AL05 - A 700 kA Alumina Reduction Cell with Downstream Cathode

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Abstract

The aluminium electrolysis industry is continuously aiming to increase cell amperage with the final goal of reducing the cell energy and financial costs. In this direction, some innovations have been proposed during the last decade. One of them is the "Downstream Cathode" [1] arrangement, which consists in cathode blocks and collector bars built and placed in a way that the collector bar ends exit only at downstream side of the cell lining and therefore, the entire cell current is pulled out from that side. The proposed arrangement produces an important busbar voltage drop reduction because the busbar path becomes shorter and the collector bars are made of copper. The Downstream Collector Bar Exit design is potentially viable because it takes advantage of high electrical conductivity of the copper collector bar, producing lower horizontal currents in the metal pad than the conventional steel collector bars.

This article presents the study of a 700 kA cell using the Downstream Collector Bar Exit concept. Magnetohydrodynamic model results are presented, considering a proposed busbar arrangement, potshell and magnetic compensation loops, necessary for controlling the vertical magnetic field generated in such high line current. In this work, the design of the collector bar is discussed, considering electrical and structural aspects. A full copper bar would present insufficient structural strength, and a combined material bar is proposed. Other aspect is the tendency of higher cathode wear at downstream. A special cathode design is presented to compensate the expected erosion difference between the two sides of the cell.

Keywords: Aluminium electrolysis cell, magnetohydrodynamics (MHD), numerical simulation, cell design, cathode design with downstream collector bar exit.

1. Introduction

In aluminium electrolysis cells, there is a trend of reducing the production costs and electrical energy consumption through the increase of the cell size and current, modifications in busbar arrangement among other initiatives such as using copper instead of steel in the collector bars. The copper collector bar became commonly employed in smelters in the last decade. Because the copper electrical resistivity is much lower than the steel, the cathode cathodic voltage drop (CVD) reduces 80–150 mV when compared to the traditional steel bars. The metal pad current density is also greatly affected reducing the transversal current density "y" (see coordinate system of Figure 1) [2, 3] and as a consequence, the MHD forces are also reduced.

The impact of the copper bar utilization opens a window for further improvements in cell design, considered not viable earlier when using traditional steel bars. The "Downstream Cathode" suggested by Dupuis [1] is one of such promising ideas. The busbar can then be greatly simplified, as shown in Figure 1, because the cathodic current path becomes shorter. It potentially decreases the cost of busbar construction, and as well as the busbar voltage drop. In this work, the downstream cathode arrangement [1] is adopted in a 700 kA cell design study. The cell geometry is presented in Figure 1 where the busbar, shell and cathode arrangement are shown. The cell is built using 32 cathode blocks of 3 620 mm (L), 670 mm (W) and 450 mm (H). Each cathode block has two collector bars. There are 32 double anode assemblies where each anode presents 685 mm (W) and 1 700 mm (L). The steel shell is 4 340 mm wide and 23 560 mm long considering internal dimensions. The cell to cell distance is 6.1 m while the returning line is placed at 150 m distance.

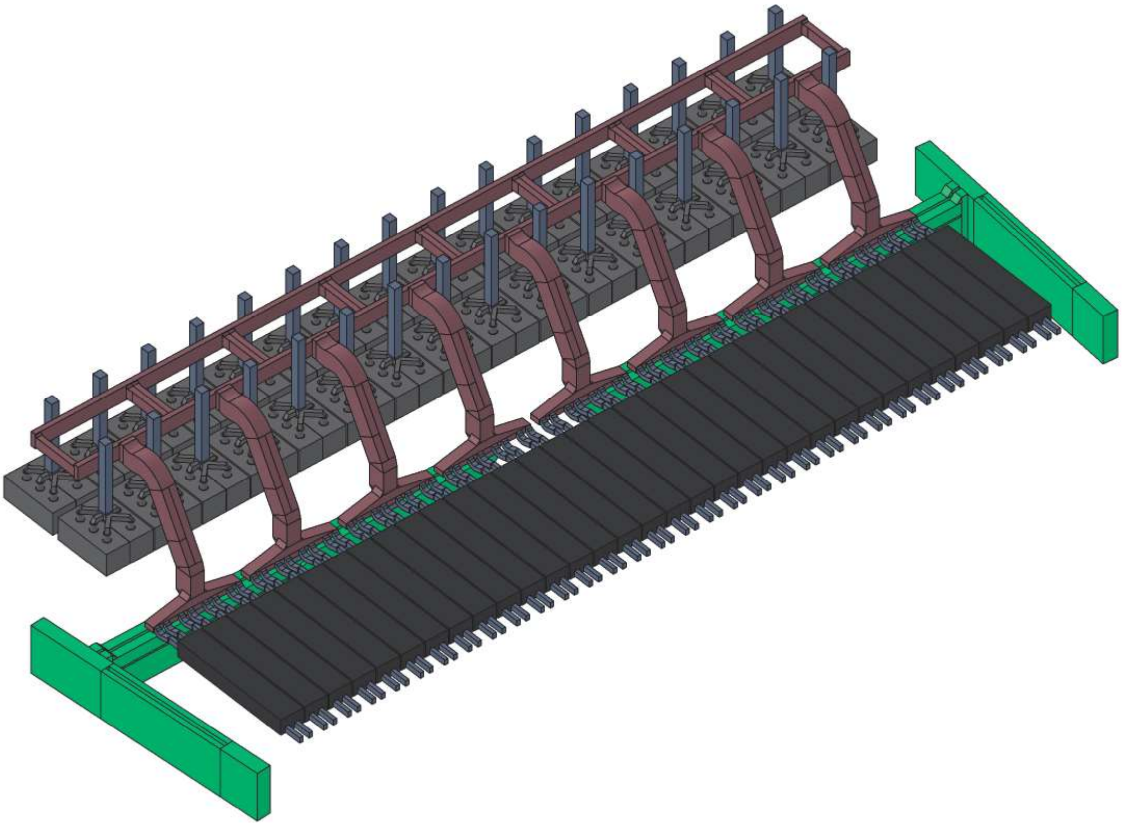

Figure 1. 700kA downstream cathode cell busbar and cathode blocks. Bypass busbar is included.

