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Wireless and Non-Contacting Measurement of Individual Anode Currents in Hall-Héroult Pots; Experience and Benefits

James W. Evans[1,2] and Nobuo Urata[1,3]

[1]Wireless Industrial Technologies
4096 Piedmont Ave #103,Oakland, CA 94611, USA

[2]Dept of Materials Science and Engineering
University of CA, Berkeley, CA

[3]Alumilab, Sunnyvale, CA

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Abstract

Continuous measurement of individual anode currents in Hall-Héroult cells is now becoming practical. It has the advantage of early warning of anode effects and possibly improvements in current efficiency and operation (e.g. warning of anode burn-off). The paper describes the approach of Wireless Industrial Technologies which entails a "master-slave" arrangement with a slave measuring the magnetic field produced by the current in each anode rod each second and the masters wirelessly communicating the data to a computer. With this system there is no direct contact with the anode rods and thereby no interference with normal pot operations such as when changing anodes. Such a system has been under test at a smelter in the USA since December, 2010. A second smelter will be conducting tests of the system by the time of the Orlando conference. Experience with this system is described and projections made concerning potential economic benefit.

Introduction

Wireless Industrial Technologies (WIT) is embarked on a development effort aimed at improved reduced energy consumption and carbon footprint in heavy industry, particularly the aluminum industry. Present focus is on determining the currents of individual anodes of Hall-Héroult cells as these show early warning of anode effects and could be key to improvements in current efficiency and other process improvements. Of course individual anode currents are routinely measured by the industry today but this is usually a contacting and intermittent measurement done by probe that determines voltage drops along anode rods. The present paper describes work on a non-contacting and "continuous" measurement of currents in individual anode rods. The principle is to measure the magnetic fields generated by currents in the anode rods and, from these, determine rod currents. Early work on such measurements was reported on by Steingart and colleagues[1]. These investigators placed devices containing Hall effect sensors, coupled to wireless transceivers, close to anode rods and on the top of the skirt of pots at two smelters in the US. Measurements were conducted for only a few days but showed that the devices could pick up variation in anode currents. Most notably the devices were able to detect a shift in the distribution of anode currents well before the AE was signaled by a rise in cell voltage. This shifting of currents (one or a few anodes shedding current while others pick it up) has been extensively studied by Tarcy and Taberaux[2] who examined anode currents for a cell equipped with pair-controlled anodes. Such cells lend themselves well to continuous anode current measurement because the voltage drop across the flex connecting anodes to the anode bus can be readily accessed; conventional cells, where the anodes are connected directly to the bus do not provide that opportunity. The current shifting is probably a consequence of uneven alumina depletion within the bath. Thus some anodes reach anode effect before others and current shifts from the former anodes to the rest without significant increase in cell voltage. Later the rest of the anodes see low alumina and all anodes are affected, raising the cell voltage. Consequently, tracking the current distribution among the anodes provides early warnings of AE that could allow AEs to be circumvented or reduced in duration. Tarcy and Taberaux report a range of such early warnings from zero (no early warning) to a few minutes and that range is consistent with the present investigation. The present investigation is aimed at conventional cells with no flex between anode bus and anode rod. This paper discusses the technique used for anode current measurement and presents results showing representative early warning of AE. We then proceed to examine the possibility of improving CE by making use of individual anode current measurements.

Methodology

Steigart et al. placed an individual wireless transceiver ("mote") at each anode rod but this is probably too expensive an approach to be used for a whole smelter. In the present work we have used a "master and slaves" approach where only two motes are used per pot. On each side of the cell a "daisy chain" of slaves are connected by a single cable to a master at the end of the pot. The masters contain motes that wirelessly report data to a computer connected to the internet for onward transmission of data. Fig. 1 depicts a slave in the final stages of assembly. A stainless steel "enclosure" contains the slave board and is designed for attachment to the anode bus with three screws. The two BNC connectors for connection of the slave into the daisy chain are seen at the back of the device. Mounted on the slave boards are Hall effect sensors that measure the magnetic field at several positions on the board.

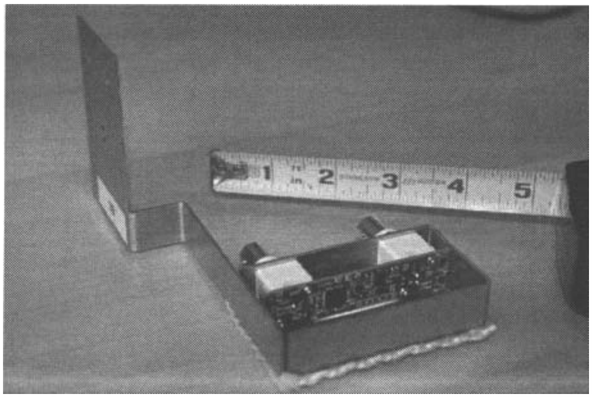

Fig. 1. A "slave" in the final stages of assembly. Scale is in inches.

