

MHD Analysis to Improve the Flow Profile in High Amperage Cells

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Abstract

Busbar configuration of large-scale aluminium reduction cells has become more complex with amperage increase in order to achieve the desired magnetic field distribution inside the cell. Magneto hydrodynamics (MHD) plays imperative role in the cell performance in terms of molten liquids flow profile and metal-bath interface stability. This paper outlines a case study to improve the molten liquids flow profile of a high amperage side-by-side cell through magnetic compensation. The molten liquids flow profile is governed by electromagnetic forces, which in turn depend on the magnetic field. To analyse this, 3-dimensional models were developed in commercial software packages: Magnetic field model using ANSYS, EMAG module, and MHD model using PHOENICS/ESTER. The metal flow profile was measured using iron rod method in a live cell of Hindalco Hirakud smelter to verify the model predictions. The models have been used to evaluate different magnetic compensation busbar designs with varying busbar positions and amperages to correct the force field and thereby improve the flow profile inside the cell.

Keywords: Magnetic compensation of cells, metal and bath flow profile, MHD models, busbar configuration.

1. Introduction

Aluminium reduction cells operate at very high current, resulting in strong magnetic field in and around the cell. The major component of electrical energy losses consists of the anode-to-cathode distance (ACD), contributing to approximately 1.5 V, which is about 35 % of the total cell voltage. The minimum ACD is governed by two important factors: (i) the heat generated in the ACD to maintain the electrolyte and aluminum in molten state and (ii) to avoid the molten metal short circuit with anode which leads to loss in the current efficiency.

Within a cell, the current flows vertically downwards through anodes, molten electrolyte, molten aluminium and cathodes before being collected by collector bars for feeding into another cell. The interaction of magnetic field with current flowing through the molten electrolyte and metal produces electromagnetic forces, which are responsible for the motion in the molten liquids as well as the deformation of the interface between the electrolyte and the metal. Electrolyte is immiscible in molten metal and floats on top of it, leading to formation of molten metal-electrolyte interface. The movement of interface and its control has been an active area of scientific research, also referred as magneto hydrodynamic (MHD) stability of cell. Over the years, research is being carried out to improve the MHD stability of the cell for increasing the energy efficiency. MHD stability of the cell is adversely affected by the waves generated due the unbalanced magnetic field resulting from poor busbar design. As per cell MHD design criteria, electromagnetic force in each quadrant of cell should be equal and balancing; indeed, it

would be best to have point-wise balance of forces over the molten liquid zone of the cell [1]. A symmetrical magnetic field distribution helps in attaining the right balance of forces. The latest improved aluminium reduction cell technology is the result of an advanced design aided by computational modeling and computer controlled electrolysis process. Over the years, improvement in the MHD stability of the cell has been achieved with efficient design of busbar configuration.

For higher energy efficiency of the cell, ACD needs to be maintained as low as possible subject to satisfying the cell thermal balance. The unstable interface at lower ACD may cause shorting of the molten metal with the anode, leading to loss of current efficiency. The minimum ACD at which the cell remains MHD stable depends on two factors - current distribution and magnetic field in the molten liquids. To improve the current distribution copper-insert collector bar has been a proven choice for the aluminium smelters, which decreases the horizontal currents significantly in the molten aluminium [2, 3]. Whereas magnetic field correction requires modification in the existing busbar network or additional compensation busbar [4]. It has been reported that the interaction of vertical magnetic field and horizontal current components are known to adversely affect the MHD stability of the cell [5, 6]. Hence, thorough understanding of the cell MHD state for correct design and control is a key to achieve high energy efficiency. The present study focuses on magnetic compensation busbar for compensation of vertical magnetic field to achieve a balanced force field for improved molten metal flow profile and stability of metal-electrolyte interface.

