Upgrade Experiment on MHD Stability of 350 kA Pot

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https://doi.org/10.71659/icsoba2024-al058

Abstract

During the process of reducing energy consumption in the SY350 potline of State Power Investment Corporation (SPIC), challenges arose in terms of insufficient magnetohydrodynamic stability. Specifically, a noticeable decline in current efficiency was observed after reducing the anode-cathode distance (ACD). To address this issue without affecting the overall production capacity of the potline, test pots were selected for an upgrade experiment on magnetohydrodynamics (MHD) stability by SAMI. The experimental plan involved the redesign of the busbar around the pot using the most advanced magnetic field calculation platform, coupled with the application of "Self-Balancing Busbar Network" Technology to enhance the anti-interference capability between adjacent pots. After the technological upgrade, the vertical component of magnetic field (B_z) of the test pots was significantly reduced, with a decrease exceeding 70 % in the 1st quadrant and over 40 % in the 2nd and 4th quadrants. Additionally, the distribution of the magnetic field is much more uniform. Both the liquid metal velocity and the bath velocity decreased, with a more regular two-pool circulation pattern. The interface deformation below the anode projection was reduced from approximately 4.3 cm to around 3.6 cm. The improvement of the above indicators has significantly increased the performance of the pot, and the MHD stability is no longer a technical bottleneck. The net voltage of the test pots is reduced from about 4.02 V to about 3.90 V and the current efficiency is no longer affected when the ACD is reduced by 3 mm, and the average DC power consumption is < 12 400 kWh/t Al.

Keywords: Magnetohydrodynamic stability, Busbar design, Self-Balancing Busbar Network (SBBN) technology, ACD, Energy saving and consumption reduction.

1. Introduction

A total of 276 pots in a SPIC's (State Power Investment Corporation, a large aluminum production enterprise in China) potline are in production using SAMI's 350 kA aluminum pot technology. After the potline was put into operation at the end of 2007, most of the pots have been in operation for more than 2 relining cycles so far. The technology route of this potline aimed at achieving high efficiency with high voltage. Its design voltage is about 4.15V. The design of magnetohydrodynamic (MHD) stability was limited by the accuracy of the simulation model at that time, which had significant technology gaps compared to the current standards. Nowadays, with the strict control of energy consumption and carbon emissions in China, the potline has to reduce anode-cathode distance (ACD) to reduce energy consumption.

However, in the daily production of this potline, if the ACD is reduced, the operation will be unstable and the noise will increase significantly. At the same time, there are also the following phenomena: when a single pot is disturbed, such as anode effect, abnormal bath-metal pad interface oscillation (pot noise), anode change, it can also lead to a decrease in the stability of adjacent upstream and downstream pots, and even anode effect and liquid metal instability may occur in adjacent pots. And during the maintenance and shutdown process of the pot, the upstream and downstream pots are also unstable, manifested by significant voltage fluctuations, which do not decrease after increasing the voltage [1–2].

To effectively solve the above problems, 5 adjacent pots were selected for technological upgrading industrial tests in this potline, with the goal of minimizing energy consumption without reducing current efficiency. For this purpose, the following innovations were implemented on the test pots: Optimized pot-to-pot busbar design with self-balancing busbar network technology [3]; lining upgrade technology; optimized design of gas collection system, etc. In this paper, we focus on exploring the optimization of MHD stability and magnetic field distribution in the pots.

2. Selection of 5 Test Pots

Five adjacent pots were selected for testing in the south potroom of the 350 kA potline (Figure 1). Three of these 5 reduction pots have come to the end of relining cycle.