According to the proposed design, the resulting nominal anode current density (at 700 kA) is 0.94 A/cm^2 while the cathode nominal current density is 0.90 A/cm^2. The cathode block grade used in all the studies is 100 % graphitic. In order to keep the metal horizontal current under a reasonable value (10 000 A/m^2), the cell presents a large length/width ratio because the downstream cathode concept tends to promote more horizontal currents towards the downstream side when compared with the traditional cathode design. Another important design aspect that deserves to be mentioned is the 8 riser's busbar, including a workable bypass. The busbar weighs 60 t of aluminium per cell, which results in around 86 kg Al/kA (at 700 kA). In this aspect, there is also a gain when comparing the typical 100–150 kg Al/kA of US/DS high amperage cells. The gain could be made bigger if another solution can be found for the need of 25 t of busbar only for the cell electrical current bypass.

In cell designs of these current magnitudes there is a need for a magnetic compensation busbar to reduce the vertical magnetic field generated by the neighbor line and by the cell internal current. Considering these characteristics, the ECC concept presented by a Pechiney 1987 patent [4] as in Figure 2 is chosen. It consists of two busbars running at both sides of the cell, at the same current flow direction of the cell line and it is the most effective for very long cells. In this case, loops running with around 90 % of the total cell current are necessary to compensate the magnetic fields. The compensation loop needs 16 tons of aluminium in its construction and it is expected to cost around 10 mV (for a 700 kA equivalent) for each cell during operation.

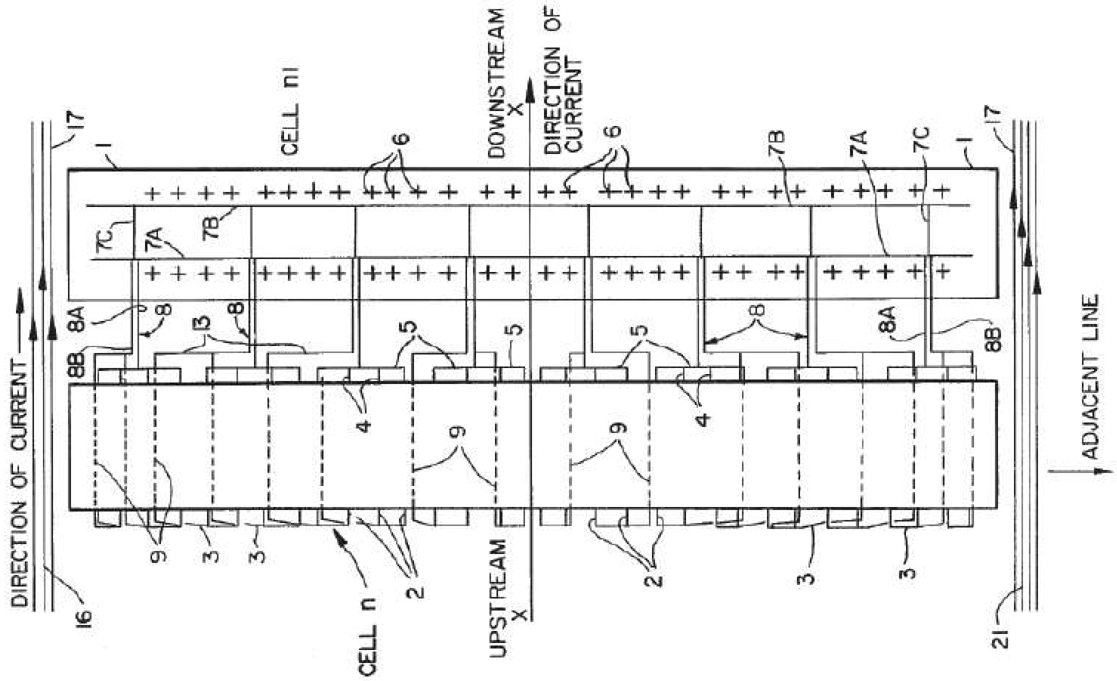

Figure 2. Magnetic compensation loop using the same direction current compensation concept. US patent 4713161 (1987) [4].

In this work, three concepts of collector bar designs are studied and compared in the models:

- Integral copper bar, which are soft and a structural solution for preventing the cathode panel movement must be developed, as well as a substitute for cast iron for rodding the bar into the carbon.
- Copper inserted into a steel collector bar (structural robust bars, capable to fix the cathode panel and prevent cathode movements deformations such as the cathode heave building);
- The novel cathode arrangement proposed by CAETE, that reduces the metal horizontal current density in the metal and also reduces the downstream cathodic current concentrations.

