Design of Smelter Magnetic Solutions Using MHD Code

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Abstract

Rio Tinto has developed an in-house MHD code to study the stability of aluminium electrolysis pots. The model is calibrated with experimental measurements of magnetic fields and pots stability. This tool plays a major role in using boosters in smelters in order to develop and test new AP Technology™ pot improvements. Furthermore, it is used to calculate the MHD stability limit for amperage increase in smelters and for designing new solutions in case of unstable pots. A recent example applied at Alma smelter is the design of a special compensation loop that increases the stability of end-line pots [1] which are known to be unstable relatively to middle-line pots, thus allowing the smelter to reach 450 kA.

Keywords: Aluminium electrolysis cells, MHD modelling, instability, magnetic solutions.

1. Introduction

Aluminium electrolysis is the industrial process used in smelters to produce primary aluminium. This process consists in dissolving alumina in an electrolytic bath at high temperature of the order of 970 °C, through which flows an electrical current, thereby launching an electrochemical reaction that transforms the dissolved alumina into liquid aluminium and CO_2 bubbles,

$$2Al_2O_3 + 3C = 4Al + 3CO_2 \tag{1}$$

The electrical current flowing through electrolysis pots is large enough (hundreds of kiloamperes) to generate a strong magnetic field that impacts its surroundings, e.g., metal transport vehicles, metallic structures, etc. Furthermore, this magnetic field modifies the metal heave and the fluid dynamics in the pot, thus impacting the alumina dissolution and pot stability. When the vertical component of the magnetic field is large, the pot becomes unstable due to generation of a horizontal MHD force that amplifies the metal-bath interface perturbations [2]. Hence, the design of busbars transporting electrical current between the different pots and providing the distribution of magnetic field in the pot, plays a major role in the conception of a stable pot-line. However, optimal conception of pot busbars is not enough in the case of important amperage increase where the potline operation point, i.e., anode-cathode distance (ACD), metal height and pot-line current, drastically change in order to conserve pot thermal and chemical equilibria. One of the solutions consists of additional electrical conductors parallel to the pot-line to compensate the neighboring potlines magnetic field and to optimize the one in the pots [1]. These additional electrical conductors are called magnetic compensation loop. Their advantage is their adjustability with respect to the pot-line current, enabling higher amperage increase without changing the pot busbars design. Such magnetic solution is designed using an in-house MHD code developed by Rio Tinto. This code will be presented in Section 2, then multiple applications will be shown in Section 3, and concluding remarks will be given in Section 4.

2. MHD Code Description

The MHD stability code was developed using shallow water model which is suitable for geometries with a horizontal length scale much greater than the vertical length scale. The model inputs are: the position of pot-line conductors and current they carry, ACD, metal height and pot geometry (anode and cathode dimensions, steel shell geometry). The model outputs are the resulting magnetic field and a pot stability criterion. Figure 1 shows pot-line conductors as in the code interface.

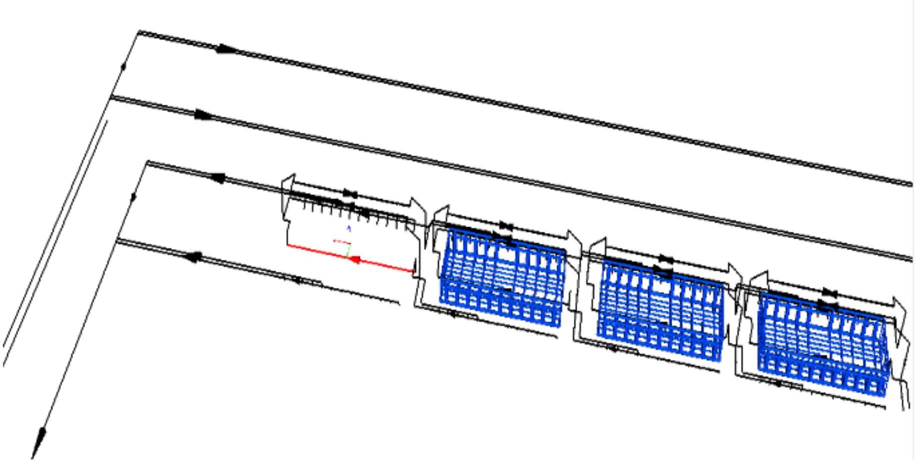

Figure 41. Interface of the MHD code showing potline conductors.

