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EXPERIMENTS ON MEASUREMENT OF ONLINE ANODE CURRENTS AT ANODE BEAM IN ALUMINUM REDUCTION CELLS

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Abstract

The anode currents provide a wealth of information on the aluminum reduction cell, especially in sub-regions in the cell. The online signals are usually measured by voltage drops along anode rods and Hall voltage near anode rods. However, measurements by these methods require that contacts be attached to anode rods or use of costly Hall sensors. An experiment on measurement of online anode currents at anode beam was carried out on 400kA cells. The results are presented and preliminarily analyzed in the paper. The study of the anode current is of great importance for improving the pot control and operation.

Introduction

For more than 50 years, the use of automatic process control in aluminum reduction cells has been the standard configuration in modern production lines. With the utilization of the curve relationship between cell resistance, ACD (anode-cathode distance) and alumina content in electrolyte, the resistance based pot control has gained great success as it improves manual operations and economic efficiency. However, the process has become more difficult to handle recently, as cells become larger and modern operational needs increase sophisticatedly, such as rigorous restriction on PFCs (perfluorocarbons) emissions. There are increasing difficulties in the effective control of the reduction process. To improve the process, the controller should firstly be provided with detailed enough information about the operation parameters of the reduction cell.

Anodes in industrial cells are connected in parallel to share the fixed line current. As cell voltages at all anodes are almost the same, the resistance of each anode can be obtained through the measurement of the current flowing through. Thus, the anode current contains information on most local status of the cell. Briefly, anode current varies along with localized electrochemical reactions, ACDs, and electrolyte conditions such as alumina contents and bath temperature. For example, Barber investigated the intermittent frequency response of anode currents under various cell conditions [1]. Bearne and co-workers examined the anode current variation with slots on anode [2]. A similar study has also been conducted by Cheung et al recently [3]. These studies suggested that the anode current signal changes in both time and frequency domain that gives a new logic to characterise local cell conditions and provides a new monitor in industrial cells.

With its apparent benefit of providing spatial information for cell monitoring, measurement of online anode currents has been improving. A traditional and most widely used method to determine anode current is to measure the so-called "isometric voltage drop" which is a voltage drop across a defined short length of the anode rod [4-6]. And some researchers raised the idea of using magnetic loop to measure current distribution in electrochemical cells such as fuel cell, based on the principle of Hall Effect [7-13]. Considering the unavoidable drawbacks of measuring "equal-distant voltage-drop" from the rod and the magnetic field produced by the current in the rod, Keniry and Shaidulin [14] suggested a new approach, measuring points that are at the anode beam

In this article, the existing methods of online anode current measurement are firstly reviewed, mainly including measuring from anode rod and determining magnetic field values near the rod. After that, a new measuring method is proposed. At last, the preliminary test results in 400kA cells are provided.

Improvement of the Measurements from Anode Beam

Measuring principle

In order to make more convenient and economic monitoring of continuous anode current distribution, a new approach based on measuring electric potential drops at the beams is presented in the article, inspired by Keniry and Shaidulin [14]. The principle of the approach is to measure the "isometric voltage drop" at the beam, a combination concept derived from measuring at the rod and at the beam.

To obtain the current into the rod, currents that pass the beam at the left and the right of the rod should be calculated first, as of the I_{BL} and I_{BR} shown in Fig.1. Therefore, the electric potential drops in a specific length of the beam are acquired at the same time in the approach. Then, currents in the beam are calculated by the Ohms' law and the rod current is obtained according to Kirchhoff's law. I_{BL} and I_{BR} are calculated by measuring the "isometric voltage drop" U_{BL} and U_{BR}:

$$I_{BL} = \frac{U_{BL}}{R_{BL}} \tag{1}$$

$$I_{BR} = \frac{U_{BR}}{R_{BR}} \tag{2}$$

where R_{BL} is the resistance of the measured section of the beam. The rod current then can be calculated by equation 3:

$$I_{Rod} = I_{BR} + I_{BL} \tag{3}$$

Most of the points can be used for calculating two adjacent rods current, except for those in the end of the beam. U_{BL} and U_{BR} are sampled at the same time to ensure that components of the rod current are at the same phase position in case that frequency range of the noise is asynchronous in the calculation.

