TECHNICAL AND OPERATIONAL BENEFITS OF INDIVIDUAL ANODE CURRENT MONITORING

James W. Evans*† and Nobuo Urata†

*Professor Emeritus, University of California,

Dept. of Materials Science and Engineering, Berkeley, California, 94720, USA

†Wireless Industrial Technologies Inc, 4096 Piedmont Ave #193, Oakland, CA 94611, USA

Abstract

Continuous measurement of individual anode currents in Hall-Héroult cells is now becoming practical. The paper describes WIT's approach of a "master-slave" arrangement with a slave measuring the magnetic field produced by the current in each anode rod and the masters wirelessly communicating the data to a computer. With this system there is no direct contact with the anode rods. Such a system has been under test at a smelter in the USA since December, 2010 with funding mostly from the US Dept. of Energy. Experiences with this system are described. Individual anode current measurement appears to offer significant benefits such as early detection of anode effects and revealing anode current imbalances that can impact current efficiency.

Keywords: anode currents, anode effects, current efficiency, wireless.

Introduction

The measurement of the currents of individual anodes within the Hall-Héroult cell has been standard practice within the industry for many years; it is well known as a contributor to the diagnosis of pot problems. Those measurements have usually been done by measuring the millivoltage drop along a known length of the anode rod. Such measurements are intermittent due largely to the operational difficulty of maintaining electrical contact with the anode rod throughout numerous anode changes. There is an alternative technique for measuring currents: the measurement of the magnetic field produced by the current and this provides an opportunity for permanent, non-contacting and continuous individual anode current measurement. The paper describes our work on exploiting this opportunity at a smelter in the USA. The system that we have developed relies on wireless transmission of current data to a computer near the potroom that serves as a relay to Amazon Web Services where the data are processed and archived.

Early wireless measurements of anode currents were carried out by Steingart and co-workers[1] who positioned battery powered wireless "motes" behind anode rods on one pot at two Alcoa smelters. The motes, a little larger than a pack of playing cards, contained magnetic field sensors and a wireless transceiver that sent the field measurements to a nearby laptop. The motes rested on the top of the anode skirt of the pot. Data were collected over a period of a few days at the two smelters. A few of the motes were powered by thermoelectric generators (TEGs), rather than batteries, to demonstrate the practicality of such "permanent" powering of the motes. Among the key results of that investigation was demonstration of the current redistribution that precedes an anode effect (AE) by a few tens of seconds. That redistribution has recently been well documented by Tarcy and Taberaux[2].

Measurement of current by measurement of magnetic field is not without difficulties, notably the "crosstalk" of the field produced by one anode current being affected by nearby anode currents. Urata and Evans have addressed this difficulty[3]. Much of this difficulty can be overcome by using two, or more, magnetic field sensors for each anode.

Measurement of individual anode currents could therefore prevent some AEs, or at least reduce their duration. Other obvious benefits include early warning of an anode burn-off due to excessive current and indication of a poorly placed anode following anode change. Equally significant is the opportunity to increase current efficiency (CE) that the measurements present. That opportunity is described below.

The Wireless Current Measurement System

In our most recent work we (Wireless Industrial Technologies - WIT) have used a "master and slave" arrangement to measure individual anode currents at a smelter. A "slave" (Fig.1) sits behind each anode rod and is "daisy-chained" through a single cable to a "master" (Fig. 2) located at the duct end of the pot; there was one master for each side of the pot. The single cable serves to both deliver power from the master to each slave and to transmit data from slave to master as well as commands from master to slave. The master then communicates wirelessly with a transceiver connected to a computer near the potroom. This master and slave arrangement has the advantage of reducing cost as the only expensive components are in the master. The arrangement also facilitates powering the system as the master is easily connected to a TEG or to the pot voltage (done in the present investigation thereby simultaneously delivering data on pot voltage to the computer).