Several magnetic field measurements in the pot are done regularly and compared to the numerical results to validate the model. This is shown in Figure 2, where the red curve corresponds to pot magnetic field measurements along the pot long-side at Alma smelter, and the blue curve corresponds to the numerical model. The close superposition of the two curves shows a good consistency between the numerical model and the pot measurements.

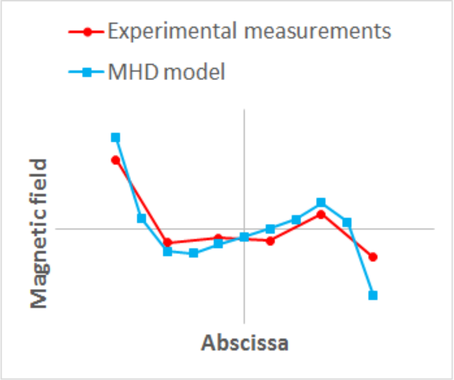

Figure 2. Comparison of magnetic field distribution resulting from experimental measurements and from MHD model.

In order to validate the pot stability prediction model, the stability criterion requires calibration. This is done via a squeezing test that consists in reducing the ACD until the pot becomes unstable, thus identifying the value of stability criterion corresponding to this threshold ACD. An example of a squeezing test is shown in Figure 3 where the green curve is the ACD and the blue curve is the measured pot voltage perturbation. During this test, the ACD was gradually decreased until the pot voltage perturbation became instantly greater than the predefined threshold, represented by point 1 in the figure. The corresponding ACD threshold is represented by point 2 in the figure, and is used to calibrate the reference value of the stability criterion threshold.

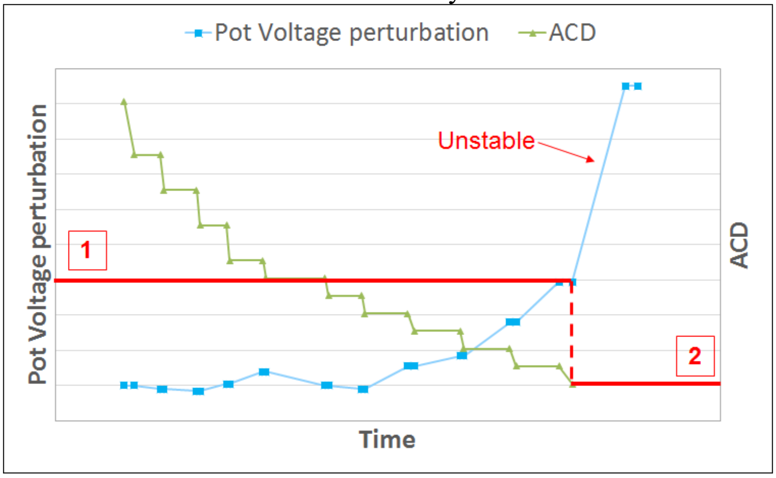

Figure 3. Time evolution of pot voltage perturbation during a squeezing test.

Having the reference value of the stability criterion, the MHD code can be used to predict pot stability in the smelter. However, this calibration is not enough to validate the MHD stability model, hence a second validation is done by comparing relatively the numerical predicted stability and the measured voltage perturbation of several pots. Figure 4 shows the stability criterion of 10 neighboring pots operating at the same ACD. Pots 2, 3, 4 and 5 are expected to be less stable than the rest of the pots, hence they would require ACD increase to stabilize them. Figure 5 shows the time evolution of total voltage and voltage perturbation of the different pots. It is clear that pots 2, 3, 4 and 5 operates at higher ACD while their voltage perturbation is of the same order of the neighboring pots. In other terms, pots 2, 3, 4 and 5 are less stable in case they operated at the same ACD of the rest of the pots. Thus, the numerical stability prediction is consistent with the pot measured data as shown in Figure 5.