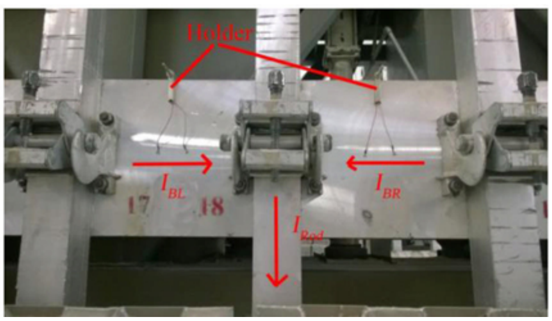

Fig. 1 Installation of the proposed system to measure anode current

System Installation

The system was installed and tested in a 400kA cell, which has 48 anodes. Anodes are defined as A1 to A24 and B1 to B24 from tap end to duct end in upstream side and downstream side respectively. According to numerical simulation, the measuring points are basically placed in the center between rods, and the installation of the system is also shown in Fig.1. Wires are riveted to the beam and protected by a special holder in case of damage during maintenance of the superstructure. The wire used in the study is able to tolerate temperature up to 150℃. The system was tested from October 10th 2013, with the sampling rate of 1Hz, to May 19th 2014. It operated quite steadily even though it experienced a series of disturbance such as cell baking, start-up and daily operations, for example metal tapping and anode setting. A collection unit with a browser was developed to transmit and display all anode currents on a monitor for convenient observation of the current distribution.

Results and discussion

Typical Current Distribution

The anode current distribution has great influence on local anode efficiency as well as cell stability [15]. The determination of individual anode current is the basic data source for further analysis and characterization of cell behaviors. An example of typical steady state of the current distribution in No.5204 cell derived from the system is shown in Fig.2.

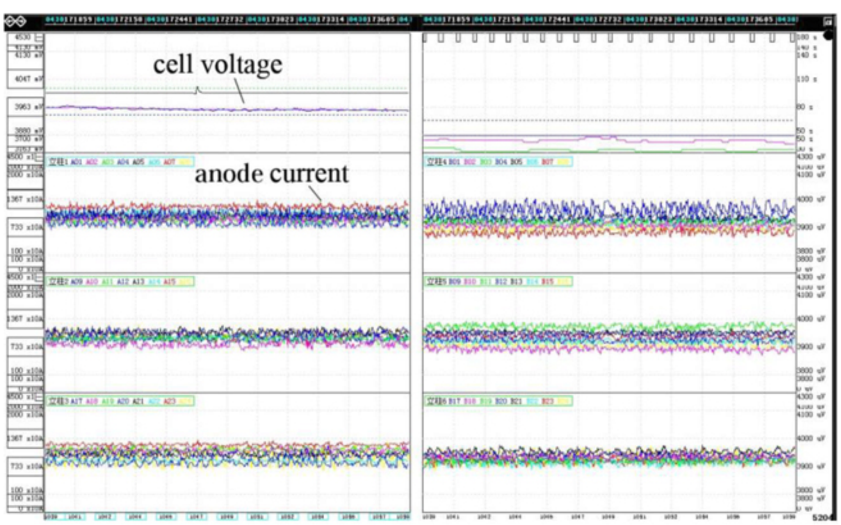

Fig. 2 Anode current distribution in normal condition

As can be seen from Fig.2, all anode currents are slightly fluctuating in the monitoring time period of 20 minutes. The current entering in all rods gets close to each other and are near the expected level, which is the designed average value of 8.35 kA for every individual anode. At the same time, the cell voltage also keeps a steady state since all anodes are in appropriate working state. The anode current measurement can help achieve uniform anode current distribution, which contributes to a high current efficiency of the process.