The novel CAETE cathode design consists of traditional carbon blocks with two steel bars, with copper inserts, rodded with cast iron. This design is structural robust, restraining the cell cathode panel deformations or movements. In each cathode, one bar is electrically insulated at the whole downstream side, with the objective of picking up current at the upstream. The other bar has only a small insulation at the end and most of the current is picked up at the downstream. The Figure 3 shows the novel cathode block design using the two collector bars with different insulation sizes. This decreases the metal pad horizontal current densities that are harmful for the MHD behavior according to well established literature [5] and, moreover, reduces the high current densities near the big joint at the downstream, improving the expected cathode life due to localized cathode wear.

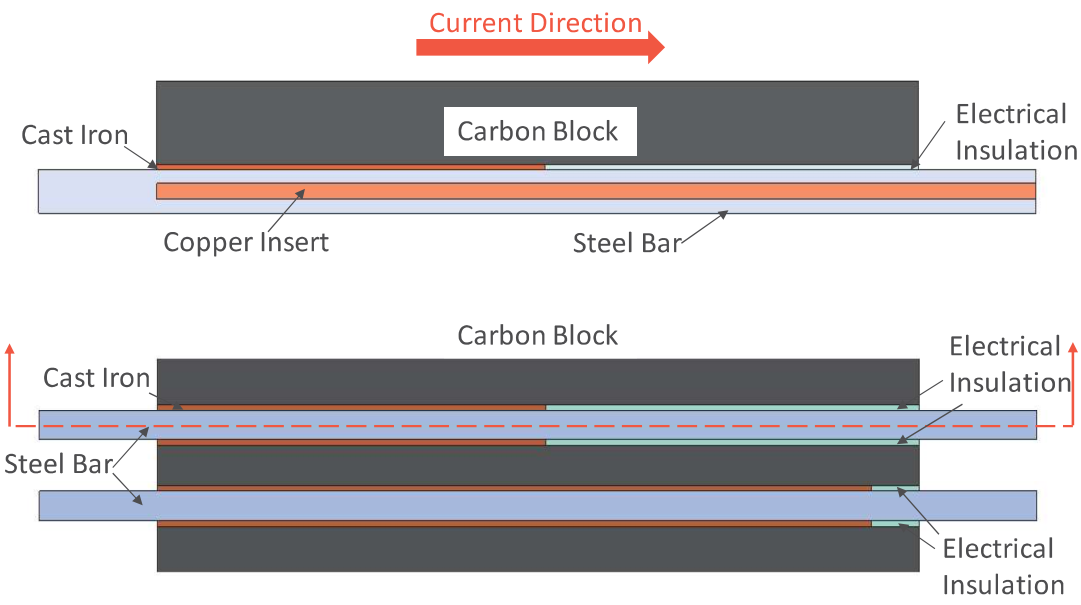

Figure 3. Novel cathode block design proposed in this work.

2. Magnetohydrodynamic Model Results

Following the same modeling assumptions and procedures previously presented [6], the electromagnetic model was built in COMSOL, the finite element mesh can be seen in Figure 4.

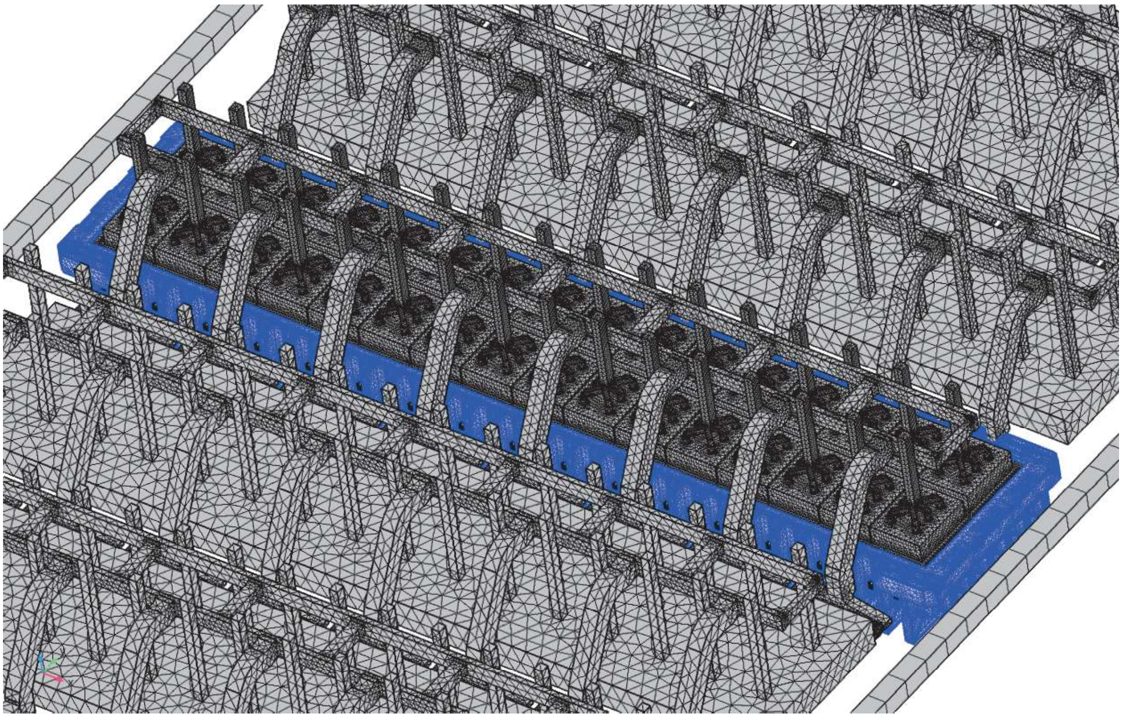

Figure 4. Finite element mesh used in COMSOL for the Downstream Cathode cell simulation.

