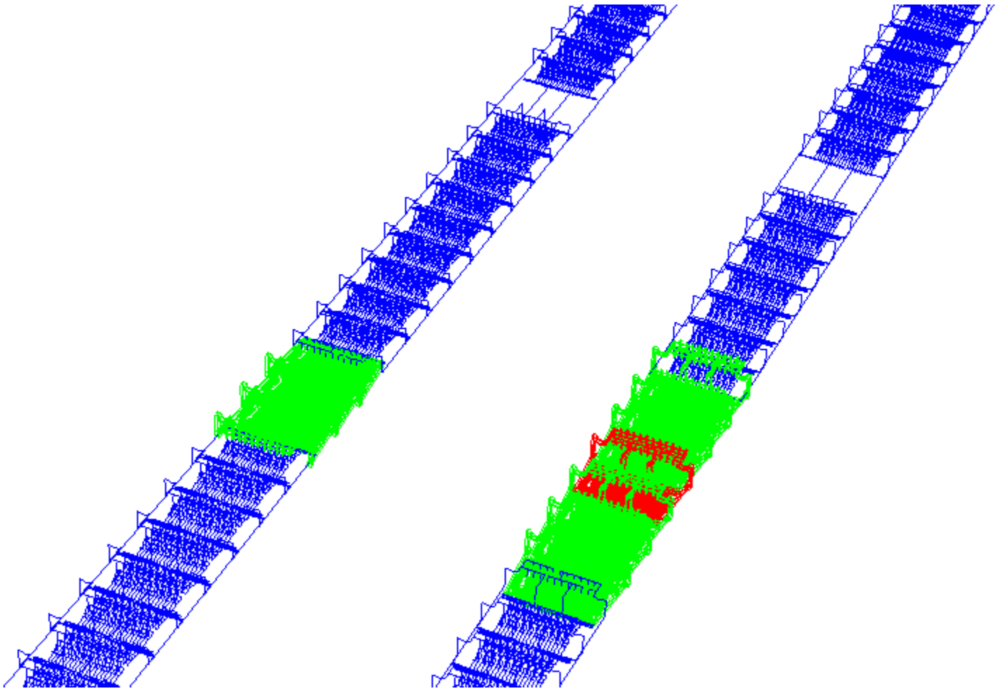
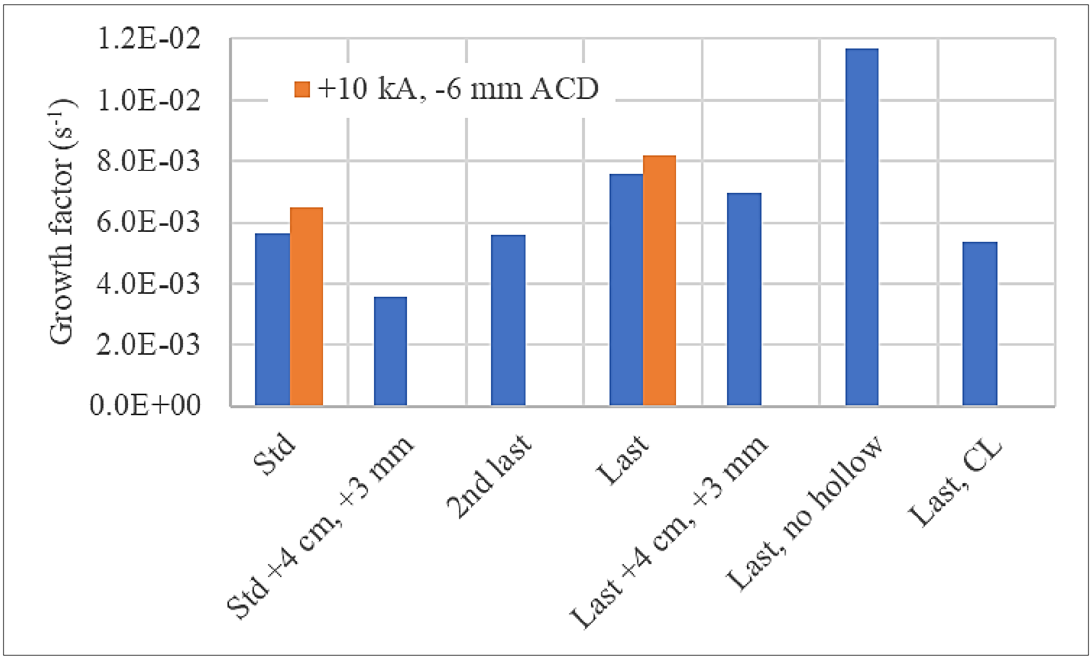


Figure 3. Full 3D model of studied cell (red) and neighbouring cells (green) and filiform 3D model of the rest of the potroom and the adjacent potroom (blue).