Fig. 2 shows slaves mounted on one of the cells used in this investigation. The slaves lie just below the anode bus and behind the anode rod where they are protected during, for example, cell cover replacement. Also visible in this photograph are the (insulated) co-axial cables connecting one slave to its neighbors.

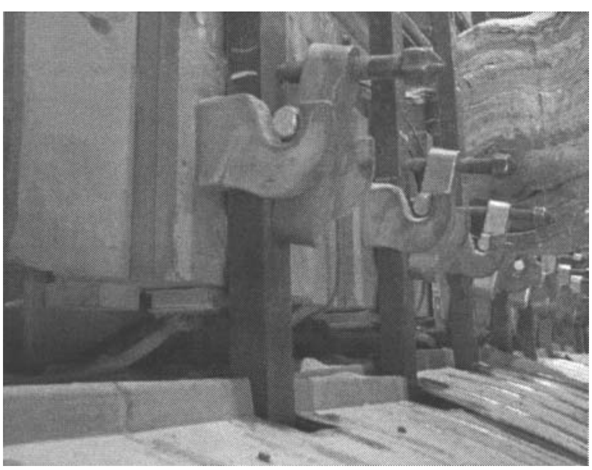

Fig. 2. Slaves mounted beneath the anode bus of the cell where the test work was done.

Fig. 3 is a photograph of a master under test at WIT. One cable runs to a daisy chain of slaves the other to a DC power supply. When installed on the cell the power for the master and slaves comes via a connection to the cell voltmeter. Thereby there is no need to use batteries, which would have to be replaced, to power the electronics (although masters contain back-up batteries so that they do not power down during any cell power failure) and there is the additional advantage that the masters track and report the cell voltage along with the field data from the slaves. Additional data relayed by the masters to the computer are the temperatures of all the slaves and the masters. All data are reported every second.

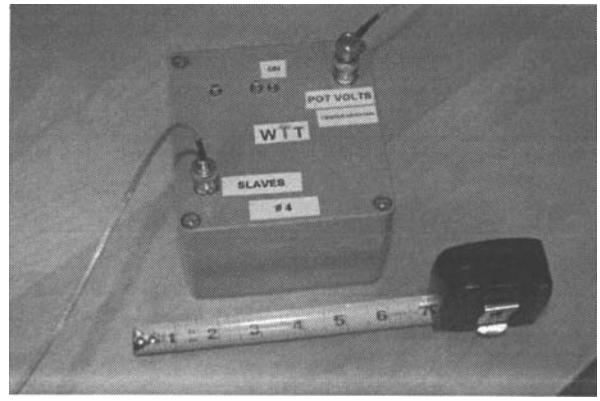

Fig. 3. A master under test at WIT before being sent to the smelter for attachment to the end of the cell.

A complication in the determination of current by measurement of magnetic field is the occurrence of additional magnetic field contributions from nearby currents. Thus, in determining the current in anode rod six, say, it is necessary to take care of field contributions from currents in rods five and seven etc. This is first achieved in the WIT system by use of multiple sensors on each slave board. The authors have described how this is achieved in a previous Light Metals paper[3].

Results from test installations

A one week preliminary installation was carried out at a US smelter in August of 2010 and served to show that measurement of individual anode currents by the WIT system was practicable. In particular an AE occurring during that week was detected by the changing of the fields (reflecting shifting of the current). A most encouraging result was that the shift was visible over one minute before the plant computer recognized an AE from the usual increase in cell volts.

There followed a longer duration test with a WIT system installed in mid-December of 2010. That system reported data every second from then to mid-April when the cell tapped out. A third test began with installation on another pot at the same smelter in May, 2011 and that system continues to report data at the time of writing (approximately four months after installation). Problems have been minor; the only difficulties have been mechanical damage to one slave (replaced easily by a smelter engineer) and a propensity for the laptop to shut down (corrected by replacing the laptop). Over the course of data acquisition since December many AEs have been spotted in the data reported by the system. Fig. 4 is a recent example. It is seen that, as usual, the currents start to shift among the anodes about a minute before the cell voltage rises to a point signaling an AE. In an analysis of the data for the first three months of 2011for the cell under test, there were 20 AEs and early warning of their occurrence showed in the current data for 17 of those effects. These data and the corresponding results reported by Tarcy and Taberaux, provide evidence that AEs might be avoided by continuous monitoring of individual anode currents.