Anode changing

In general, the most severe disturbance to the anode current in aluminum reduction cell is anode replacement. A newly mounted anode would attract barely any current because a layer of frozen bath is covered in the bottom as the temperature of new anodes is much lower than that of the bath, which is almost 950 ℃ in typical industrial cells [16]. Once heated to the electrolysis temperature gradually, the new anodes start to draw current with the melting of the frozen layer. After 24 hours more or less, it gets to the regular level of current-carrying. An example of current redistribution of an anode changing and current pick-up of new anodes in No.5206 cell is shown in Fig.3, the current curve showed in the figure is filtered using a median filter algorithm.

After the anode changing operation, current into the new anodes B13, B14 reduced to near zero, as shown in part.2 in Fig.3. Since the system didn't count the effect of beam temperature, it seems that B13, B14 still attracted some current. At the same time, the current was transferred to the opposite anodes, shown in current increasing of A13, A14 and A15. The part.1 demonstrated the current climbing in 6 hours of last set anode A5, A6 in the day before.

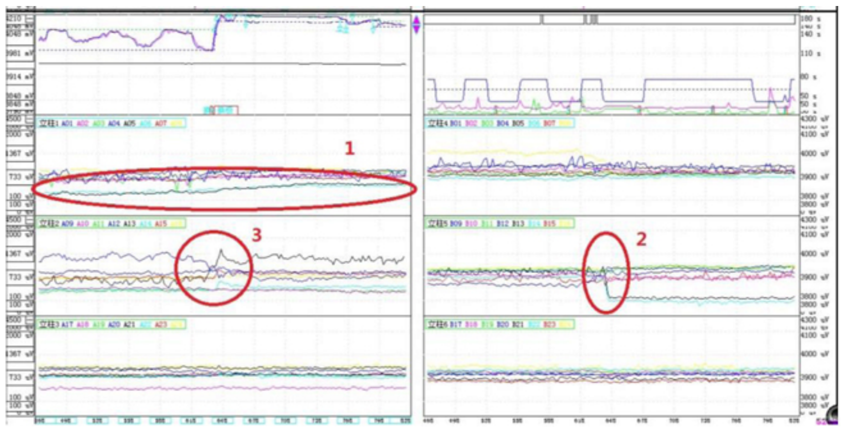

Fig. 3 Anode current redistribution after anode change

Anode Effect

As many studies suggested, the onset of an AE usually starts at one or several anodes starved of alumina, then spreads to other areas with the pot voltage quickly rising to more than 8V. The low alumina content not only leads to low conductivity in the local bath, but also makes it difficult for bubbles to escape. As a result, current into an anode approaching an AE would diminish and sharply cut down prior to AE. A current redistribution prior to an AE in No.5206 cell is shown in Fig.4.

Fig. 4 Anode current change prior to an AE

As can be seen from Fig.4, currents into anodes B23, B24 show a clear downward trend 3 hours prior to the AE, similar to the data acquired by Evans et al [9]. This allows early detection and inhibition of an approaching AE, moreover, it helps to adjust the feeding strategies for the cell, especially for additional feedings only to the nearest feeder while keeping others unchanged. It is beneficial to reduce the occurrence of AE as it consumes extra energy and adds interference to the reduction, as well as generate PFCs.

Pot Instabilities

Driven by Magneto-Hydrodynamics (MHD), the fluctuation of bath-metal interface creates a dynamic ACD for each anode. Thus the current changes periodically in each anode. Amplitude of the current varies with MHD factors such as magnitude of ACD, bath electrical resistivity, stirring intensity and metal depth. The dynamic ACD is as a matter of the interface moving which can be characterized by the anode current distribution. Fig.5 and Fig.6 provided two examples of MHD instabilities that occurred in local and whole cell.