2. Computational Analysis

To improve the MHD flow profile and stability of the metal-electrolyte interface in a side-by-side HIRAKUD 235 kA smelter, 3-dimensional computational models were used. The electromagnetic and the steady state MHD model was developed using commercial software packages ANSYS EMAG module and PHOENICS/ESTER. Electrical and magnetic calculations were performed using ANSYS EMAG, assuming that interface between the metal and electrolyte is flat. For electromagnetic model development two cells on either side of the analyzed cell are considered and rest of the potline is modelled as line elements. Center of analyzed cell is taken as origin for all the calculations. Effect of neighbouring line is also modeled using the line element. The governing equation and modeling setup for electromagnetic and MHD model had been reported earlier [7]. Figure 1 shows the electromagnetic model of existing design of 235 kA smelter, referred as Base-case subsequently.

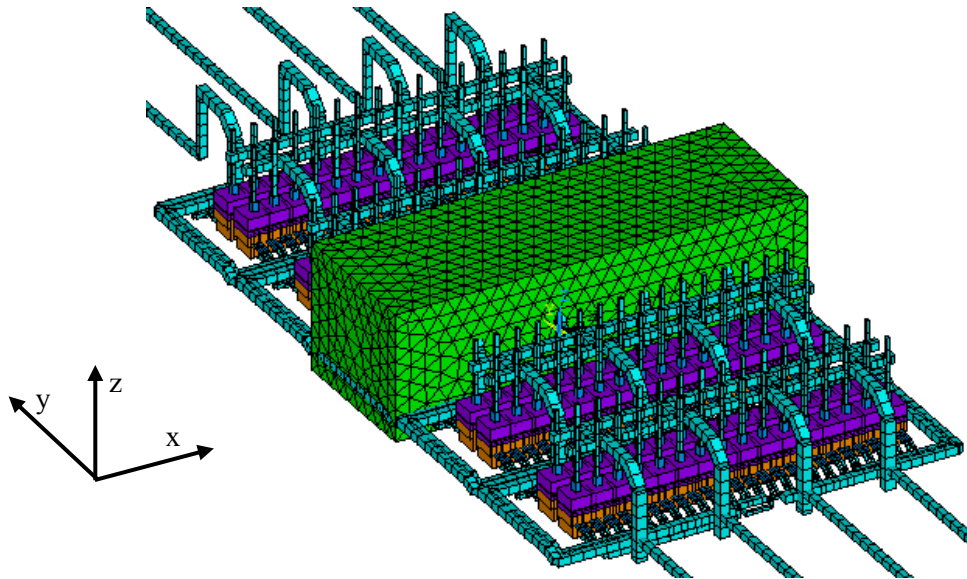


Figure 1. Electromagnetic model and mesh of Base-case.

Figure 2 shows the x, y and z component of magnetic field distribution at the mid-height of metal pad for Base-case. The B_x component is responsible for the transverse force field acting along the width of pot, hence symmetric B_x distribution along the x-axis does not adversely affect the flow profile as well as the MHD stability, even at higher magnitude of the B_x . The distribution of B_y component is found to be almost symmetrical about y-axis, with low magnitude (-3.5 to +3.5 mT), which provide symmetrical longitudinal force field. The longitudinal force is crucial for flow distribution and MHD stability, as it acts along the length of cell, hence much lower magnitude of the B_y is desirable. The magnitude of B_z found to be varying in the range of -1.7 to +2.1 mT. Low magnitude of B_z implies higher MHD stability of cell, however the B_z distribution, indeed the B_z gradient play crucial role in the force field distribution which ultimately affect the MHD stability of the cell. This would be discussed in subsequent sections, describing the role of the B_z distribution on the MHD flow profile.