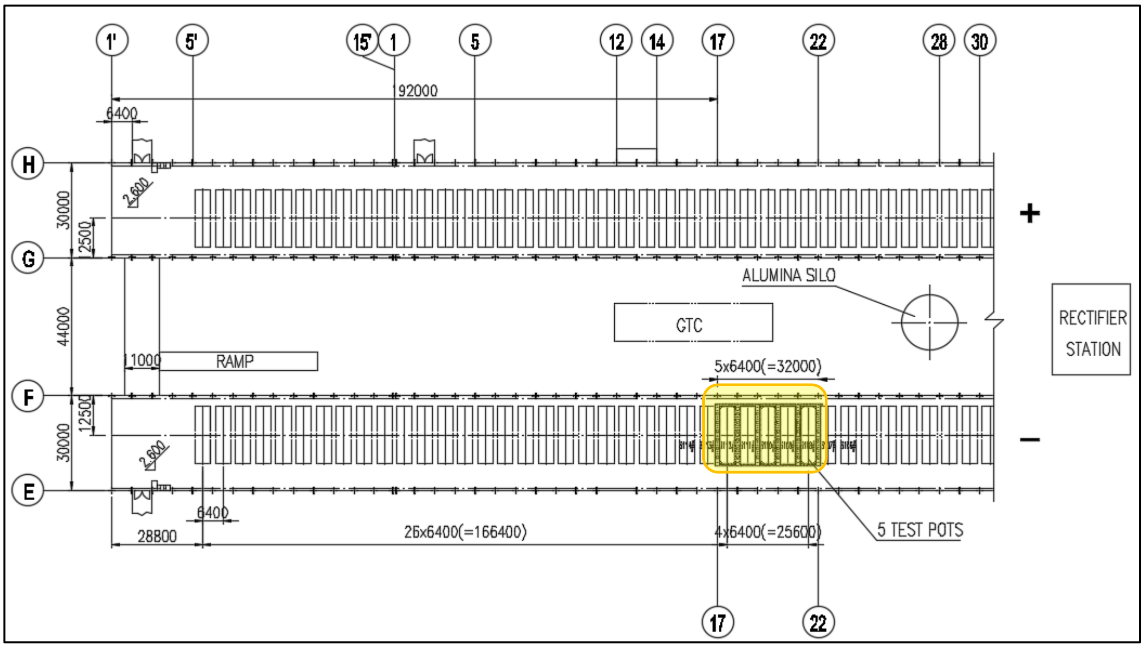


Figure 1. Location diagram of test pots (in yellow frame).

3. Establishment and Simulation of Electromagnetic Field Model for Test Pots

The establishment of magnetic and electric field models requires consideration of all components through which current flows, including anodic and cathodic busbars, anodes, bath and metal, cathode carbon blocks and collector bars, bimetallic (or trimetallic) transition joints, etc. [4–7].

The magnetic field and electric balance model of the test pots is shown in Figures 2 and 3.

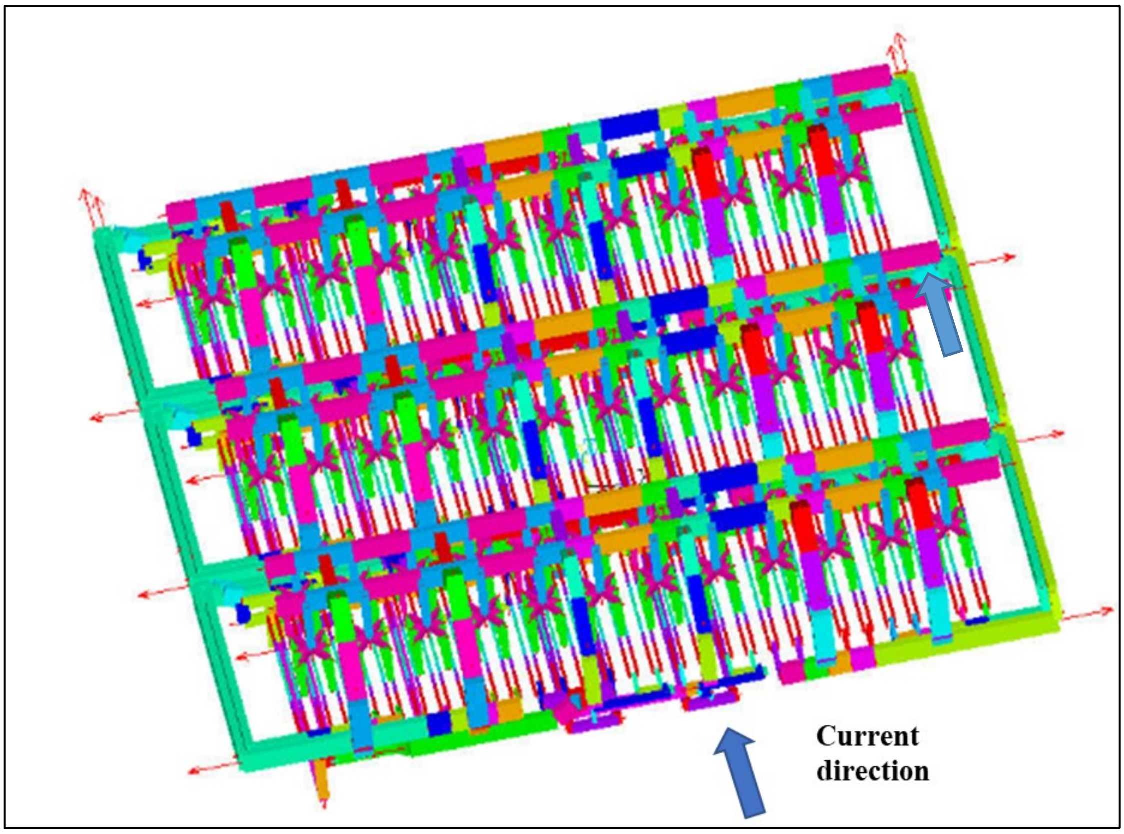


Figure 2. Pot-to-pot busbars for the computation of magnetic field of SY350 pot.