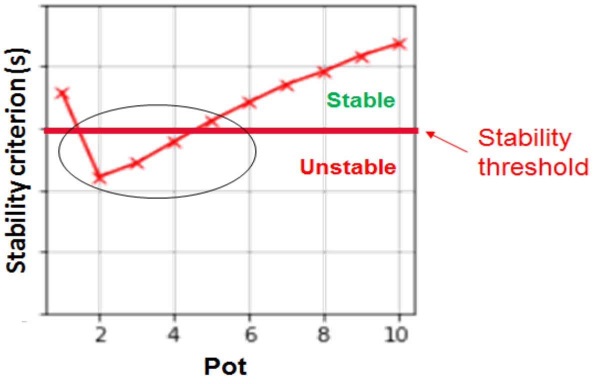

Figure 4. Stability criterion of 10 pots in a pot-line.

3. Examples of Use

The arrangement of electrical conductors and their position play a crucial role in developing new technology and optimizing pot-line stability. In this section will be presented the examples of use of the MHD code to adjust magnetic compensation loop, improve end-line pots stability and identify MHD stability limits of new technologies tested in the booster.

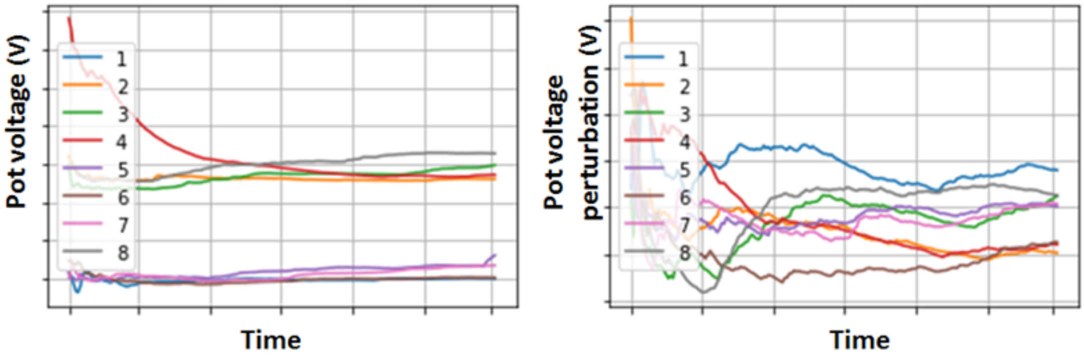

Figure 5. Time evolution of pot voltage and its perturbation for different pots.

3.1. Magnetic Compensation Loop

The interaction of horizontal current with vertical magnetic field generates an MHD force that induces vortexes in the molten liquids which destabilize the bath-metal interface and thus lead to a loss of current efficiency. In a potline, the vertical magnetic field is mainly generated by neighboring potlines, pots and conductors between pots. To enhance the bath-metal interface stability, the vertical magnetic field should be compensated. This is done by constructing a magnetic compensation loop parallel and close to the potline, and located between the potroom and its neighboring one (see Figure 6). The vertical magnetic field generated by this loop is opposite to the one of the neighboring potroom, and can be adjusted by modifying the magnetic compensation loop current. The optimal loop current is calculated using the MHD code. This is shown in Figure 7 (left) where the variation of the stability criterion with respect to the loop current is plotted. The optimal configuration corresponds to I_{loop}=30 kA, where the stability criterion is the highest.