Concerning the electrical model results, the busbar voltage drop (from end of collector bar to anodic beam of the next pot) resulted in only 136 mV. This is a very relevant gain over typical a 240 mV of voltage drop for US/DS found in regular side-by-side high amperage cells.

The vertical magnetic field component B_z is presented in Figure 5 for the integral copper bar case. It was possible to design a busbar that resulted in low vertical magnetic field over the metal pad area (maximum magnitude 33 G). Most of the areas present B_z magnitude lower than 15 G.

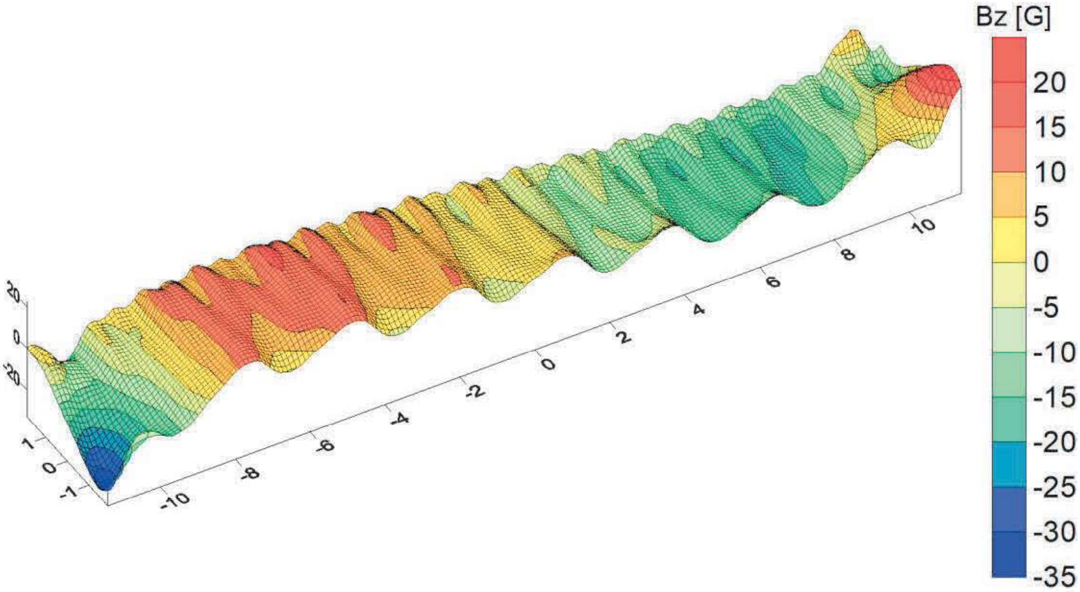

Figure 5. Vertical field (B_z in G) for the 700 kA cell. Integral copper bar model.

The metal heave (metal-bath interface) for the integral copper bar case is presented in Figure 6. No excessive heaving is shown. The longitudinal variation is maximum 30 mm. In transverse direction, up to 50 mm variation are found.

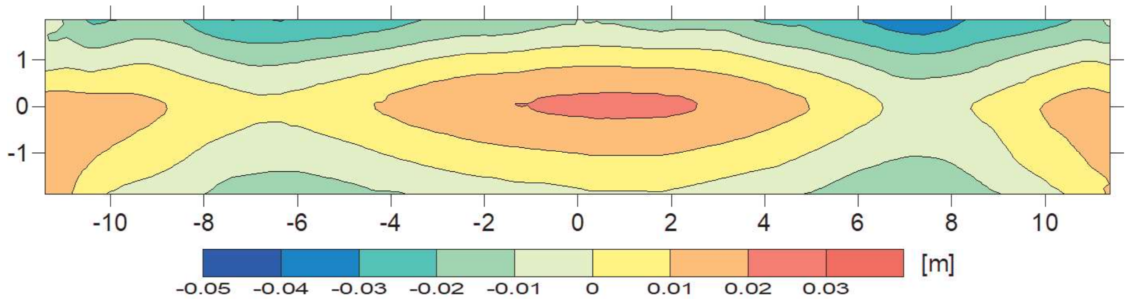

Figure 6. Metal/bath interface deformation (m). Integral copper bar model.

The metal velocity profile at the middle of the metal pad is shown in Figure 7, for the integral copper bar case. The metal movement presents two big pools, with similar sizes showing that the magnetic compensation is effective. A maximum velocity of 20 cm/s is found, that is a reasonable value for a large, high amperage cell.

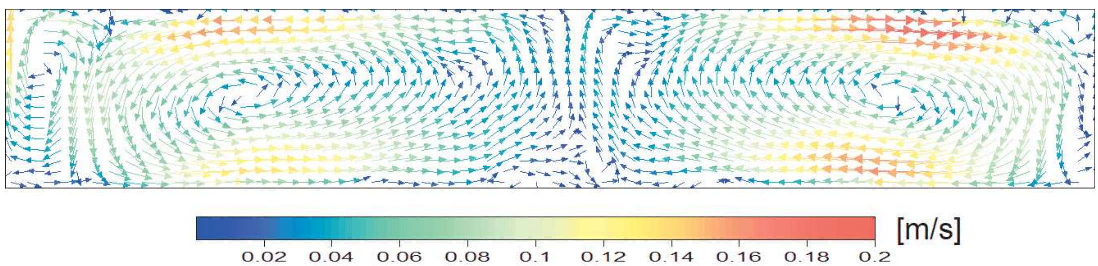

Figure 7. Metal velocities at the middle of the metal pad (m/s). Integral copper bar model.