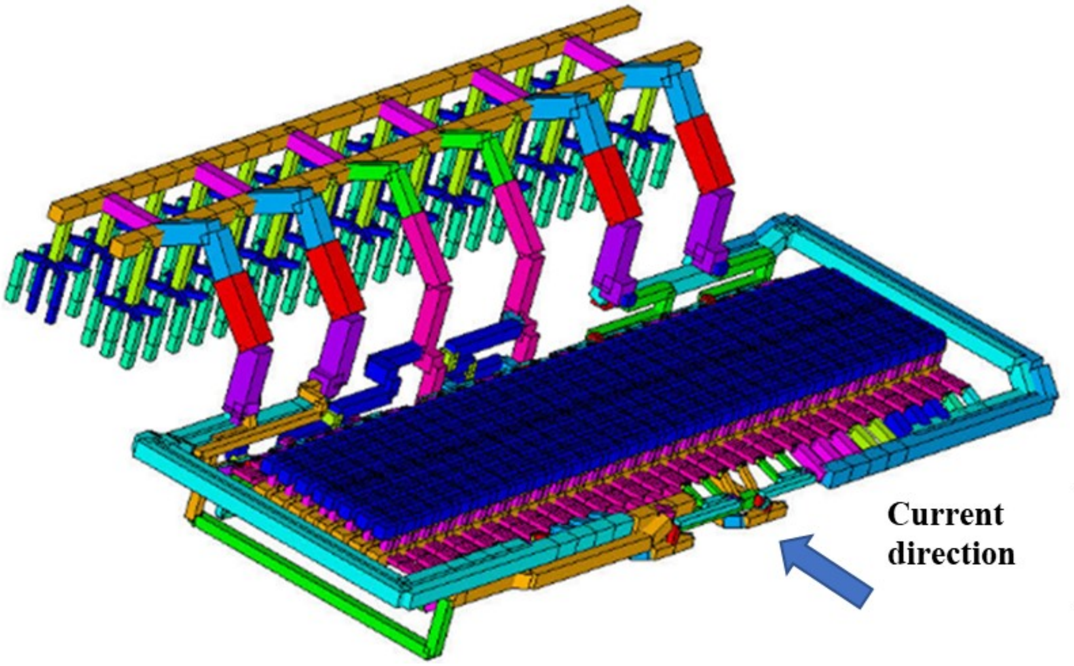


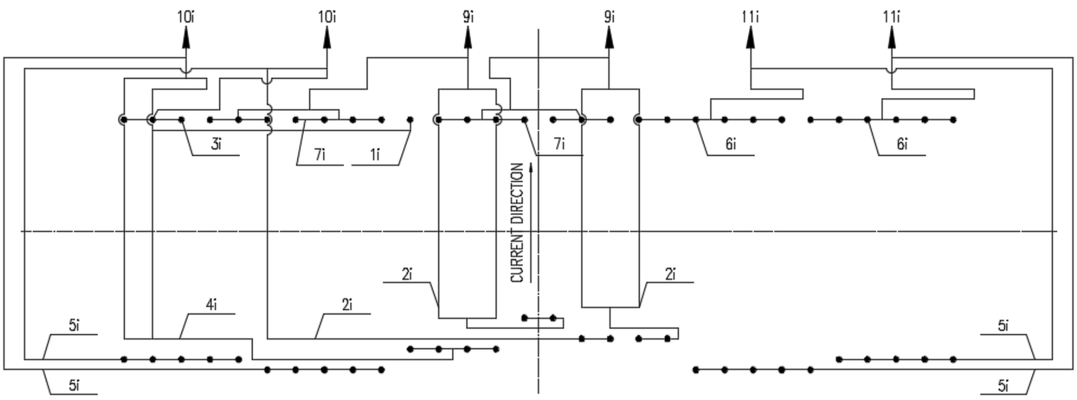
Figure 3. Electrical balance model of SY350 pot.

This 350 kA pot has 30 cathode blocks. Each cathode block has two collector bars, on the upstream and another on the downstream side. Therefore, each pot has a total of 60 collector bars. The single-line diagram of the original design busbar is shown in Figure 4.

Based on this magnetic field calculation model, the calculated vertical magnetic field distribution results are shown in Table 1. According to the distribution of the original magnetic field, we have implemented several key modifications to enhance the performance of the electrical system. Specifically, we have modified the under-pot busbar, redirecting more current to both ends of the pot. Furthermore, we have redesigned the bus configuration to create a novel busbar technology.

Self-balancing busbar network technology is a patented proprietary technology of SAMI [3]. When an unstable condition occurs in this pot, the current distribution in the aluminum liquid layer deviates, and the traditional busbar structure cannot correct imbalance in current distribution, because each anode riser circuit constitutes an independent circuit. Therefore, the current deviation of the fluctuating pot is transmitted to the upstream and downstream pots through the independent busbars, inducing a cascade effect. The larger the potline current, the stronger the mutual interference. The self-balancing busbar network technology can correct the current distribution deviation by establishing a new equipotential surface on the busbar system. Due to the addition of an equipotential surface in the cathode busbar system, the unbalanced currents passing through this equipotential surface will interconnect and redistribute, thereby achieving a current homogenization effect. So, the new cathode busbar equipotential surface blocks the mutual interference between upstream and downstream pots, and reduces the uneven distribution of anode and cathode currents in the unstable state of the pot.

