Development and Application of SAMI's Low Voltage Energy-Saving Technology

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Abstract

In this paper one low voltage energy-saving technology for aluminum reduction cell is developed by SAMI, this technology can largely reduce horizontal current in the metal pad and improve the MHD stability of the cell. Some industrial testing results of this technology by SAMI and its application on different type cells in Chinese smelter are finally presented to illustrate how their contributions is to make D.C. power consumption close to 12000 kWh/t-Al without current efficiency loss compare to the prior technology.

Introduction

China's aluminum industry, after nearly decades of booming development, has become the biggest one in the world's aluminum industry. Since 2008, the global financial crisis make a great impact on China's aluminum industry in our country, China has issued a number of energy conservation and emission reduction policy, the energy consumption index put forward definite requirement. Under this background, electrolytic aluminum industry in China accelerate the energy saving technology development, and several energy saving technologies with good energy saving effect have obtained, such as metal flow pattern (retarding flow) optimization energy-saving technology[2], abnormity cathode energy-saving technology, the new structure energy-saving pot technology and so on. These technologies have a common feature that some barrier blocks are placed on the surface or made on the cathode surface which will directly reduce the velocity and restrain the metal wave and improve the stability of the cell. The above technologies, while the effect of reducing energy consumption can reach, but for the production operation will produce certain negative effect, long-term stability of the time still need to be further tested.

In view of the above situation, the deep theoretical research and industrial experiments on the stability of the cell are made by shenyang aluminium & magnesium Engineering & Research institute Co., LTD (SAMI) which formed a new theory system [3] on energy-saving pot technology. Base on this theory system, SAMI obtains the low voltage energy-saving technology which sharply reduces the horizontal current in metal pad, optimizes electromagnetic force ($F = J \times B$) from the source, weakens the factors which causing the instability of pot, through using a new structure of cathode steel. So the stability of the pot is fundamentally improved, thus the polar distance can be further reduced. The pot after applying this technology can operate steadily with high efficiency at a lower pot voltage. In addition, there are no negative influences on the operation and the lifespan of the pot, because this technology keeps the same flate cathode surface as the traditional pot. This technology is applied on several SY200 (actual operation current 220 kA) pots to industrial experiment, the pots produce steadily with low pot voltage of 3.7~3.8V, and the current efficiency keeps the same as the whole potline, and the D.C. power consumption per ton is close to 12000 kWh.

Brief Introduction of Energy-saving Technology Principle

The total pot voltage is consisted of external voltage, anode voltage, bubble voltage, bath voltage, cathode voltage and back EMF and so on. As shown in figure 1.

As shown in figure 1, assuming a total pot voltage of 4.19V and an external loss of 0.15V, the voltage corresponding to the amount of heat lost from the pot is about 2.013V which is 51.4 percent of the total pot voltage. In the voltage of heat generation part, the bath voltage 1.334V account for 66 percent of it. Therefore, from the analysis on the energy consumption of the aluminum electrolysis process, the most important and effective way to reduce no functional energy consumption and improve the utilization ratio of energy is reduce the pot polar distance.

How to decrease the polar distance, reduce pot voltage, save energy consumption? It is well known that the stability of the pot is related to the interaction between the horizontal current and the magnetic field existence in the pot, which produces the electromagnetic force and promote the fluctuation of the liquid aluminum. It is very difficult to decrease the pot voltage without loss current efficiency if the stability of the pot is not further improved. Therefore, we should find the factors influence the stability of the pot and take effective measures to weaken or eliminate these factors to improve the stability of the pot fundamentally. This is the only way to reduce the ACD and improve the utilization rate of energy.

