REDUCTION OF ANODE EFFECT DURATION IN 400KA PREBAKE CELLS

Wei Zhang[1], David Wong[1], Michel Gilbert[1], Yashuang Gao[1], Mark Dorreen[1], Mark Taylor[1]
Alton Tabereaux[2], Melinda Soffer[2], Xiaopu Sun[2]
Changping Hu[3]
Xueming Liang[4], Haitang Qin[4]
Jihong Mao[5], Xuehui Lin[5]
[1]Light Metals Research Centre, the University of Auckland, New Zealand
[2]Institute for Governance and Sustainable Development, US
[3]China Nonferrous Metals Industry Association
[4]Henan Zhongfu Industrial Co. Ltd, China
[5]Northeastern University Engineering& Research Institute, China

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Abstract

In order to improve energy efficiency and reduce green house gas emissions, the aluminum smelting industry has been continuously working on reducing both anode effect frequency (AEF) and duration (AED). However, there is still a long way to go to achieve zero anode effect (AE) on very high amperage, low specific power consumption cells due to the added complexity of the process. A new program to quickly terminate AEs has been developed by Light Metals Research Centre, the University of Auckland, in conjunction with the efforts of the Asia Pacific Partnership on Clean Development and Climate (APP) to facilitate investment in clean technologies and to accelerate the sharing of energy efficient best practices. A pilot project was initiated to test an automatic Anode Effect Termination (AET) program on 400kA cells in Zhongfu, China. This paper demonstrates the success of the new anode effect termination (AET) program in killing AEs on this cell technology without conflicting with normal cell operations. The resulting decrease in average anode effect duration (AED) is demonstrated.

Introduction

The primary aluminium production process has been identified as the largest anthropogenic source of two kinds of perfluorocarbon (PFC): tetrafluoromethane (CF_4) and hexafluoroethane (C_2F_6). PFCs comprise one category of major greenhouse gases with long atmospheric lifetimes and significant global warming potential (GWP). PFCs have an estimated atmospheric lifetime of 10,000-50,000 years, and an estimated Global Warming Potential (GWP) of 6,500 and 9,200 times that of carbon dioxide (CO_2) [1]. Human-made PFCs are very effective absorbers of infrared radiation, so that even small amounts of these gases contribute significantly to the radiative forcing of the climate system [2]. Therefore the aluminium smelting industry has been trying to reduce PFCs emissions [3, 4]. PFCs are generated during anode effects (AEs) in aluminium electrolysis process. Anode effects occur when the concentration of dissolved alumina in the molten bath reaches low values or anode current density is higher than the critical current density [5]. During an anode effect, an insulating layer of gas bubbles appears under the anodes, increasing pot voltage from 4-5V to more than 8V, up to 40-50V, which depend on the type and operating conditions of pots) [6].

In addition to causing environmental damage from the production of PFCs, AEs have other negative impacts. These are increased energy consumption, current efficiency loss, overheating the cell, stress to the cell lining from expansion and contraction, melting of the side ledge causing the electrolyte composition to change and increased anode consumption. Other negative impacts include increased hydrogen fluoride emissions, increased operator intervention, exposure of operators to safety risks during manual AE termination, bath spillages and floor damage. The primary aluminium industry is striving to decrease both the number and duration of anode effects [5]. Moreover, with the prospect of a future price on carbon, the emission of these greenhouse gases will impact production costs. It has been calculated that with a CO_2 tax of 15 US$ /ton CO_2, each anode effect minute per day per cell will increase production cost by about 1.2% [7].

The frequency and the duration of anode effects depend upon the technology of the cell, the operational procedures and also upon process control at each smelter. Hence, the amount of CF_4 and C_2F_6 may vary from one plant to the other, according to these parameters. Some types of pot allow more sophisticated interventions to minimize the consequences of an anode effect, such as computer process to control the feed and voltage [8].