Side B



Side A

Figure 4. Single-line diagram of the original pot design.

4. Comparison of Magnetic Field Calculation Results

When calculating the magnetic field distribution of the test pots, the contribution of the internal current distribution in the pot itself needs to be considered. It is also necessary to consider the influence of adjacent upstream and downstream pots and adjacent pot rows. Table 1 and Figure 5 show the comparison between the vertical component of magnetic field (B_z) distribution of 5 test pots and the original design pot. B_z indicates the average value in the middle of the metal pad height over each quadrant.

From the calculated magnetic field in the test pot, it can be concluded that: the magnetic field results of the 5 test pots are relatively close. Compared with the original design (Figure 6), the average magnetic field in the test pot is significantly reduced, and the magnetic field distribution in each quadrant is relatively uniform. B_z ranges from -23 G to 24 G (Figure 7).

Table 1. B_z distribution (average in each quadrant) of the test pots and the original pots.

B_z, (G)	Original design pot	3108#	3109#	3110#	3111#	3112#
Quadrant 1	11.75	2.21	2.82	2.88	2.70	1.83
Quadrant 2	5.35	4.99	3.88	3.70	3.74	4.95
Quadrant 3	4.66	5.53	4.69	4.51	4.57	6.54
Quadrant 4	7.54	3.65	4.14	4.14	3.90	4.49

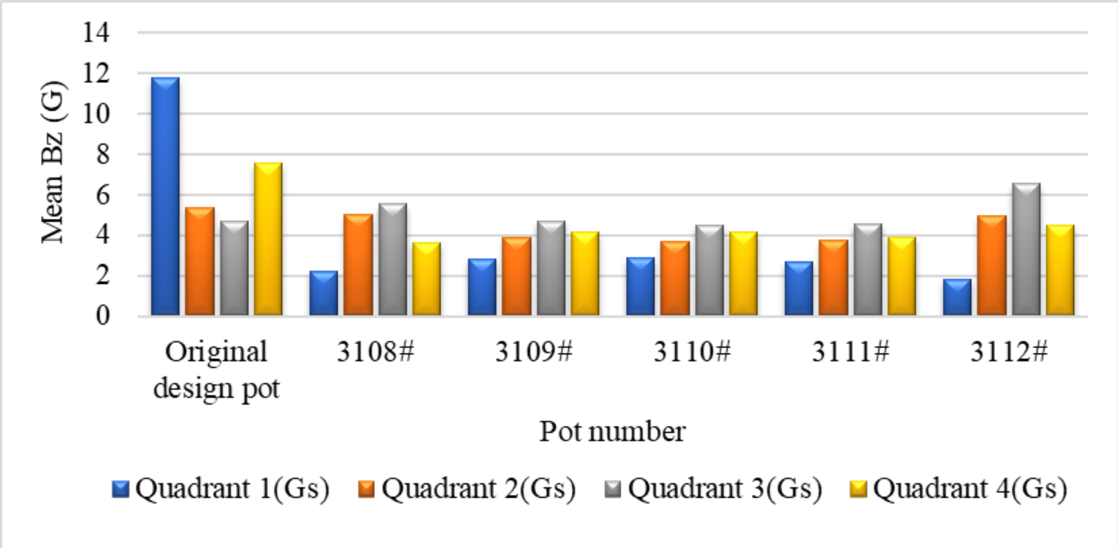


Figure 5. Comparison of B_z distribution (average in each quadrant) between the test pots and the original pots.

Pot 3110 is in the middle of the 5 test pots. Figure 6 compares the B_z distribution in the melt region of the original reduction pot with that of the test Pot 3110, shown in Figure 7. The average absolute values of B_z in the 1^{st}, 2^{nd}, 3^{rd}, and 4^{th} quadrants of the Pot 3110 are 0.29 mT (2.9 G), 0.37 mT (3.7 G), 0.45 mT (4.5 G), and 0.41 mT (4.1 G), respectively. After the technological upgrade, B_z distribution was significantly reduced, with a decrease exceeding 70 % in the 1^{st} quadrant and over 40 % in the 2^{nd} and 4^{th} quadrants. From the three-dimensional schematic diagram of the magnetic field results, it can be found that the B_z values of the test pot are relatively small, evenly distributed, and have small gradient. The maximum values of magnetic field occur in the four corners of the pot, and the mean absolute values in all four quadrants are below 0.5 mT (5 G).