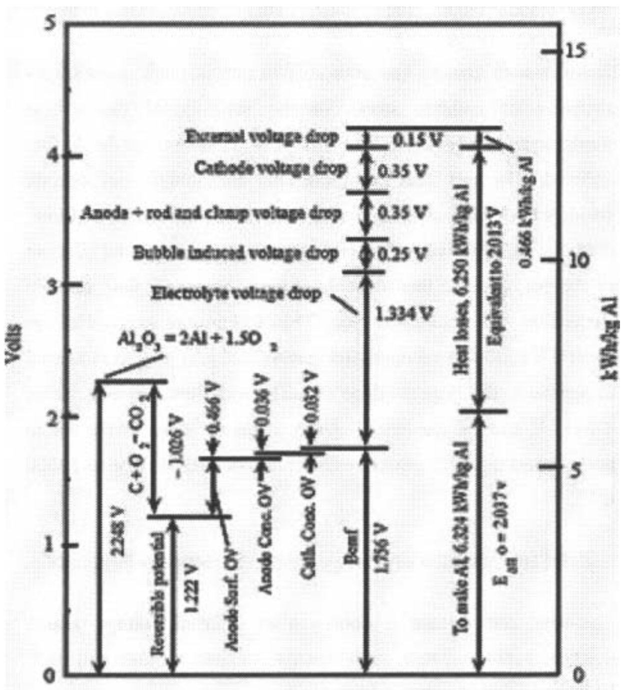

Figure 1: Pot voltage distribution

The horizontal current in the metal aluminum is an important part related to the electromagnetic force, which is one of the most key factors influencing the stability of the pot. The new structure collector bar introduced in this article exactly deals with this factor and effectively reduce the horizontal current in the metal pad, as result further improve the stability of the pot.

The Relationship Between MHD and Horizontal Current

Under the strong electromagnetic force, the metal aluminum and the molten bath will produce the warp, rotation and wave, this movement is objective existence. The movement in the pot can be reduced to two types as central vortex and metal pad roll. Some researchers think that the pot will have higher stability and production efficiency by slowing down the central vortex, this concept is proved correct through Metal Flow Pattern (Retarding Flow) Optimization Energy-Saving Technology, abnormity cathode energy-saving technology and the new structure energy-saving pot technology which widely used in China. Other scholars have found that besides the velocity, the more important factor affect the stability of the pot is the characteristics of the interface wave. M. Segatz and C. Droste put forward the interface wave equations [1]:

In molten metal and bath:

$$\left(\frac{\rho_a}{h_a}+\frac{\rho_b}{h_b}\right)\frac{\partial^2\zeta}{\partial t_2}-g\Delta\rho\nabla^2\zeta=\left(j_y\frac{\partial B_Z}{\partial x}-j_x\frac{\partial B_Z}{\partial y}\right) \quad (1)$$

On the boundary wall:

$$\left(\frac{\rho_a}{h_a}+\frac{\rho_b}{h_b}\right)\frac{\partial^2\xi}{\partial t^2}-g\Delta\rho\nabla^2\xi=B_Z\left(\vec{n}_y j_X-\vec{n}_x j_Y\right) \quad (2)$$

According to the above formulas, Segatz think that the reason cause the interface fluctuation in the molten metal and bath is the disturbance of the horizontal current j_x and j_y and vertical magnetic field gradient in horizontal direction. On the solid wall boundary, the reason is the disturbance of the horizontal current j_x and j_y and vertical magnetic field itself.

The said disturbance of horizontal current is related to the fluctuation of the metal and the bath which make the current density changing as the interface wave, as shown in figure 2. The changing current density can be equivalent to an additional disturbance of horizontal current j_a and j_c, as shown in figure 3.

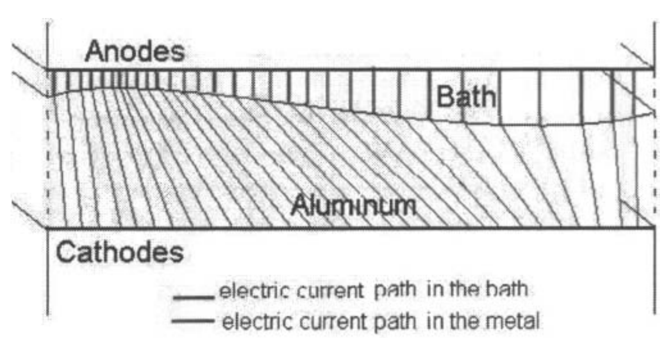

Figure 2: The relationship between fluctuation and current density

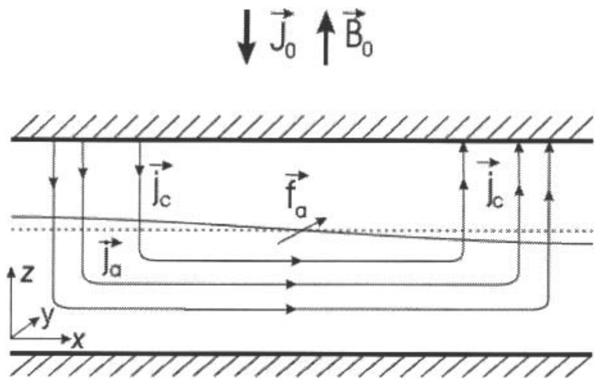

Figure 3: The relationship between fluctuation and disturbance horizontal current