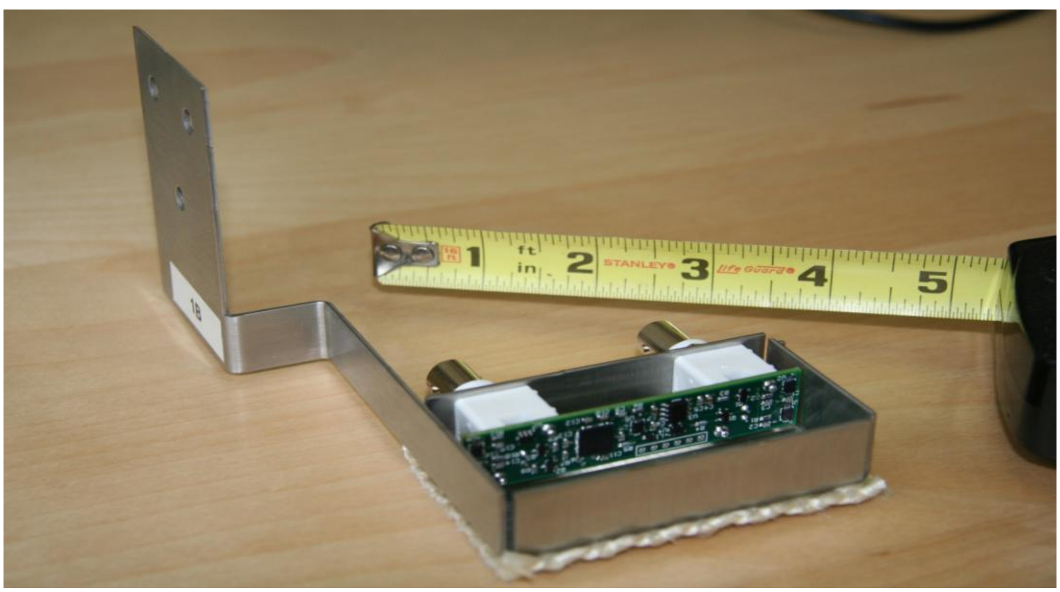

Figure 1. A "slave" used to measure the magnetic field produced by an anode current and thereby the current. The scale is in insulation. Assembly completed by adding an insulated lid and attaching cables to the BNC connectors.

Figure 2. A “master” to be located at the end of the pot. Connections to the slaves and to pot voltage are shown. The master communicates wirelessly with a nearby computer.

The slaves each had five Hall effect sensors of various sensitivities mounted on their printed circuit boards. The multiple sensors enabled a range of magnetic fields to be measured and allowed for minimization of the crosstalk difficulty. The principle behind the this minimization of crosstalk is illustrated in Fig. 3

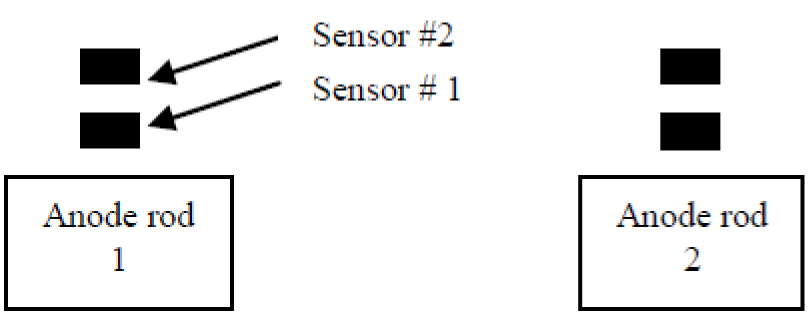

Figure 3. Schematic diagram of two anode rods, seen from above, each with two magnetic field sensors.

Sensors 1 and 2 are affected by both the current in anode rod 1 and anode rod 2. The *difference* between the fields measured by sensors 1 and 2 is strongly affected by current in rod 1 but hardly at all by the current in rod 2 because sensors 1 and 2 are almost the same distance from rod 2. Consequently the current in rod 1 can be calculated with reasonable precision from this *difference*. For yet greater precision mathematical models can be employed to relate the suite of field measurements to the anode currents as described by Urata and Evans[3]

In an early version of the system the slaves were located on top of the anode skirt but in more recent work we have mounted the slaves directly below the anode beam. In this position the slaves and their cable are well protected from damage during, say, an anode change. Fig. 4 shows slaves mounted below the anode beam of the pot.

Figure 4. Slaves below the anode beam near the completion of installation.