Several strategies for AE quenching have been tested and implemented in aluminium smelters, such as pumping or quenching of the anode system, or lowering anodes until they are short-circuited by the metal [9]. Recently, a new AE quenching method has been proposed by Pablo Navarro et al. While a pot is in an anode effect a high proportion of electrical current is conducted from the sides rather than the bottom surfaces of the anodes. This is because the insulating gas layer considerably hinders the flow of current through their bottom surface. This produces an increase in the horizontal current densities and therefore the magnetohydrodynamic (MHD) instability in a pot during the AE. With Navarro's AET strategy, the anode beam is lowered to a particular ACD, at which the MHD instability of the pot is further increased, generating a self-sustained metal wave that short-circuits the anodes, resulting in removal of the insulating gas layer and ultimately termination of the AE. An intense bath circulation is also generated, redistributing alumina within the bath. The particular ACD required to do this is characteristic of each pot technology and depends upon the MHD design. Compared to the traditional AET strategy of physically immersing anodes in the metal pad to short circuit the anodes, this new approach is more energy efficient and faster in killing AEs [9-11].

The Institute for Governance and Sustainable Development (Washington, DC, USA) initiated a project to develop generic computer software for AE termination in China, which complemented the on-going work of the Asia Pacific Partnership Aluminum Task Force PFC Management Project. Support from this project provided the means for the development of a fast automatic anode effect termination (AET) program based upon the new AE fast kill strategy as discussed in [8]. The program is aimed at terminating AEs as fast as possible to reduce PFC emissions from aluminium smelters. The program has been implemented on 36 cells on the 400kA potline in Zhongfu Smelter, Henan province, China.

Before the AET project started in Zhongfu, AEs are killed manually. In order to determine the effectiveness of the AET program, baseline anode effect duration (AED) was compared with the AED of the test pots. The baseline AED, i.e. 28s, of the 400 kA potline was calculated using 36 pots' 3 months data from a normal operation period, i.e. excluding pot start up and amperage fluctuating period. As a result of implementing the AET program, the average AED has been reduced to 13s, achieving 53% reduction compared to the baseline AED.

Experimental

To develop and implement the new AET program, the project was conducted with five key stages.

Beam movement tests in the 1st stage of the project were used to determine the particular beam positions, at which MHD instability in the pot generates self-sustained metal waving to short-circuit the anodes. As a result, the gas film at the anode bottom surface during AE is removed and then the AE is terminated.

The experiments were carried out on different pots with different pot conditions to ensure the results were reliable. Beams of these pots were progressively lowered, up to 20mm from original beam position, to observe how pot stability changed with different beam positions. Pot stability can be measured by "pot noise", which is due to fluctuations in anode-cathode distance (ACD). Pot noise can be calculated as the difference between the maximum and minimum pot resistance reading within a specified period of time – this is called "*peak-to-peak noise*" or PPN [12]. In the beam movement tests, these specified periods of time are numbered for different beam positions as "stage 1, stage 2, etc." The noisiest stage was determined based on the PPN, and the corresponding beam position is the particular position which can generate MHD instability to kill AEs.

The pot noise indicator, PPN, was calculated with the following equation (1):

$$\text{PPN} = \text{Max (Pot resistance of Stage n)} - \text{Min (Pot resistance of Stage n)} \quad (n=1, 2, 3, 4) \tag{1}$$

The pot pseudo-resistance, R, was calculated with the following equation (2):

$$R\ (ohm) = \frac{Working\ voltage\ (V) - 1.65V}{Working\ current\ (A)} \tag{2}$$

Wherein working voltage is the cell voltage measured as pot to pot voltage on the bus work.

Some other factors were also taken into consideration during the beam movement tests. Firstly, there shouldn't be bath spillage during the beam movement. Secondly, the anode cover shouldn't collapse during the fast beam downward movement. Hence, during the tests the bath level change and anode cover condition were also observed.