From the figure 3, we can see that the existence and the magnitude of the disturbance of horizontal current is directly related to the horizontal current in the metal aluminum. If we can eliminate or minish the occurrence and the magnitude of the horizontal current in the metal aluminum, then the disturbance of the horizontal current will be disappear or reduced, the stability of the pot will be vastly improved.

Horizontal Current Reduce Technology

Base on the above basic theory and stability analysis, a horizontal current reducing technology and a new structure of cathode collector bar are come up with. This technology, through suitably adjust the size of collector bar and the height of cathode carbon, change the conductive structure of the collector bar, at the same time, optimize the assembly form of collector bar and the cathode carbon to adjust the resistance distribution of the cathode assembly which makes the current more vertically flow into the cathode carbon from the metal aluminum, reduces the horizontal current in the metal pad. The horizontal current optimization result by the new collector bar is shown in figure 4.

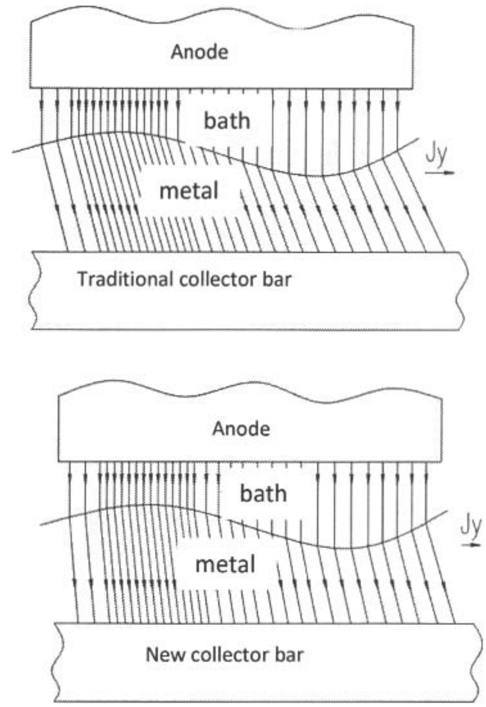

Figure 4: The optimization of horizontal current with the new collector bar

The stability of the pot is greatly improved and the horizontal current is reduced largely through applying this new collector bar.

Horizontal Current Simulation Analysis

In this paper, a SY200 pot is used to make the horizontal current analysis before and after applying the new collector bar. Base on the modeling result, a pilot pot was made and put in to the industrial experiment in Liancheng branch of Chalco.

The SY200 pot are designed by SAMI, the original current is 200kA, before the industrial experiment of the pilot pot the current of the pot increase to 220kA, the anodic current density reach to 0.794 A/cm^2, other most of the key technical parameters are listed in table 1. In the pilot pot, the collector bar height is changed from 180mm to 230mm, one slot is made at a certain position. The cathode carbon height is kept the same as the traditional pot, but the groove of the collector bar in the carbon is made deeper in order to suit for the height collector bar. According to the new collector structure, different types of paste are use to connect the collector bar to the cathode block, one type of paste is conductive material, and the other one is insulation material. Through simulation modeling, the horizontal current of the pilot pot is 30 percent reduced compare to the traditional pot. The detailed modeling results are shown and listed in figrure5 and table2 respectively.

Table 1: The key technical parameters of 220kA pot

Items	Units	Values
Current intensity	kA	220
Anodic current density	A/cm^2	0.794
Anode size	mm	1500×660×550
Anode assembly	Block (Single anode)	28
Cathode size	mm	3250×515×450
Cathode assembly	block	18
Cavity size in plane	mm	10600×3780
Side size	mm	300
End size	mm	420
Center channel	mm	180