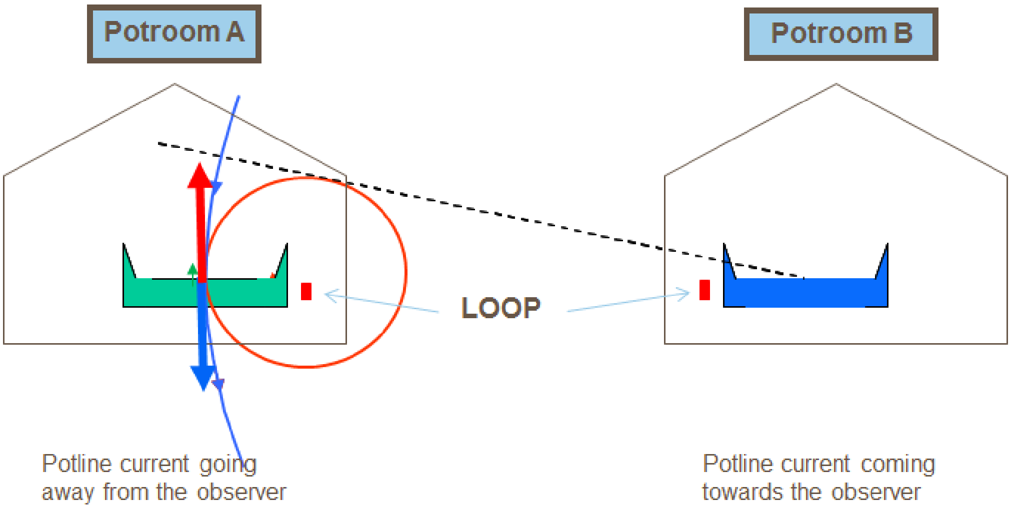

Figure 6. A sketch of magnetic compensation loop concept.

In the case of some technologies, an additional loop is constructed on the other side of the pot-line. Similarly, our code is used to calculate the optimal current of the loops, as shown in Figure 7 (right). The stable configurations correspond to the area between the two black dashed lines in the figure.

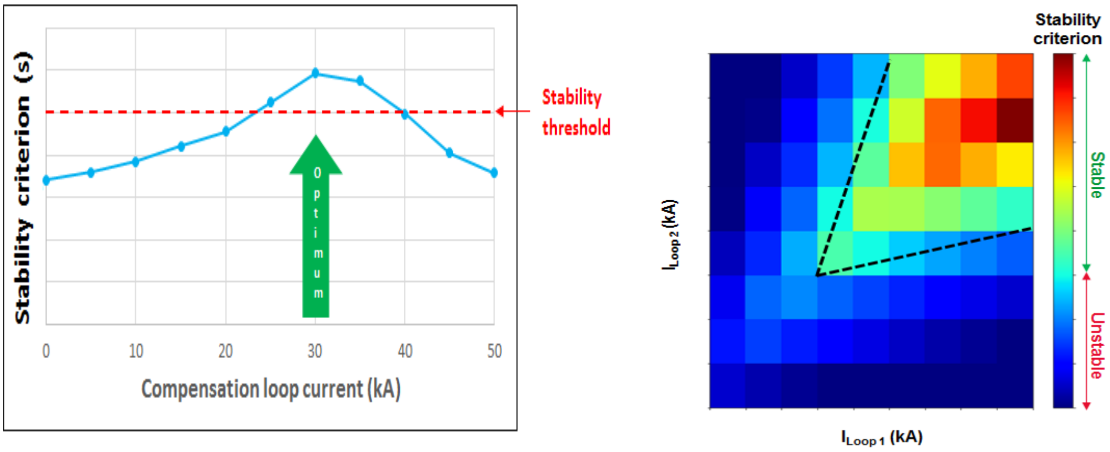

Figure 7. Variation of pot stability. Left: with respect to the magnetic compensation loop current. Right: with respect to the currents in two magnetic compensation loops.

3.2. Stability Improvement of Pots at Ends of the Potroom

End-of-potroom pots are known to be relatively less stable than the rest of the pots in the potline due to asymmetry of the magnetic field between downstream and upstream. This can be challenging in the case of an amperage increase since these pots will reach their MHD stability limit before reaching the target amperage. At Alma smelter, pots at the end of potrooms in one sector were blocking the 405 kA amperage increase plan. Moreover, the adjustment of current in the magnetic compensation loop was not enough to stabilize these pots. Hence the modelling team reviewed the design of the compensation loop using the MHD code and developed a new electric busbars arrangement (see Figure 8 left) that improves the stability of end-of-potroom pots and even enables an amperage increase to 450 kA [1]. The results at 450 kA are shown in Figure 8 (right), where the blue curve corresponds to stability of the end pots before the modification of magnetic compensation loop and the green curve corresponds to the case with the new magnetic compensation loop design. It is clear that the modification of the compensation loop improved the stability of the pots. Moreover, this solution yields an optimized capital expenditure (CAPEX) with respect to the one of modification of the pot-to-pot busbars design.