The 2nd stage of the project was to program an AET module to activate the automatic beam movement for AE termination after AE is detected. In order to make sure that AE is not to reoccur, two key procedures in the program included: (1) After downward movement, the beam was held at the lowered position for 15 seconds before it goes up; and (2) Extra fast feed of 115 liters of alumina was programmed into the AET module to increase the alumina concentration in the bath after AE is detected. As the beam moves down, the bath stirring caused by the instability during short circuiting increases the transfer of alumina into the bath under the anodes. Moreover, when beam is dropped down and ACD reduces, bath gets displaced. When beam returns up and ACD increases again, this displaced bath comes back under the anodes, and can bring with it more alumina and help to quickly terminate AE. The anode current density is reduced as more anode surface area is submerged into the bath. All these factors contribute to quick AE termination. After AE termination is confirmed, the pot control system goes back to its normal control program.

The 3rd stage of the project was to test the newly programmed AET module. During the tests AEs were triggered for a number of pots by stopping the alumina feed to the test cells. The automatic beam movement and feeding behavior of the cells were observed after AEs started. AE durations were recorded accordingly. At this stage, an adjustment to beam upward movement was made to the AET module. Instead of moving back to its original position, the beam was returned up to a position 2~3 mm lower than its original position after AE termination. The reason is that there is some bath loss due to the downward movement of the beam. When the beam moves down, the bath level increases. When the beam goes up, the bath level decreases. However, during this process some of the bath will remain on the cell sidewall, carbon blocks and/or the bottom of the crust, resulting in the total volume of bath being reduced. To compensate for bath loss and maintain a relatively stable bath level, which is particularly important for low level bath pots, the beam's upward movement distance was adjusted to 2~3mm less than its downward movement distance. During the AET module testing, it was also observed that due to the difference in feeding hardware of different cells the extra fast feed did at times result in different feed intervals. However, all the AEs were successfully terminated with the AET module. The cell voltage stayed stable after AE termination.

After the success of AET module tests, the project proceeded to its 4th stage: a 7-week single pot trial. One test pot operated with the AET program integrated into its control system for 7 weeks. The purposes of the trial were: (1) to ensure that the AET module was functioning as programmed; and (2) the AET program did not conflict with the pot daily operations and other automatic control functions.

The 5th stage of the project was a 4-week 72 pots trial. The new control system including AET program was installed for 72 cells. The purpose of this trial is to further verify the reliability of the AET program. Within these 72 pots, 36 pots operated with the

AET module switched on, and the other 36 pots were operated with the AET module switched off, which means that when an AE occurs, manual kill will be carried out. The addition of the AET module switch is to give the process engineers an option to disable the AET module in case of any abnormalities on the cell.

Results and Discussions

(1) Beam movement test results

The beam movement tests first started at a normal pot. The PPN and beam position change is shown in Figure 1.

From Figure 1, it can be seen that the pot instability increased with the beam moving down. When the beam was dropped for 15-20mm, there was a sharp increase in PPN. Therefore, a similar beam downward movement was tested for other pots with other conditions, as listed in Table 1.

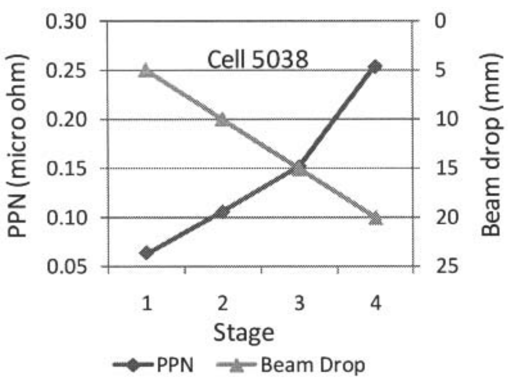

Figure 1. Pot instability change with beam position

Table 1 Conditions of test cells for beam movement tests

Cell Number	Cell Condition
5045	High bath level
5051	With carbon dust, skimmed before beam movement test
5056	High metal level
5059	Low metal level
5069	With carbon dust, not skimmed before beam movement test

Figure 2 shows the PPN change with different beam down distances. The beam downward movement distance of each test cell at different stages is shown in Table 2.

The test pots had highest PPN values at stage 3, as shown in Figure 2, indicating the cell had the highest instability at stage 3.