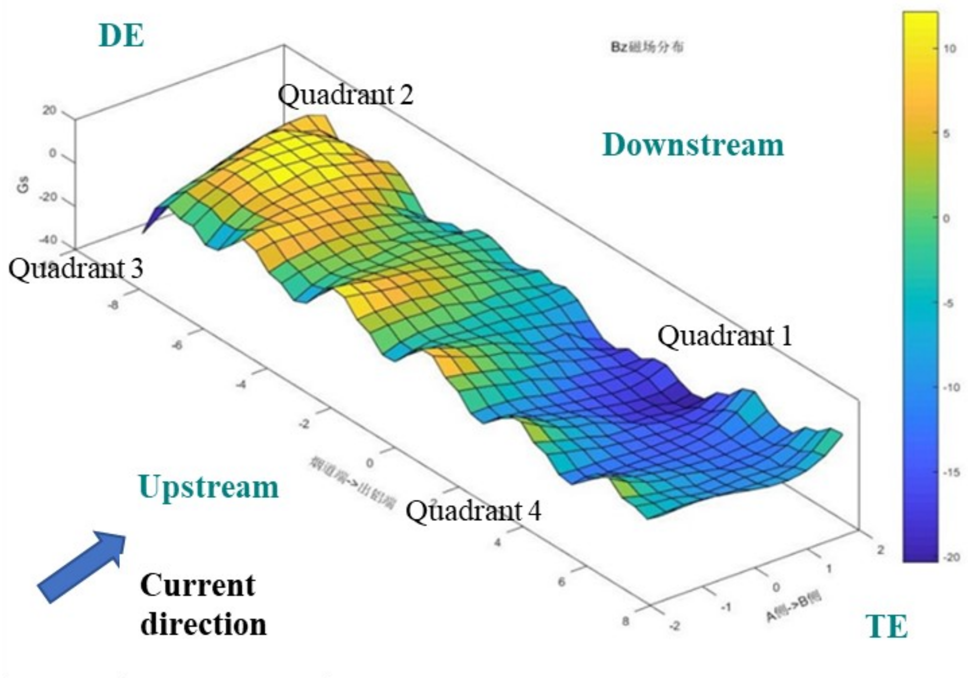


Figure 6. Bz distribution in the middle of the metal pad height of the original pot.

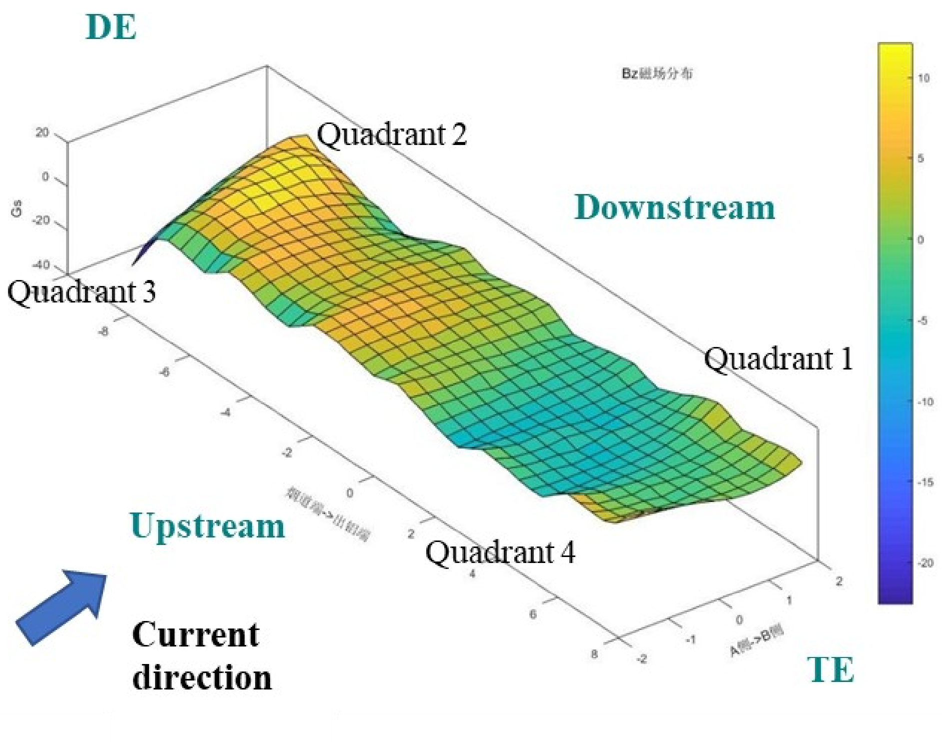


Figure 7. Distribution of B_z in the middle of the metal pad height of test Pot 3110.

5. Comparison of Calculated Electrical Balance

Figures 8 and 9 show the cathode current distribution of the original pot and the 5 test pots. The potline current is 375 kA at present, with 30 cathode blocks in each pot. From Figures 8 and 9, it can be seen that the cathode current distribution of the original pot and the test pot are both relatively uniform. There is a slight difference in cathode current among the cathode blocks, but the overall deviation is relatively small. Due to the special configuration of the test pot busbar, the current of the cathode blocks 15–22 on side A of the test pot is slightly lower, but the deviation of the current in each cathode collector bar is within 4 % of the average.