Results of Measurements – Anode Effects

The main focus of the investigation, largely funded by the US EPA and DOE, was early warning of anode effects. Fig.5 shows an early warning given by the first master-slave system installed at the smelter in August, 2010. The current (represented by the magnetic field) in four of the anodes under measurement is plotted versus time shortly before the plant computer recognizes an AE from the pot voltage increase. Clearly the WIT system has detected this AE over a minute before the plant computer recognizes it.

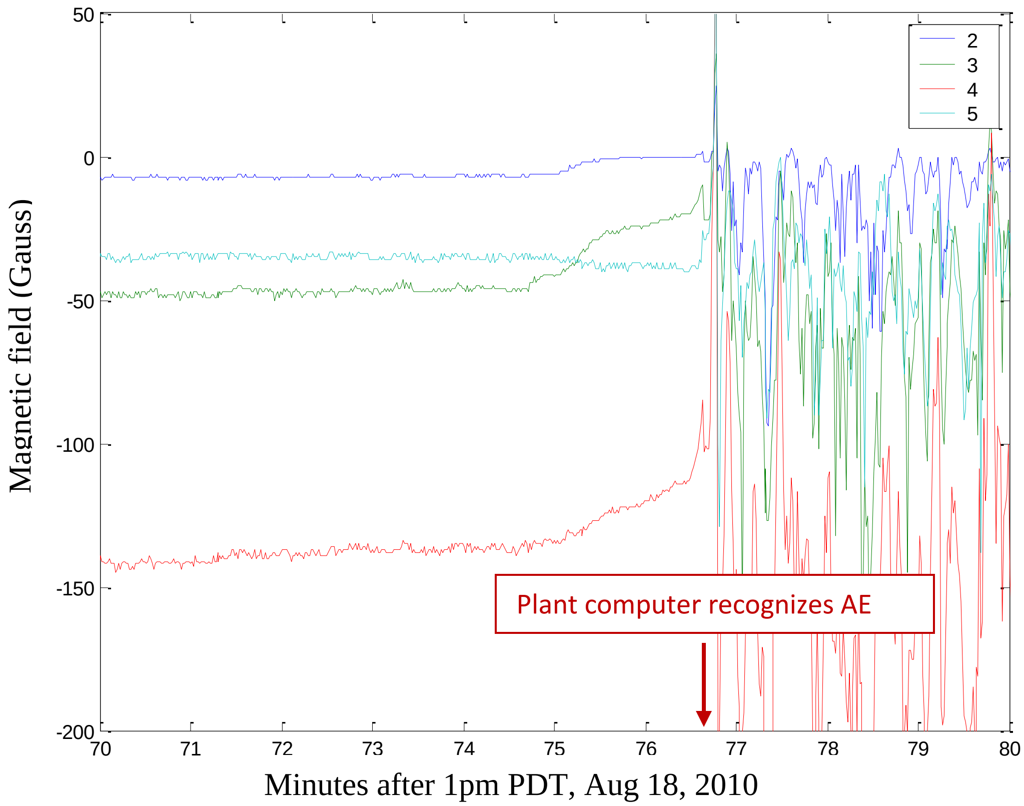

Figure 5. Traces of four anode currents (as reflected in magnetic field) as an anode effect starts – data from August test.