The magnetic instability model resulted in a growth rate of the waves of 1.10×10^{-2} s^{-1}. This value is considered good and compatible with state of the art aluminium electrolysis cells. The magnetic field results of the novel cathode model are similar to the previously presented copper bar model. The vertical component B_z is shown in Figure 8.

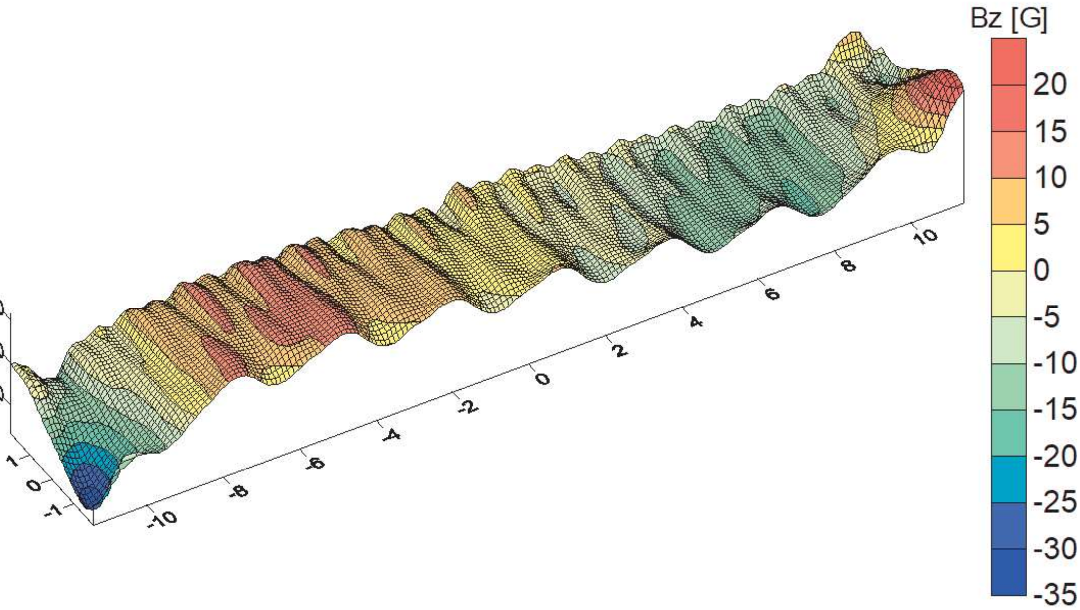

Figure 8. Vertical field (B_z in G) for the 700 kA cell. Novel cathode assembly model.

Figure 9 and Figure 10 present the metal/bath interface deformation (metal heave) and the metal velocities respectively. The metal heave is slightly lower at the center when comparing to the integral copper bar model result, while the metal velocities are slightly higher.

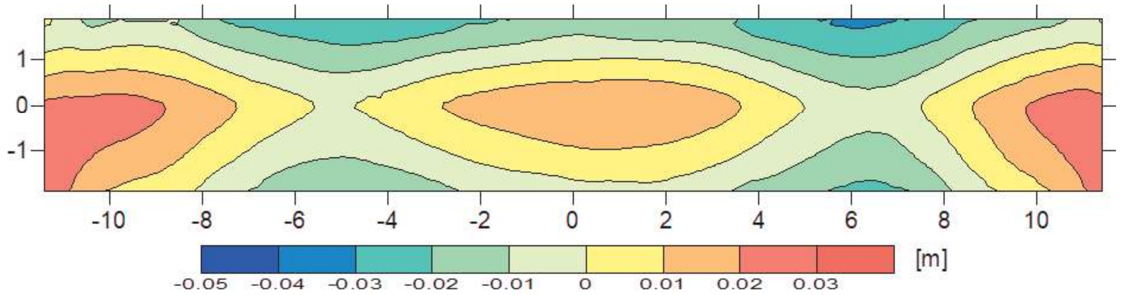

Figure 9. Metal/bath interface deformation (m). Novel cathode assembly model.

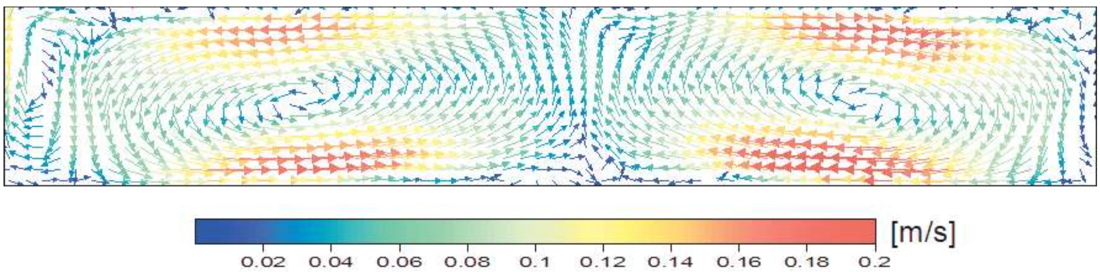

Figure 10. Metal velocities at the middle of the metal pad height (m/s). Novel cathode assembly model.

The magnetic instability model resulted in a growth rate of the waves of 1.19×10^{-2} s^{-1}. Again, a similar result with previous integral copper bar model and compatible with state of the art aluminium electrolysis cells. The magnetic field and metal flow results for the inserted steel bar case will not be presented in this work, as they are very similar to the previous integral copper bar case, only its electrical results will be presented in the following chapters.