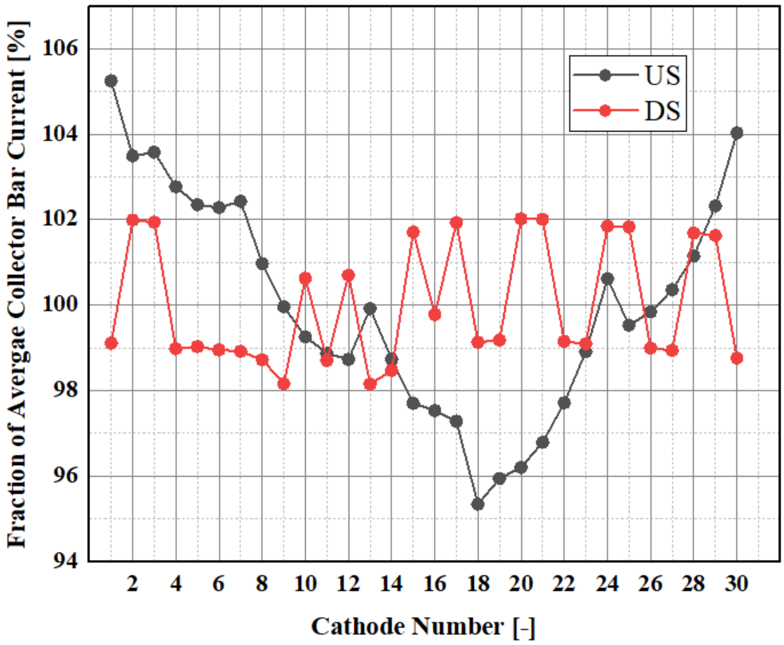


Figure 8. Collector bar current distribution diagram of the original reduction pot.

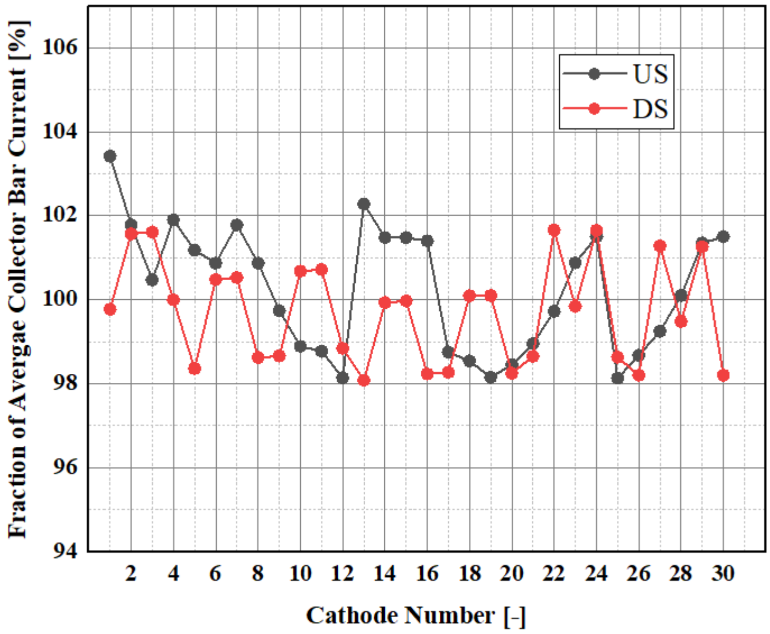


Figure 9. Collector bar current distribution diagram of the test pot.

6. Comparison of Calculated Metal and Bath Flow

The goal of upgrading the magnetic field of the pot is to achieve a flat interface between the bath and the metal pad, limit the velocities of the liquid metal within a certain range, and get high

MHD stability when the pot ACD reduces [8–9]. The calculated flow of the metal pad and the bath are shown in Figures 10-13.

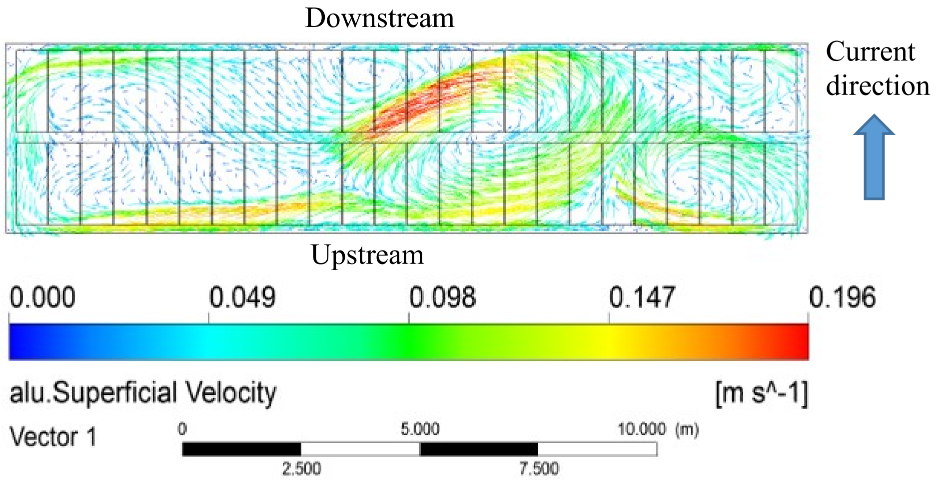


Figure 10. Velocity distribution of the metal pad before the upgrade.