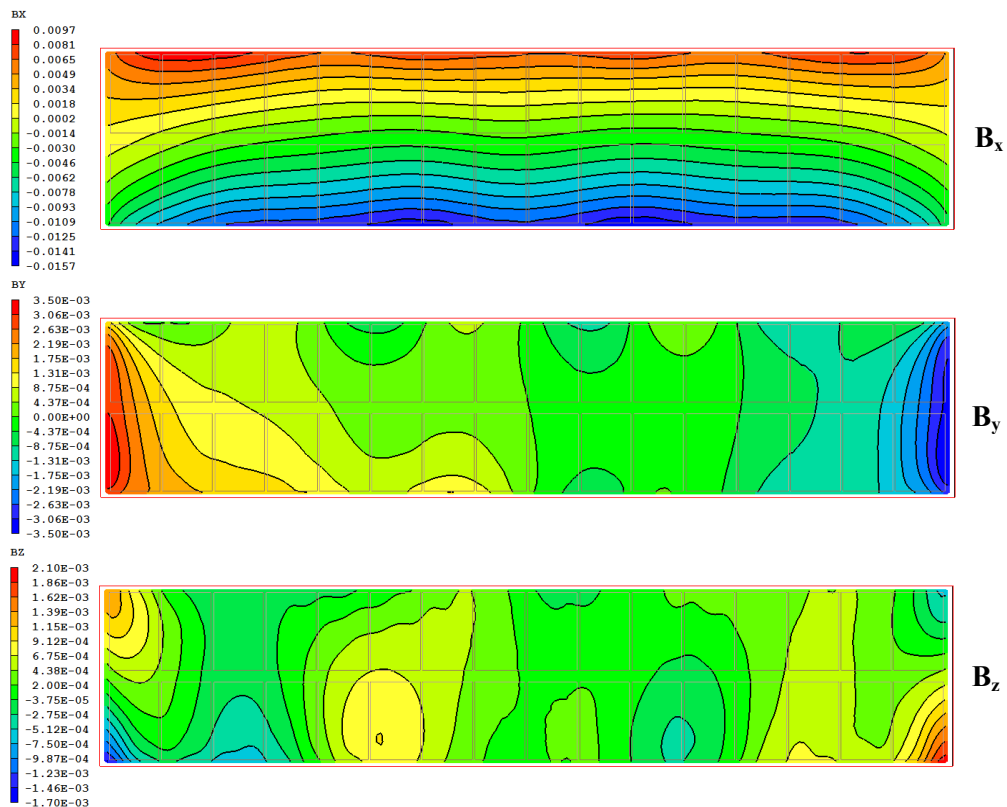


Figure 2. Magnetic field distribution (B_x , B_y , B_z) at mid-height of metal (mT).

Steady state MHD simulations were run in PHOENICS-ESTER with the magnetic field values obtained from the ANSYS EMAG module. In order to maintain the constant ACD, the anode height was adjusted in ESTER with respect to the metal-electrolyte interface position. For simplification, the influence of gas bubbles generated by the anode reaction on the electrolyte flow was not taken into account in this analysis. Figure 3 shows the simulated flow profile at the mid-height of metal pad for the Base-case.

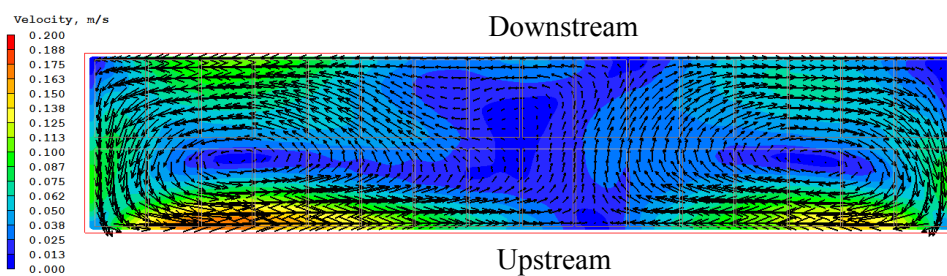


Figure 3. Simulated flow profile at mid-height of metal for Base-case (m/s).