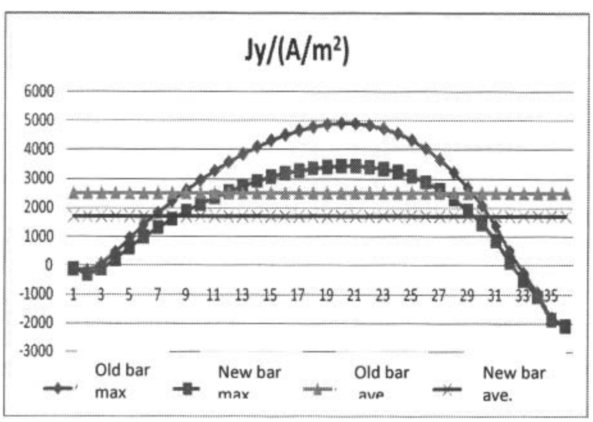

Figure 5: Modeling results of horizontal current

Table 2: Modeling results of horizontal current and cathode voltage drop

	Units	Traditional bar	New bar	Difference	Reduce %
Horizontal Current (max)	A/m^2	4895.6	3438.6	1457	30%
Horizontal current (ave.)	A/m^2	2516.27	1708.58	807.7	32%
CVD	mV	298	261	37	12%

The simulation results of horizontal current in table 2 are just related to the 220kA pilot pot. The horizontal current can be more greatly reduced through further optimize the collector bar, the maximum of the horizontal current can be reduced to below 1000 A/m2, the stability of the pot will be enormously increased.

Magnetic Field Simulation Analysis

In order to check the impact of the new technology on the magnetic field, the compared calculation of magnetic field on both the new pilot pot and the traditional one is made, there are nearly no difference on both the distribution and the magnitude in four quadrant of the pot. See the detail results in table 3.

Table 3: Distribution of the Bz component in four quadrant

	First quadrant Gs	Second quadrant Gs	Third quadrant GS	Fourth quadrant Gs	Max Gs
Traditional pot	7.885	7.725	4.396	4.127	−27.057
New pilot pot	7.886	7.737	4.394	4.127	−27.839

Flow Field Simulation Analysis

The steady-state flow simulation is made using the fluid calculation software ANSYS Fluent [4]. The results are shown in table 4.

We can see from the table 4, the velocities of both metal aluminum and liquid bath in the new pilot pot are basically same as the traditional one, there is just a 0.4cm difference on interface deformation.

Table 4: The results of steady-state flow simulation

	Velocity in metal /cm s^{-1}		Velocity in bath /cm s^{-1}		Interface deformation /cm
	Max.	Ave.	Max.	Ave.	—
Traditional pot	23.3	9.9	17.9	8.7	4.8
New pilot pot	24.0	10.1	18.1	8.8	4.4

Stability Test Experiment

The stability test experiment is made on the pilot pot. The experiment is made through the following process: decrease the pot voltage in 50mv every 15 minutes, in each step, carefully observe the noise, at the same time, measure the anode current distribution, until the noise reach a high level and the anode current distribution uneven. According to both noise signal and anode current distribution, judge the pot condition is still stable or not.

The same test experiment is carried on three times on the same pilot pot, we get almost the same result from the test, the lowest voltage that the pilot pot can produce in a stable condition is below 3.5V. The records on the controller of the three tests are shown in figure 6.