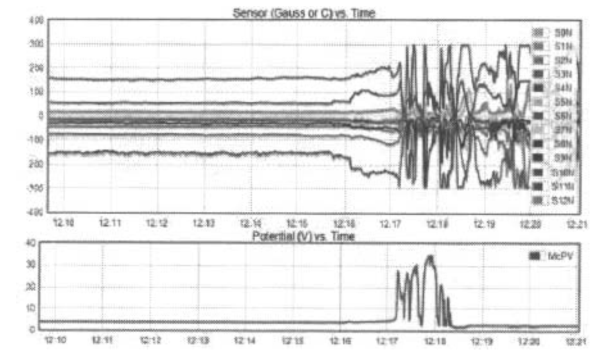

Fig. 4. Representative traces of selected anode currents (represented by magnetic field) and cell voltage before and during an anode effect. Time axis is in hours and minutes. Data gathered by WIT's system on Sept. 4, 2011.

There are now markets where reductions in GHG emissions can be traded and there is prospect of a substantial carbon tax in Australia. However, in North America there is presently no direct value in reducing GHG emissions through curtailing AEs. Consequently the question arises as to whether tracking individual anode currents can have other economic impact. Data suggest that this is the case. Fig. 5 is a plot kindly provided by Gary Tarcy of Alcoa showing the results of his CE measurements (by the silver dilution method) at the smelter where the WIT measurements were carried out (but in a different year)[4]. Tarcy's results plot the effect on CE when the current distribution among anodes becomes uneven. In this case unevenness is represented by the maximum anode current although other metrics, such as the standard deviation, are possible. The vertical blue bar is the point where all currents are the same. Tarcy's data show that CE declines as the current distribution becomes more uneven. Taking Tarc's correlating line from this figure we have calculated the loss in CE (from the supposed 95.4% of perfectly balanced currents) using our WIT's current measurements for four weeks in February, 2011. The results appear in Fig. 6 where the pink line is the case of even currents.

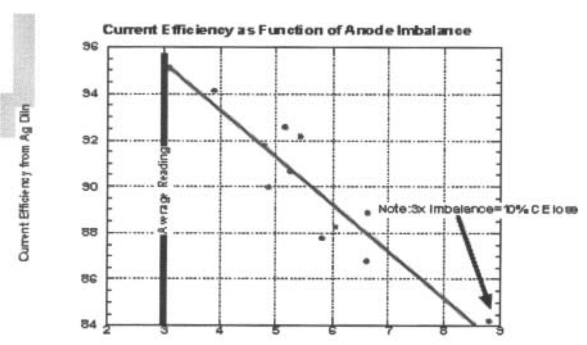

Fig. 5. Tarcy's experimental data on the effect on current efficiency of uneven currents among the anodes.

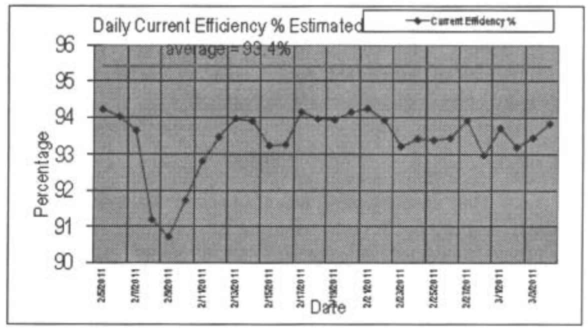

Fig. 6. Current efficiency of the cell under test calculated from Tarcy's experimental correlation and WIT's measurements of anode currents for a period of four weeks in early 2011.

It is clear from Fig. 6 that a substantial price is paid if anode currents are uneven; that price, extrapolating to a whole smelter, would be in the range of a few million dollars per year. Two issues appear when further contemplating this potential economic benefit. Does the benefit of adjusting individual anodes to balance the currents outweigh the potential benefits? Would the anodes "self adjust" anyway as the anodes carrying higher current are consumed more rapidly? The former question has been examined by the authors previously[5] to show that in many instances there is economic benefit to individual anode adjustment. The second question can be answered by tracking the currents in the WIT data. As seen in Fig. 7 the return of an abnormally high anode current to its normal value can be as long as a few days.

Fig. 7 Record of an anode current over a period of approximately 100 hours showing slow return of current to normal.

Concluding Remarks

There is now a lot of data, from both Alcoa and WIT, showing that measurement of individual anode currents provides early warnings of anode effects. These measurements can be carried out continuously, and without contacting the anode rod, using the master-slave arrangement described in this paper. Results in this paper also suggest that measurement of individual anode currents provides an opportunity for CE improvement if individual anodes are adjusted. Other results (not shown here) track the pick-up of anode current following an anode change) and suggest that measurement of individual anode currents could help reduce operational problems such as anode burn-off.

Acknowledgement

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[4] G. Tarcy, Alcoa, unpublished work.

[5] J. W. Evans and N. Urata, Technical and Operational Benefits of Individual Anode Current Monitoring, Proceedings of the 10th Australasian Aluminium Smelting Conference, Launceston, Australia, Oct., 2011