Table 2 Beam drop distances for tested cells at different stages

Cell Number	Beam Drop Distance (cm)			
	Stage 1	Stage 2	Stage 3	Stage 4
5045	0	5	20	0
5051	0	10	20	0
5056	0	12.5	17.5	0
5059	0	10	20	0
5069	0	10	20	0

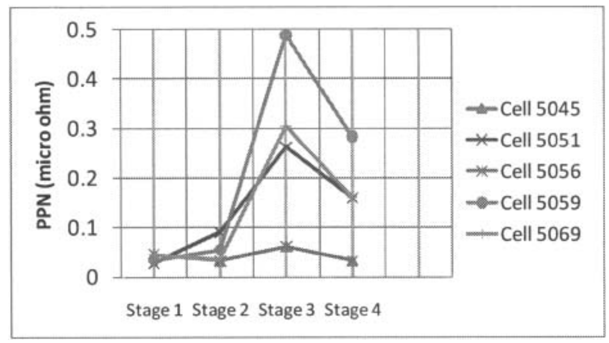

Figure 2. Noise change for different cells during beam movement test

From these tests, it was observed that 15-20mm of downward beam movement resulted in significant instability in most test pots during the beam movement tests. However, for termination of an AE, the anode beam should not need to move down to the same extent. The instability already present in the cell during an AE would likely mean that only 10-15mm beam movement would be required to generate the same level of metal waving to short-circuit the anodes and kill an AE.

During the beam movement tests, cells with different conditions responded similarly to beam down movements, i.e. no cover collapse, no bath spillage, with bath level returning to normal after the beam was returned to its original position. These results indicated that beam downward movements of up to 20mm could potentially be used to kill AE at Zhongfu smelter's 400kA prebake cells.

(2) AET module tests

An automatic AET module was programmed based on the beam movement tests, which activated downward beam movements of 10-15mm to kill an AE. Also extra 115 liters of alumina feed of was triggered by the module to restore alumina levels in the bath, terminating AE and also preventing AE from reoccurring.

Figure 3 is the screenshot of one AET module test on a pot before, during and after AE with the AET module functioning.

From Figure 3, it can be seen that when AE occurred, the beam automatically lowered to kill the AE and went back to a position reaching the set voltage of the cell. Meanwhile, feeding was activated. The test had an AED of only 5s and demonstrated that the AET module functioned as programmed.