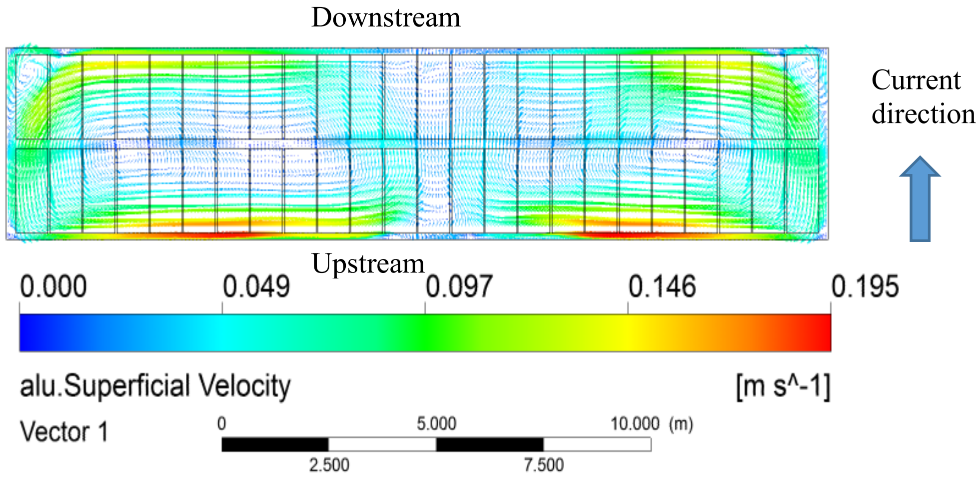


Figure 11. Velocity distribution of the metal pad of the test pot.

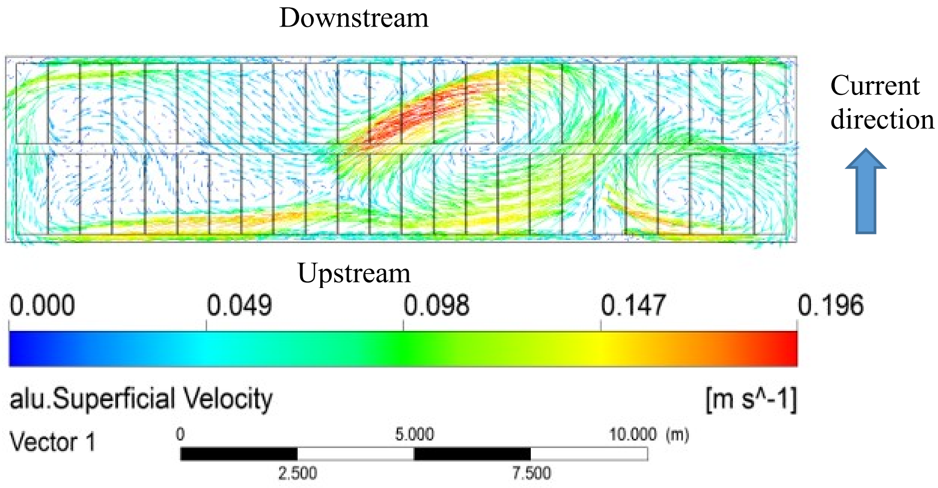


Figure 12. Velocity distribution of the bath before the upgrade.

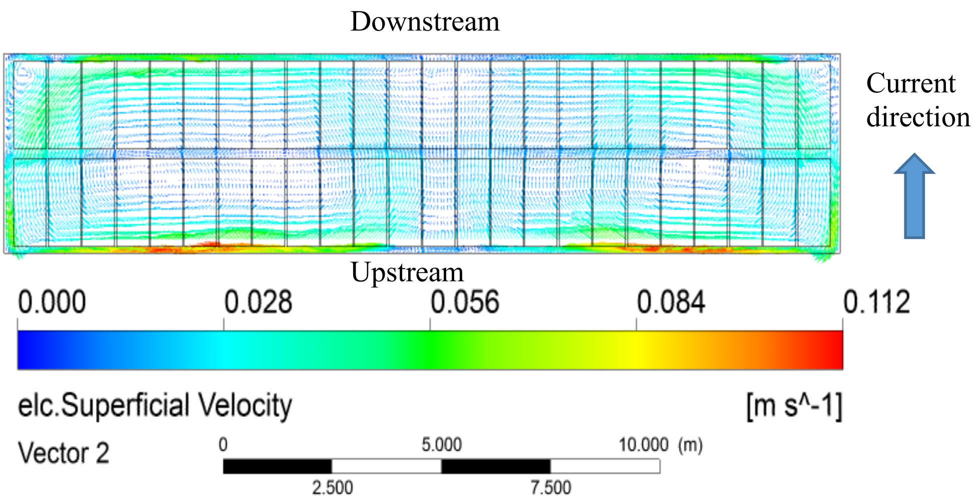


Figure 13. Velocity distribution of the bath after the upgrade.