3. Horizontal Current in the Metal Pad

The main problem of using the DS concept is the high horizontal currents inside the metal because the currents are totally directed to the downstream. Using the integral copper bar reduces the magnitude of such currents within acceptable levels. However, the currents will never be symmetric with respect to the longitudinal axis "x" of the cell. More important, in the long term its structural function is compromised. Because the copper above 950 °C is too soft, there is a need for a steel structural element at the bar in order to withstand to the unavoidable heave forces that will be built up in time. These forces appear during the cell life due to material infiltration through the cathode panel/ lining, pushing up the cathode panel. In traditional cell designs, the steel bars contribute with the rigidity and are responsible to hold the panel in place.

In addition, the melting point of copper is only 1085 °C. This temperature can be reached in high temperature excursions, mainly at the end of the potlife when there is less carbon above the bar. In our models, steel collector bar with copper insert was tried, but the horizontal current issue in the metal becomes worse compared with the 100 % copper bar, as can be seen in the comparison of Figure 12 against Figure 11.

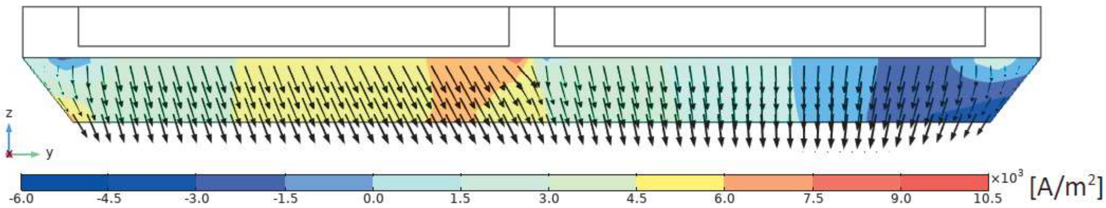

Figure 11. Metal current density vectors at the cell vertical cut. Integral copper bar model.

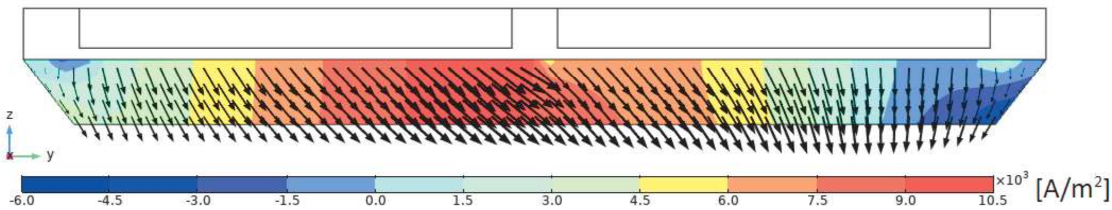

Figure 12. Metal current density vectors at the cell vertical cut. Inserted steel bar model.

The alternative cathode assembly concept presented in this work is capable of maintaining the metal horizontal currents low, good upstream/downstream current pickup balance, and simultaneously presenting good structural integrity. The design features are shown in Figure 3. Figure 13 presents the metal vertical current density of the novel CAETE cathode assembly design. Horizontal components became lower when compared with previous models.

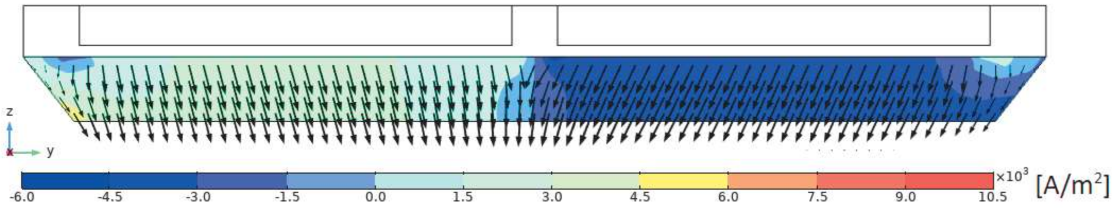

Figure 13. Metal current density vectors at the cell vertical cut. Novel cathode assembly model.

4. Cathode Top Current Density

Another major issue with the DS cathode design is the high current density on the cathode top at the downstream side, which will erode the cathode faster at that region, this is also mentioned in a previous work [1]. Figure 14 presents the cathode top current density obtained at the integral copper bar case. This problem would become worse in an inserted steel bar model as shown in Figure 15.

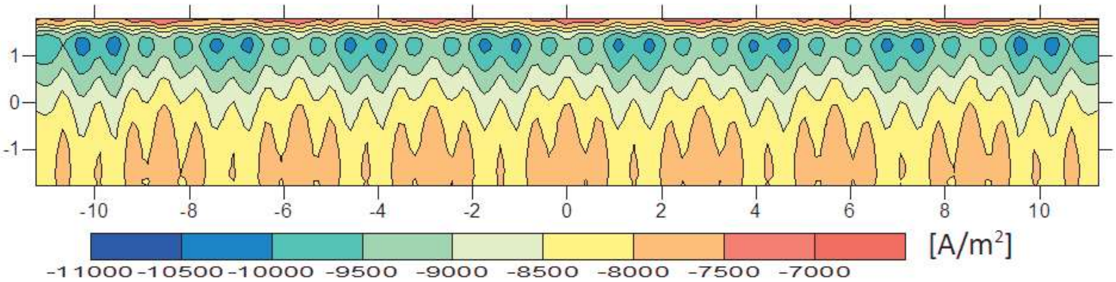

Figure 14. Cathode panel current density on the top surface (in contact with metal). Integral copper bar case.