From Figure 3, it is evident that two circulation loops are formed with a very low velocity region found in the center of the cell towards the downstream end. The electrolyte typically follows similar flow profile, nevertheless it is also affected by the movement of gas bubbles at the anode. The low velocity region may adversely affect the alumina dissolution and result in higher tendency of the sludge deposition, which eventually lead to higher energy consumption.

3. Velocity Measurement

In order to validate the MHD model prediction, molten aluminium velocity was measured in the live cell using iron rod dissolution method [8]. In this method, high purity (99.5 %) iron rods

were inserted into the molten metal at various locations near to anode corner in the cell. The moving metal pad dissolves the iron rods in such a way that a careful examination of the erosion pattern on rod provides the velocity direction. Figure 4 shows the schematic of the metal flow measurement; where in an iron rod is dipped into the molten metal for a specified time period.

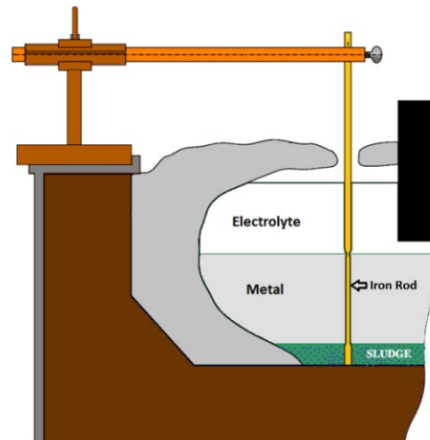


Figure 4. Schematic of metal velocity measurement in the cell.

Figure 5 shows the flow profile measured in the molten aluminium. The flow pattern of the measured velocity is found in good accordance with the flow profile predicted by the MHD model. The size of the arrow indicates the magnitude of measured metal velocity at that location and overall velocity was found in the range of 0.03 m/s to 0.18 m/s.

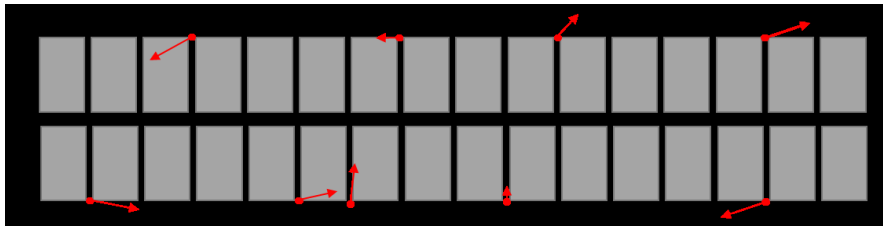


Figure 5. Measured metal flow profile.

4. Magnetic Compensation

The magnetic field plays a major role in the performance of an aluminum electrolysis cell, even small variations of busbar configuration have strong influence on the molten liquid flow profile and metal-electrolyte interface stability [9]. The stability of interface has strong reliance on electromagnetic forces originated from the interaction of the horizontal current and the vertical magnetic field. Hence to enhance the stability of interface, the magnetic fields are compensated to have low and balanced values of the vertical magnetic field (B_z). There are two types of magnetic compensation; if the current used for compensating the cell is independent of the line current, it is called the external current compensation and if the line current is used, it is called internal current compensation.

To understand the role of the B_z on electromagnetic forces and subsequently on the molten liquid flow profile, a hypothetical Case-1 was analyzed, which may not be possible with busbar modification. In the Case-1, only B_z was artificially made equals to zero in the molten liquid region, whereas B_x and B_y remained the same as Base-case. Based on the results of Case-1, an internal current compensation design was developed, denoted as Case-2. In the subsequent sections, the results of Base-case, Case-1 and Case-2 will be compared and discussed. Figure 6 shows the typical busbar configuration of Base-case.