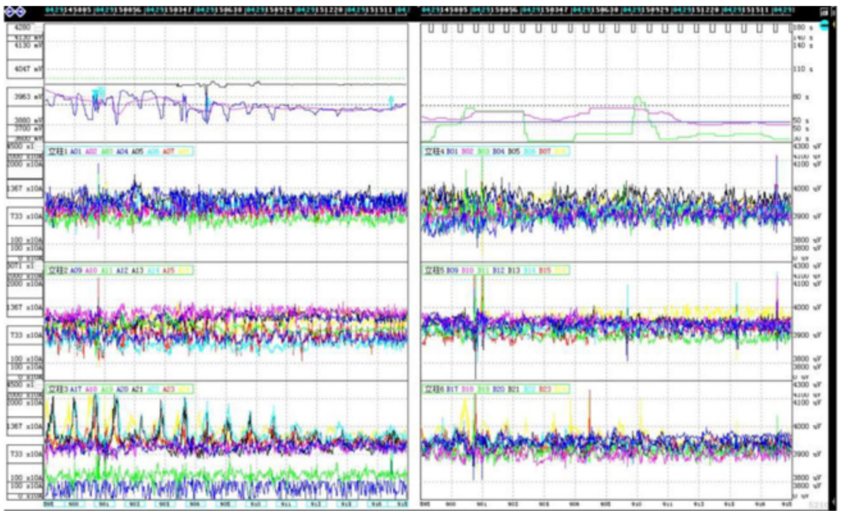

Fig.5 Local instabilities characterized by local anode current fluctuation

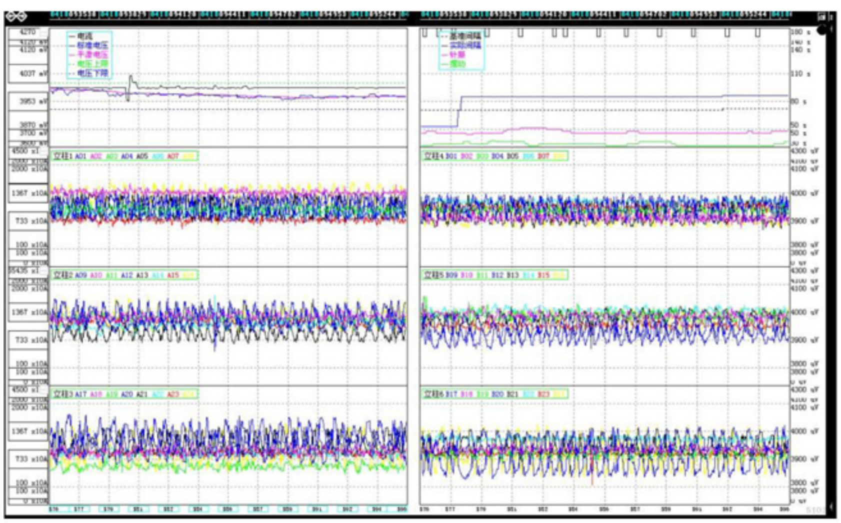

Fig.6 Anode current fluctuation of metal instabilities in whole cell

As can be seen in Fig.5, currents into anodes A21to A24 that near the sixth riser of No.5210 cell fluctuates with a period of 65 to75s, each anode has a phase difference of 1 to 5s. The maximum current value can be up to 20kA. Then, the current fluctuation gradually reduces to normal state. At the same time, the pot voltage shows similar behavior with the local anode currents fluctuating, and can be positioned near the sixth riser where there is an unstable bath-metal interface.

Fig.5 shows an example of anode currents fluctuation that demonstrates a slight metal instability in the whole cell No.5102. While the pot voltage is fairly stable to keep the pot resistance constant, the anode currents show the unstable bath-metal interface at that time. As bath-metal interface fluctuation could have negative effects on CE, the currents state showed in Fig.6 is unfavorable to the process. Intervention should be carried out to improve the interface stability, lift the anode beam for instance. Thus, control actions need to be conducted to increase the anode plane to re-establish the interface stability.

Conclusions

The utilization of individual anode current signals as an additional information for the aluminum reduction process control and operation has been widely recognized as a promising approach. Online acquisition and processing of anode current signals are becoming increasingly important as the cells become larger. However, the online measurement of individual anode current can only be put into practice when low-cost and high capacity sensor is available for the process. And further analysis of the signals relies on the accuracy and stability of the sampling system which makes the sensor a key factor for the successful application.

In this article, an improved measuring approach is then proposed inspired by measuring from both anode rod and from anode beam. The industrial test was carried out on several 400kA cells with each has 48 anodes that confirms the stability and accuracy of the system. In addition, the test results show that the system has the capabilities of characterizing the reduction process behaviors, making it promising for improving the pot control and operation.

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