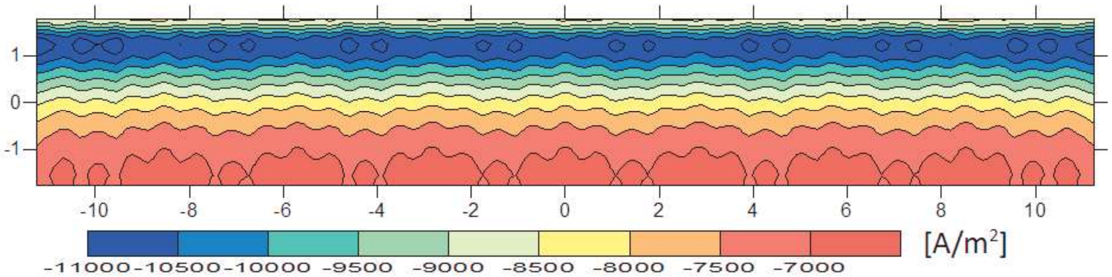

Figure 15. Cathode panel current density on the top surface (in contact with metal). Steel inserted bar case.

The integral copper collector bar cathode pickup is around 10 000 A/m^2 at downstream and 8 000 A/m^2 at upstream. The model with steel collector bar and copper insert amplifies the difference – 12 000 A/m^2 at downstream and 7 000 A/m^2 at upstream. In Figure 16, the top cathode panel current density map is presented for the new CAETE cathode assembly showing a more equalized upstream/downstream cathode current pickup. There is a higher concentration near the cell longitudinal center line “x”. This fact is counterbalanced by the lower metal velocities found at this region, and therefore a balanced cathode wearing is expected comparing the cathode top middle and ends. Lower values of cathode current pick up are found near big joints which potentially increases the cells’ life. At the downstream center, low current pickup appears due to the side-by-side insulated bars. In order to keep the symmetry of the cathode panel features, in the left half of the cell the insulated bar is placed at right side of each cathode, and in the other half of the panel, at the left side of each cathode, causing two insulated collector bars to be neighboring each other at the center.

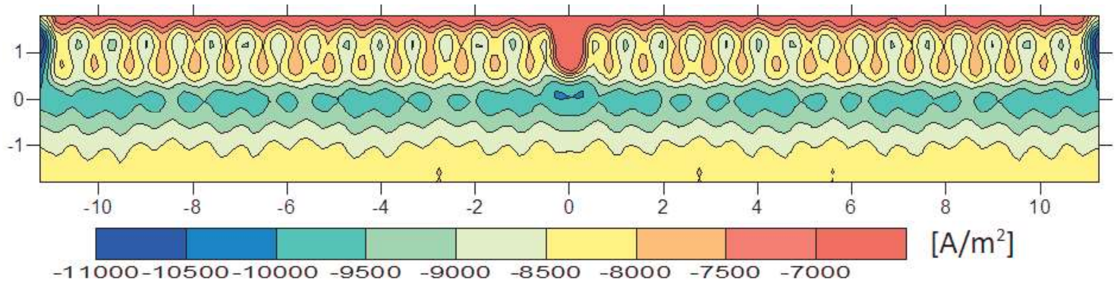

Figure 16. Cathode panel current density on the top surface (in contact with metal). Novel cathode assembly model.

The differences in cathode pickup between the three cases are also illustrated in Figure 17, where the values are taken along the y axis (from upstream to downstream). In the novel design the pickup is more equalized concerning the upstream/downstream split.