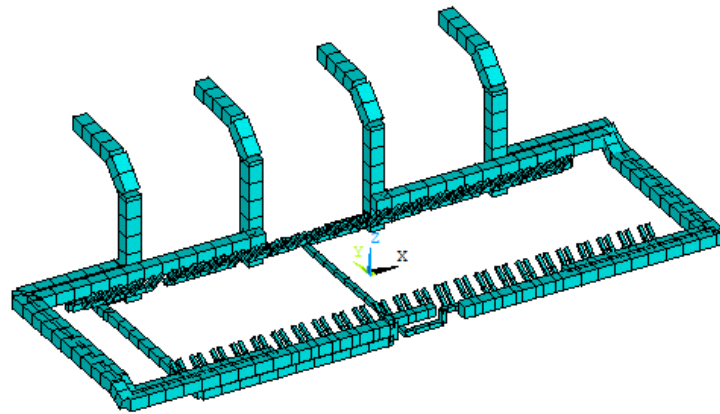


Figure 6. Busbar configuration of Base-case.

Figure 7 and Figure 8 shows the longitudinal electromagnetic force field for the Base-case and the Case-1. By comparing the longitudinal force field for both the cases, it is evident that only the central part of the cell is different, whereas the rest of the region is almost similar in force direction and magnitude. For Case-1, the assumption of B_z equals to zero has changed the longitudinal force field, especially at the center of the cell, highlighted as dotted section in Figure 8. The impact of this (Case-1) was also seen in the flow profile of the molten aluminium as displayed in Figure 9.

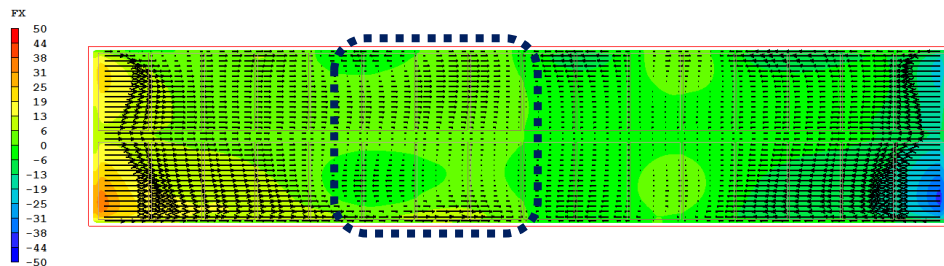


Figure 7. Longitudinal electromagnetic force (F_x) for Base-case.

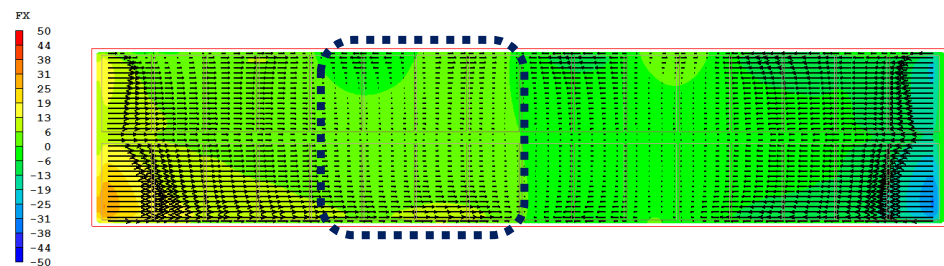


Figure 8. Longitudinal electromagnetic force (F_x) for Case-1.

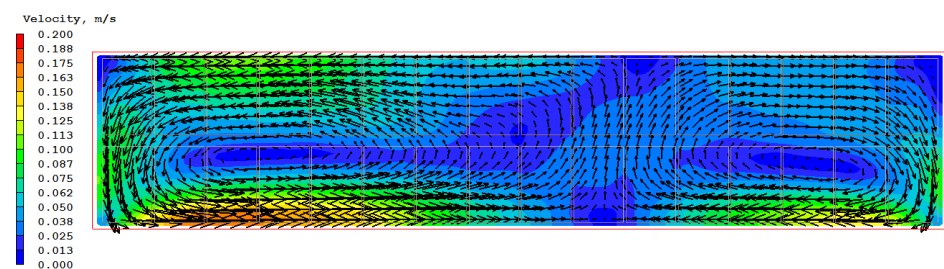


Figure 9. Simulated flow profile at mid-height of metal for Case-1 (m/s).