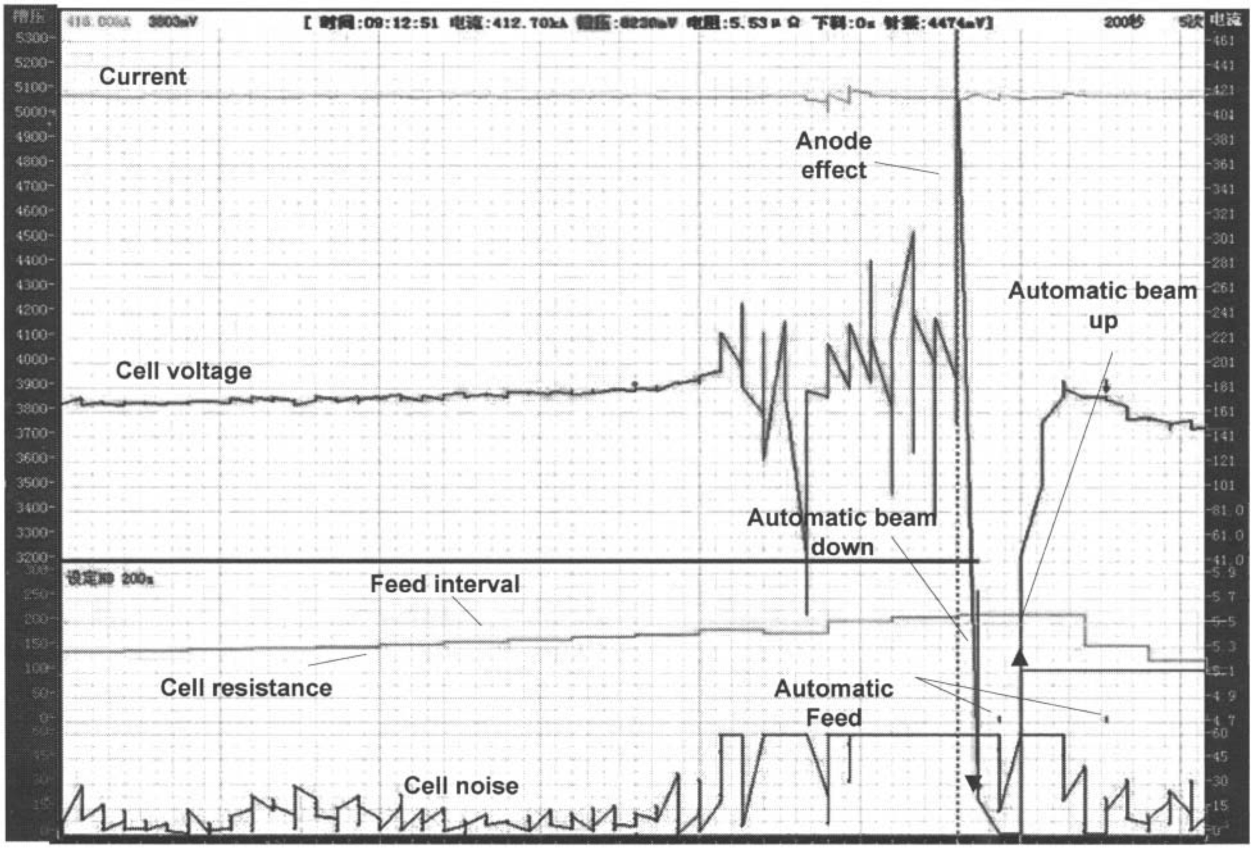

Figure 3 AET module functioning as programmed

Altogether seven AET module tests were carried out during the 2nd stage of the project. It was confirmed that the AET program was able to kill AEs quickly and safely. Results of the tests are listed in Table 3.

Table 3 AE durations (AEDs) during AET module testing

Test Number	1	2	3	4	5	6	7
AED (s)	25	13	19	35	9	5	32
Average AED (s)	20						

(3) Single pot 7-week trial

After stage 2 was finished, the AET module was integrated into the control system of one 400kA pot in Zhongfu. The single pot trial ran from July 6th, 2010 to August 19th, 2010. Nine AEs were recorded during this period. The average AED was 13s. No conflicts between the AET module and daily operations were observed during the trial period.

(4) Group pots trial

After the 7-week single pot trial, the AET module was integrated into the control system of 72 pots. For the 36 pots with the AET module enabled, AEs were successfully killed during the trial period with an average AED of 13s, a performance which matched the single pot 7-week trial. The average AED of the other 36 pots with the AET module disabled, i.e. AEs were killed manually, was 17s, 4s longer than those pots with the AET module enabled. No conflicts with daily operations were observed in the 4 weeks among the 72 pots. This again proved that the AET program can reduce the AED at the 400kA prebake cells. It was also observed that the average AEF of the test pots was not changed after implementing AET program compared to the baseline AEF.

Conclusions

A fast anode effect termination program has been developed and tested at 400kA prebake cells. After implementation of the new AET program, the average anode effect duration was reduced to 13s, achieving 53% reduction compared to baseline anode effect duration of 28s. The results reveal that the new anode effect termination program has a huge potential to reduce anode effect duration in Chinese aluminium smelters, which accounted for 13 million tonnes (MMt) of annual aluminum production during 2009 [13] and most of which still rely on "manual kill" to stop anode effects. Implementation of similar automatic AET programs at all Chinese manual kill smelters have the potential to reduce the annual PFCs emissions by about 4.6 MMt CO_2-eq. [13] and would contribute to overall improvements in energy efficiencies in the primary aluminum production process worldwide.

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