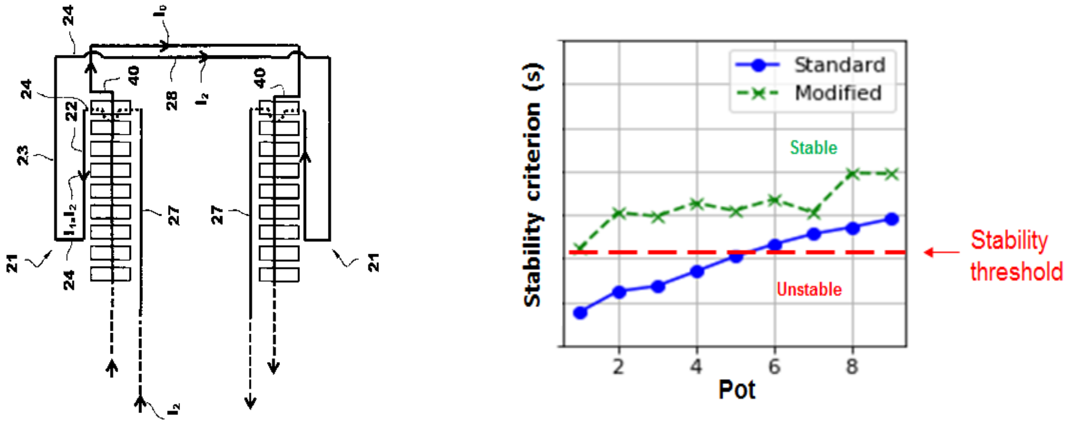

Figure 8. Left: sketch of the modified magnetic compensation loop (taken from [1]). Right: comparison of end-line pots stability before and after the modification of the compensation loop.

3.3. Booster Design

A booster is the section in the pot-line where a secondary electrical network is connected to the main one, letting an additional current flow in the pots of this section (see Figure 9 left). Whence the name "Booster" or "Boosted pots". Indeed, the secondary electrical network generates additional magnetic field that might be detrimental to the stability of the boosted pots. Therefore, the design of booster should be carefully done by taking into consideration the MHD stability of the pots, but it should also provide a magnetic environment as close as possible to the one generated at the target current in the whole pot-line. Boosters are used as experimental sections to test and validate new technologies and amperage increase.

The MHD code in this case is not only used to design the arrangement of booster conductors, but also to identify MHD stability limits of new technologies. Figure 9 (right) shows the variation of the stability criterion with respect to the ACD and the pot current. The area colored in green is the recommended window for a magnetically stable pot. However, this recommendation should be validated with the thermo-electrical window [3].