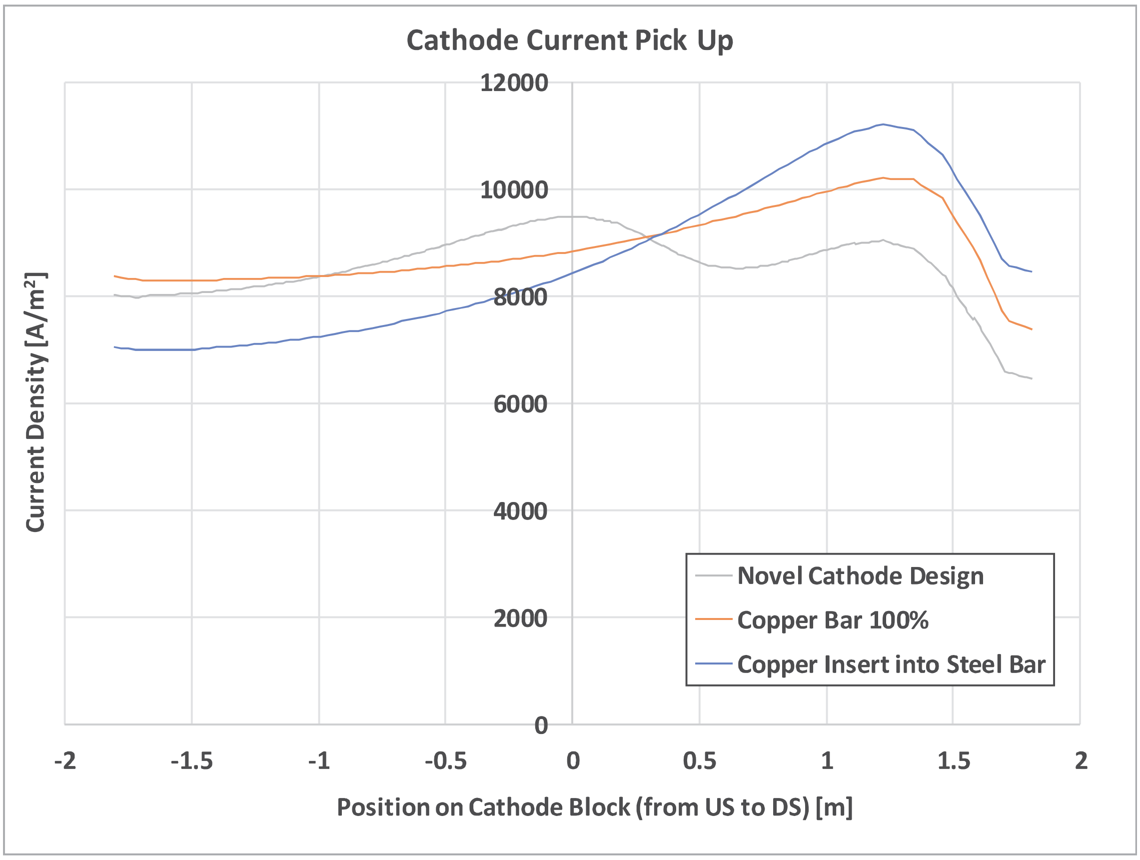

Figure 17. Current density magnitude at the cathode top for the three models.

In addition, Figure 18 shows the metal horizontal current at the transverse direction "Jy" for the three studied cases. In the novel cathode design, lower and symmetric Jy pattern was achieved, in contrast with the other cases where the Jy is predominantly positive and higher in magnitude. A positive/negative balance split is desirable as a better MHD feature, in line with consolidated literature [5].

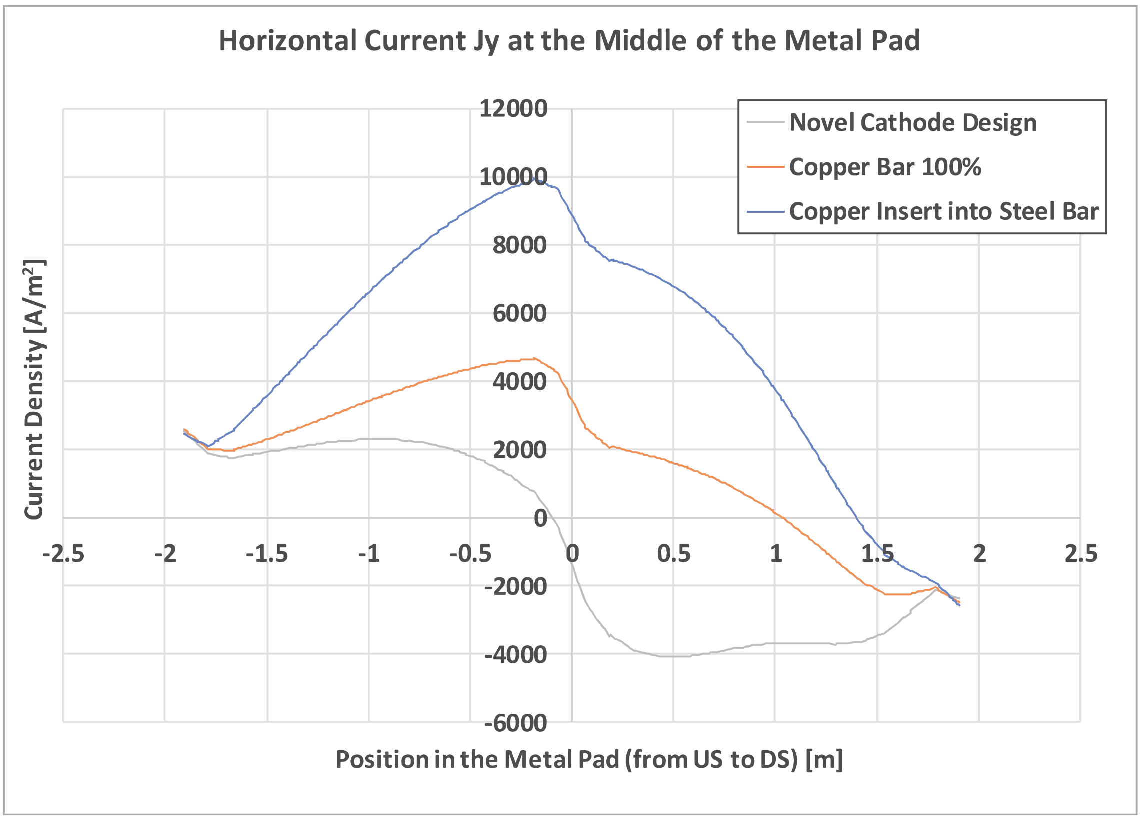

Figure 18. Current density at the cathode top for the models.

5. Conclusions

According to the model results presented in this article, it was possible to propose a novel cathode assembly design to be used in a "Downstream Cathode" arrangement that presents the following features:

- Adequate structural stiffness to withstand over time to the heave forces from the material build up under the cathode panel of the cell, which is not possible using integral copper bars;
- Low metal transversal current density "Jy", with good symmetry;
- More balanced current pickup split upstream/downstream compared with previous designs;
- Avoid excessive cathode pickup current near the sidewalls and big joint, decreasing wearing rates at these regions and potentially increasing cathode life;
- Good resulting MHD features: metal heave, metal vector velocities and growth rate of waves.

Finally, special lining design features would be also required, since there will be more heat being extracted through the downstream side of the cell. Upstream and downstream sidewalls would present different thermal insulation projects. The thermal aspects of the downstream cell are outside the scope of this article and might be disclosed in future works.

6. References

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