Based on the above simulation results, Table 2 can be obtained.

Table 2. Comparison of flow velocity and interface deformation between the original design and test pot.

Busbar design	**Max metal velocity (cm/s)**	**Average metal velocity (cm/s)**	**Max bath velocity (cm/s)**	**Average bath velocity (cm/s)**	**Interface deformation under anode (cm)**
Original design	19.6	5.16	10.9	2.42	4.3
Upgrade design	19.5	5.01	11.2	2.50	3.6

The above flow field distribution diagram indicates that the flow fields of the metal pad and bath in both original pot and the test pots. In the original design, the metal and the bath flow on upstream side are faster, and excessive molten flow would cause side lining erosion, thereby affecting its service life. In the upgraded pot, the velocities below the anode projection are lower and the distribution is more uniform than in the original pot, which leads to better alumina dispersion and more uniform alumina concentration. The velocity patterns of the metal and bath are preferred because they are symmetric with respect to the transverse axis of the pot.

Based on the analysis of the provided data, it is evident that the new simulation and optimized design of the test pot busbar have had a notable impact on the MHD stability and interface deformation between the metal and bath. The key improvements observed are:

1) The maximum flow rate of the metal pad has decreased from 19.6 cm/s to 19.5 cm/s, indicating a slight but favorable reduction in metal movement. More effect is observed in circulation patterns which are symmetric with respect to transverse axis of the pot in upgraded design.
2) The maximum bath flow rate has increased from 10.9 cm/s to 11.2 cm/s, suggesting an improved circulation within the bath and better alumina dispersion.
3) The interface deformation below the anode projection has significantly decreased from 4.3 cm to 3.6 cm, indicating a flatter metal-bath interface.

Before the upgrade, the maximum flow rate of the metal pad was located under the anode projection. However, after the renovation, the metal and bath flows beneath the anode projection exhibit a basic double vortex with strong directional regularity. This enhanced flow pattern results in more stable operation of the pot.

The decrease in metal velocities of molten aluminum is expected to mitigate the erosion of the side wall of the pot lining, thus contributing to longer pot life. This improvement holds significant value for energy conservation, lower energy consumption, and smoother production operations.

7. Comparison of Production and Operation Parameters

Table 3 lists the main process technical parameters of the original pot and the 5 test pots.

Table 3. Main process key performance indicators (KPIs) of the 350 kA pots.

KPI	Unit	Original pots	Test pots
Pot Current	kA	375	375
Anode current density	A/cm^2	0.754	0.754
Average pot voltage	V	4.02	3.90
Current efficiency	%	93	94
DC power consumption	kWh/t Al	13 060	12 398
Metal height	cm	14~16	16~18
Bath height	cm	17~19	17~19
Anode cover thickness	cm	10	16
Electrolyte composition			
Al_2O_3	%	2.3	2.3
CaF_2	%	4.52	4.52
MgF_2	%	0.43	0.43
LiF	%	0.21	0.21
KF	%	0.69	0.69
Bath ratio	–	2.35	2.35

From the above table, it can be seen that by optimizing the busbars and combining the application of SBB technology and lining upgrade technology of the 5 test pots, the DC power consumption per tonne of aluminum in the test pot was reduced by 662 kWh/t Al. The average DC power consumption per tonne of aluminum in 5 test pots is 12 398 kWh/t Al, which is in a leading position in energy conservation in Chinese primary aluminum production.

8. Conclusions

Through the optimization of the pot-to-pot busbar design, combining the application of SBB technology and lining upgrade technology, the 5 test pots have shown better performance.

1) Compared to the original design, the test pots have significantly reduced B_z, with a more uniform gradient. Specifically, the z-direction magnetic field in the test pots has decreased by over 70 % in the 1st quadrant and more than 40 % in the 2nd and the 4th quadrants.
2) The electrical balance in both, the original and the test pots is relatively uniform, with the current in each collector within 4 % of the average.
3) The optimized busbar design of the test pots, has had a marked impact on MHD stability and metal-bath interface deformation. The flow rate of the metal pad has decreased and the circulation pattern are symmetric. The metal heave beneath the anode projection has significantly decreased from 4.3 cm to 3.6 cm.
4) After normal operation of five test pots, the average DC power consumption was recorded at 12 398 kWh/t Al, whereas the original design had an average DC power consumption of 13 060 kWh/t Al. This significant reduction in DC power consumption per tonne of aluminum in the test pots places them in an advanced class among Chinese aluminum potlines.

9. References

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