3. Results

Figure 4 illustrates the maximum growth factor (least stable oscillation mode, bars and values in the Figure 4) computed for the different scenarios: standard cell, standard cell at higher amperage and metal height, 2nd last cell, last cell, last cell at higher amperage and metal height, last cell without hollow cell and last cell with compensation loop. Following comments can be made:

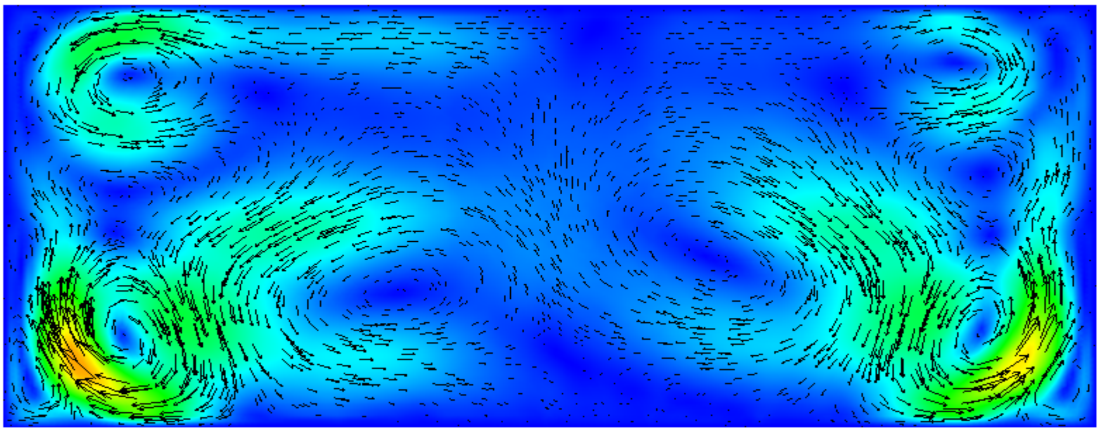
- The standard cell is the most stable cell (excluding the compensation loop case). It is even more stable at higher metal height and ACD and its stability decreases at higher amperage and lower ACD as expected.
- The 2nd last cell is marginally more stable than the standard cell and thus more stable than the standard cell at higher amperage and lower ACD.
- The last cell is the least stable cell and it is less stable than the standard cell at higher amperage and lower ACD. This will affect the cell performance through higher instability, lower CE, higher cell voltage and possibly shorter cell life.
- With higher metal height and ACD, the stability of the last cell can be improved but not to the level of the standard cell at higher amperage. Still, it could be a way to make the operation easier at the cost of specific energy consumption.
- The two last scenarios show the importance of the busbars design on cell stability. Without hollow cell i.e., busbars mimicking a neighbouring cell after the last cell and moving the cross-over busbars away, the stability of the last cell would be significantly worse.
- A compensation loop in between potrooms with optimal amperage to compensate for the effect of the adjacent potroom would improve significantly the stability of the last cell and would make it even more stable than the standard cell without compensation loop. This shows the potential of a compensation loop, not only for end cells but also for standard cells, especially if the amperage is crept over time.



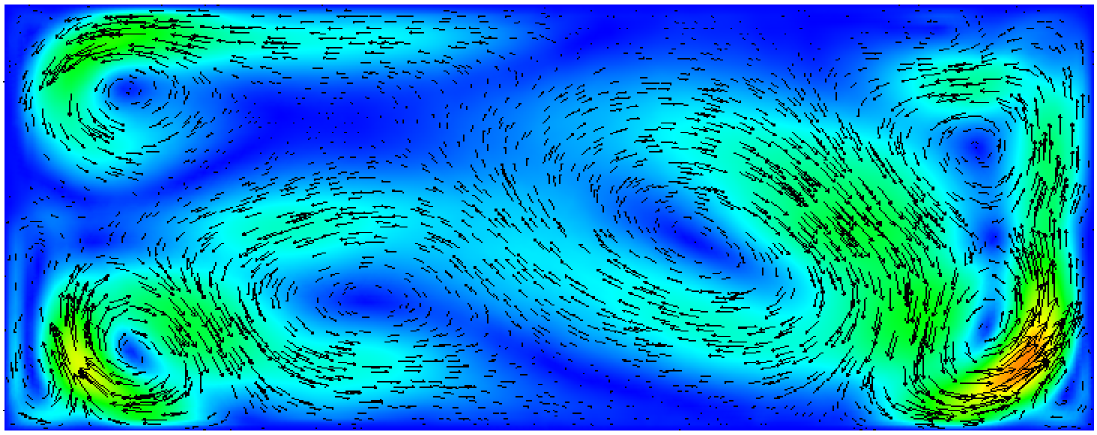
Std			2nd last	Last				
	+4 cm, +3 mm	+10 kA, -6 mm			+4 cm, +3 mm	+10 kA, -6 mm	no hollow	CL
5.65E-03	3.59E-03	6.52E-03	5.60E-03	7.59E-03	6.95E-03	8.22E-03	1.17E-02	5.36E-03

Figure 4. Maximum growth factor for different scenarios.

Figure 5 compares the stationary metal velocity field 10 cm above the cathode surface of the standard cell and of the last cell. The maximum metal velocity is 6 % higher for the last cell compared to the standard cell whereas the mean velocity is 15 % higher. Metal velocity correlates with instability (as well as cathode erosion and non-uniform ledge shape) since it results from the same magnetic forces.



Standard cell



Last cell

Figure 5. Metal velocity field 10 cm above the cathode surface for standard and last cells.

4. Conclusions

End cells experiencing higher instability, lower CE, higher cell voltage and shorter cell life can be a thorn in the side of smelters, jeopardizing potential amperage increase. Their particular magnetic configuration as well as possibly different busbars current distribution explain their higher metal velocity, metal upheaval and amplitude and frequency of waves at the metal surface.

A specialized software is used to quantify the MHD stability of different cells across the potroom and the impact of operating parameters such as amperage, ACD and metal height. The last cell in potroom is the least stable cell. Even with higher metal height (+4 cm) and ACD, it is less stable than a standard cell at higher amperage (+10 kA) and lower ACD. Busbars design features such as hollow cell and compensation loop are effective means of improving the MHD stability of end cells.

5. References

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