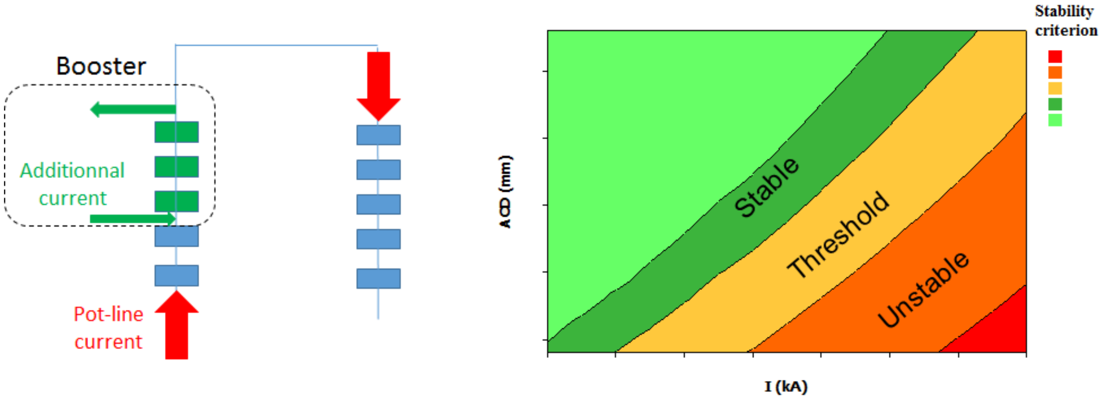

Figure 9. Left: booster circuit sketch. Right: stability variation with respect to pot current and ACD.

It should be noted that new technology development is not only done using this code. To check more precisely the stability and the fluid dynamics in a pot, ALUCELL software suite is coupled with this code [4] and used for example to calculate the velocity field (see Figure 10) and optimize alumina dissolution as shown in Figure 11.

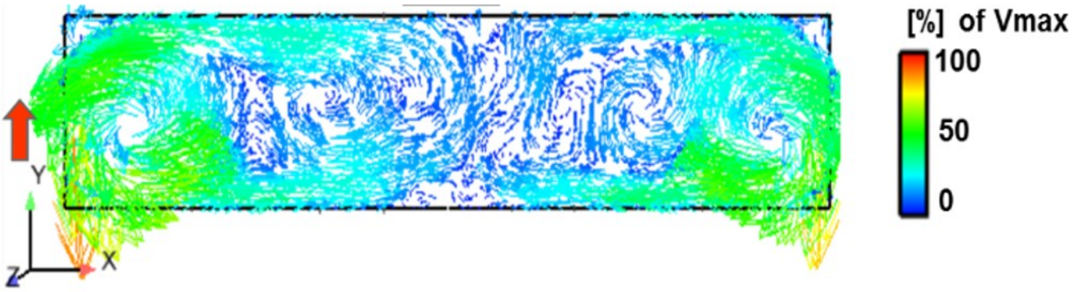

Figure 10. Velocity field in a pot calculated with Alucell.

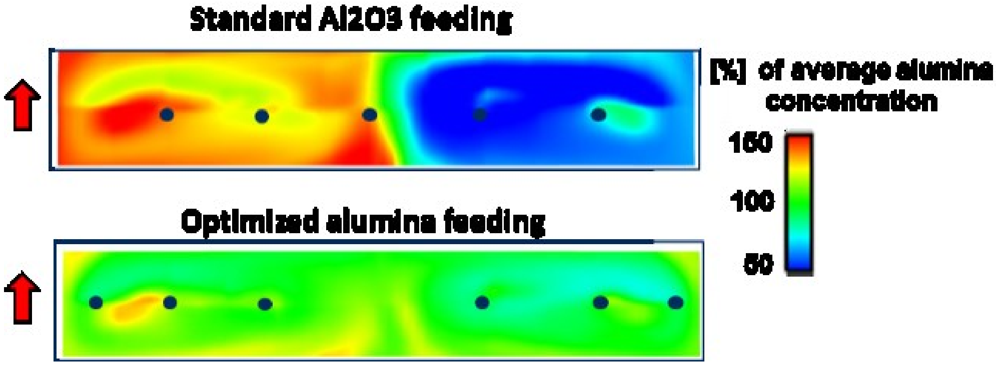

Figure 11. Alumina concentration field in the bath calculated with ALUCELL.

4. Conclusions

The MHD code presented in this article has been developed by Rio Tinto to calculate magnetic fields in the pot-line and predict pot stability. This code was validated with pot measurements and proved to be a main contributor in pot-line development and in the design of multiple magnetic solutions, e.g., magnetic compensation loops, boosters, new pot technology.

Furthermore, these solutions are designed by taking into consideration the optimization of financial aspects (CAPEX/OPEX). Moreover, the code works on different technologies and was used to provide solutions for AP Technology^{TM}, P-69/P-155, Alusuisse, Sumitomo and CD200.

5. References

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