Interestingly, for the Case-1, the metal velocity magnitudes at the low velocity region found in the Base-case have improved, hence it was envisaged that low velocity region found in the centre of cell for the Base-case was due to variation in the longitudinal force field. Therefore, the busbar configuration of Case-2 was developed in such a way that it results in similar longitudinal force field as of the Case-1. The under cell busbar located near the cell center in the Base-case has been moved towards left (towards neighbouring pot room) of cell center by a specified distance. Figure 10 shows the modified busbar configuration of Case-2, to provide the required magnetic compensation and the longitudinal force field. Figure 11 indicates B_z distribution for the Case-2.

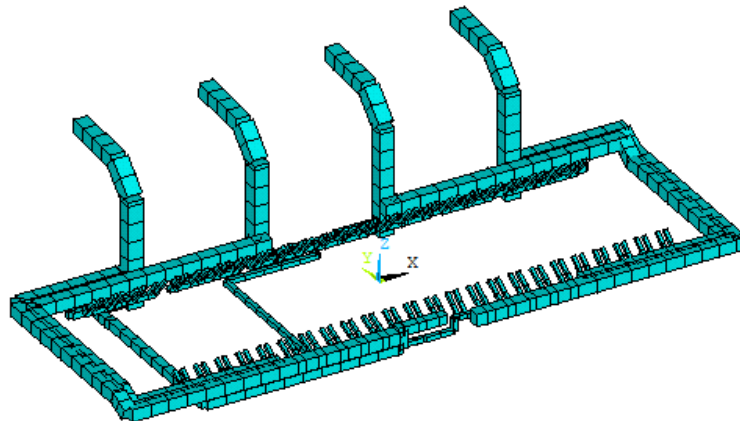


Figure 10. Modified busbar configuration of Case-2.

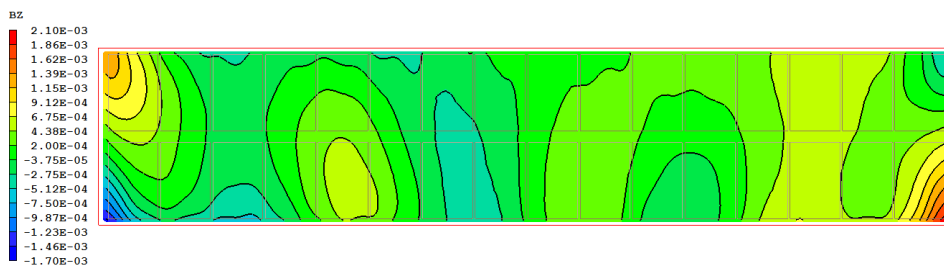


Figure 11. Vertical magnetic field distribution (B_z) for Case-2.

Table 1 shows a comparison of the average values of vertical magnetic field (B_z) under the shadow of each anode at mid-height of the metal. It can be seen that average B_z on the downstream side for Base-case is mostly positive, which has been improved in the Case-2, resulting in the improved longitudinal force field.

Table 1. Comparison of average B_z under each anode at mid-height of metal (mT).

Downstream	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16
Base-Case	0.772	0.115	-0.145	0.011	0.290	0.441	0.469	0.287	0.064	0.084	0.086	0.115	0.317	0.474	0.378	0.036
Case-2	0.762	0.093	-0.159	0.034	0.161	-0.127	-0.244	-0.091	0.128	0.237	0.221	0.227	0.386	0.523	0.452	0.121
Upstream	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16
Base-Case	-0.071	-0.024	-0.356	-0.022	0.620	0.804	0.480	0.218	0.196	0.154	-0.178	-0.137	0.340	0.593	0.436	0.805
Case-2	-0.076	0.012	-0.265	0.058	0.472	0.176	-0.289	-0.199	0.235	0.321	-0.029	-0.049	0.345	0.523	0.378	0.803