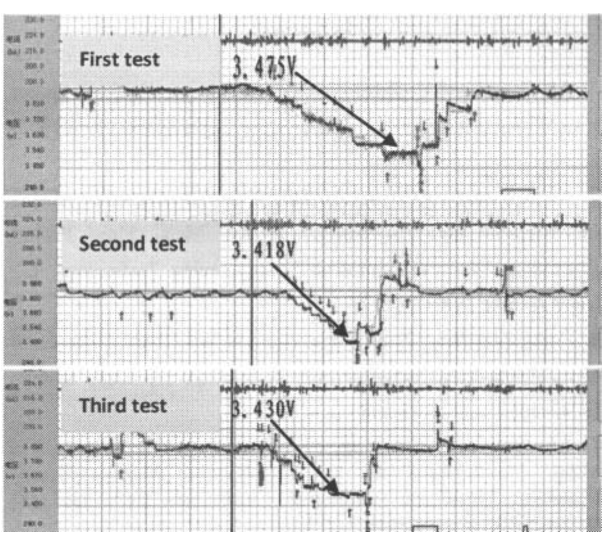

Figure 6: Stability test experiment on new pilot pot

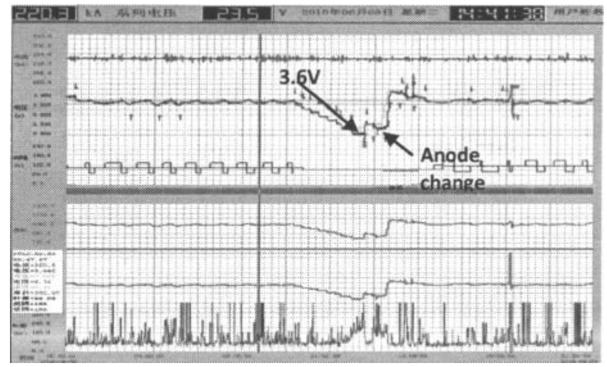

Figure 7: Stability test experiment on new pilot pot

In addition, in order to validate the stability of the new pilot pot under the operation condition, anode change test experiment is made at the pot voltage which is the lowest voltage obtained in the above experiment plus 100mv, that is 3.6V. the result is that the pot still is stable after anode change as shown in figure 7. The stability of the new pilot pot is fully proved by this test experiment.

Thermo-electric Balance Analysis

The thermo-electric balance design of the new pilot pot is made base on the stability test experiment, the pilot pot voltage is near 3.7V about 200mV above the lowest voltage obtained through stability test. The lining design of the pilot pot based on this voltage. The simulation results [5] of voltage distribution are listed in table 5, and the heat balance are listed in table 6.

Table 5: Pot voltage

Item	Units	Traditional pot	New pilot pot
Anode voltage	V	0.345	0.344
Emf	V	1.650	1.650
Bath voltage	V	1.567	1.150
Cathode voltage	V	0.300	0.308
External voltage	V	0.220	0.220
Pot voltage	V	4.082	3.672

Table 6: Heat balance

Items	Traditional pot	New pilot pot
Bath temperature (℃)	959.5	944.1
Superheat (℃)	9.5	8.1
Pot voltage (V)	4.082	3.672
Pot shell temperature max. (℃)	326.1	177.2
Ledge thickness (cm)	7.6	9.5

Industrial Test of Horizontal Current Reduce Technology

Shenyang aluminum and magnesium design institute Co., Ltd. and Liancheng Branch of CHALCO together complete the industrial experiment of the horizontal current restrain technology (new cathode collector bar). There are two pilot pots that have been put into operation since July 2010, up to now more than one year operation at low pot voltage without current efficiency loss. In this article, the earlier datum are used both the new pilot pots and the traditional ones. The comparison is shown from table 7 ~ table9.

Table 7: Technical indices

Pot	Set voltage (V)	Work voltage (V)	$V_{set} - V_{work}$ (mV)	AE (1/pot·d)	Noise (mV)	2010
Pot1	3.75	3.76	10	0.165	7.9	8-12
Pot2	3.75	3.764	14	0.04	7.9	
Pilot pot ave.	3.75	3.762	12.0	0.103	7.9	
Traditional pot	3.957	3.97	13	0.096	7.8	8-12

Table 8: Technical parameters

Pot	Bath level (cm)	Metal level (cm)	Bath temperature (℃)	Ledge (cm)	CVD (mV)	2010
Pot1	19.5	20.6	936	13.6	325	8-12
Pot2	19.5	19.8	941	11.9	330	
Pilot pot ave.	19.5	20.20	938.5	12.75	327.5	
Traditional pot	19.6	22.4	937	9.9	366	8-12

Table 9: Key technical and economic indices

Pot number	Average Voltage (mV)	C.E. (%)	D.C. Power Consumption (kWh/t)	2010
Pot1	3.770	93.78	11982	8-12
Pot2	3.771	93.37	12038	
Pilot pot ave.	3.771	93.575	12010	
Traditional pot	3.971	92.85	12748	8-12

During the August to December 2010, the 2 pilot pot get average voltage 3.771V which is 200mV less than the traditional ones, the current efficiency 93.575% which is 0.725% higher than the traditional ones, the D.C. power consumption to produce per ton primary aluminum 12010kWh which is 738kWh less than the traditional ones.

The energy saving technology has outstanding advantages of low investment, remarkable energy saving and implement simple, so it is quickly and widely applied in the aluminum smelters of China with Significant effect in energy saving, electrolytic cell capacity from 160kA to 500kA.

Acknowledgements

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