The change in B_z distribution alters the longitudinal force field at the central part of cell without affecting the rest, as indicated in Figure 12. The resultant longitudinal force field is similar to Figure 8 of the Case-1. The impact of the changed longitudinal force field is evident in the molten aluminium flow profile highlighted in Figure 13. The calculated longitudinal force field for the Case-2 is in analogous to longitudinal force field of the Case-1, where vertical magnetic

field is assumed to be zero. Hence the compensation design of Case-2 would potentially have higher MHD stability due to the similar longitudinal force field as of the Case-1.

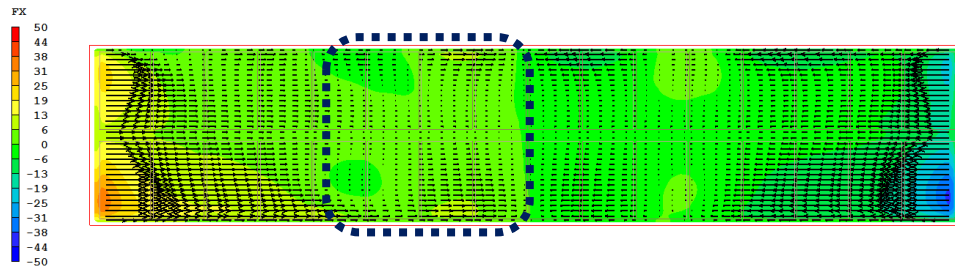


Figure 12: Longitudinal electromagnetic force (F_x) for Case-2

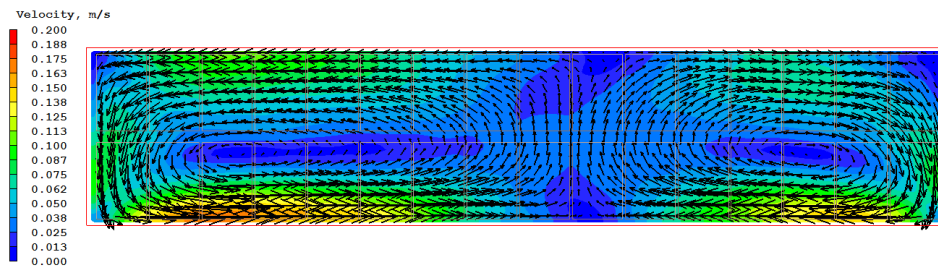


Figure 13. Simulated flow profile at mid-height of metal for Case-2.

External current compensation can also provide similar or better magnetic compensation, however the implementation would require significant CAPEX, hence it was not considered in this study. From the analysis it was identified that the location of compensation current is very important to achieve the low values of B_z and of its gradient. Indeed, it is always beneficial to carry out a point-wise balance of the electromagnetic force field in the molten liquid region to attain good MHD performance of cell.

5. Conclusion

MHD stability could be improved either by reducing the vertical magnetic field or by reducing the horizontal currents in the metal pad. Tweaking the magnetic field requires modification in the busbar configuration. However, magnetic field compensation becomes extremely important where the pot performance is inferior because of the faulty busbar design. In the existing side-by-side 235-kA potline, the magnetic compensation is achieved by deliberately shifting under the cell compensation busbar towards the neighbouring potroom of the potline. In Case-2, the internal magnetic compensation has altered the vertical magnetic field distribution in such a way that the opposing force field is diminished, thus improving the molten metal flow profile.

The compensated busbar design improves the overall molten metal flow profile inside the pot, hence it would impact the pot performance positively. The longitudinal force field of compensation design, i.e. Case-2, is similar to the force field of Case-1 whose B_z equals to zero, thus Case-2 would have comparatively higher MHD stability than Base-case. It would also provide an opportunity to squeeze the inter-electrode gap and thus reduce the specific energy consumption.

6. References

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