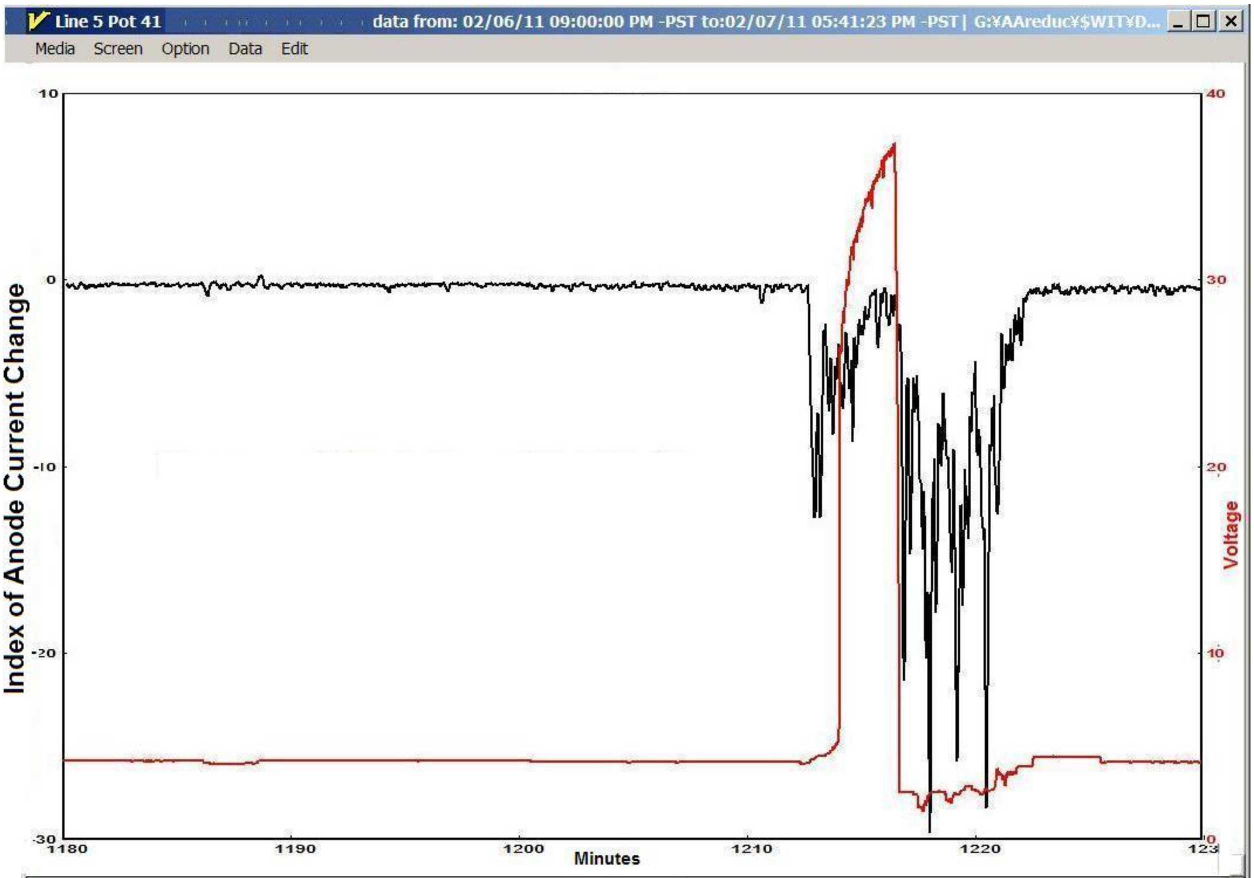

Figure 6. Representative plot showing early warning of anode effect from anode current distribution (blue line) compared to the pot voltage (red line)

The second master and slave system was installed on a pot in mid-December, 2010 and lasted until late April, 2011, when the pot tapped out. Only one slave was damaged during this period and slave temperatures (also measured by slaves and reported via the master) were not excessive, despite thermal radiation exposure during the usual removal of pot covers to replace anodes etc. Fig. 6 shows the behavior of the pot in the 35 minutes before an anode effect. The red line is the pot voltage (now reported by the masters) and the blue line is an index of the rate of change of the anode current distribution. Note that this index stays very steady until approximately 3 minutes before the sharp increase in pot volts due to an AE, whereupon it starts to change rapidly. We have analyzed 20 AEs occurring in the first three months of 2011 for the pot under study. The early warning, obtained from the sudden drop in index, ranged from zero to several minutes. Only three of the 20 AEs gave zero early warning.

Results of Measurements – Current Efficiency

It has long been recognized that the CE of a pot is dependent on the anode-cathode distance. If an individual anode is repositioned then its ACD is different and thereby its current. Consequently there is every expectation that CE is affected by the distribution of current among the anodes and that a more skewed distribution gives lower CE. This is borne out by data gathered by Tarcy[4] presented in Fig. 7. These data are from silver dilution measurements on a commercial pot and clearly show that CE is impaired if one anode is carrying a larger current than its fellow anodes.

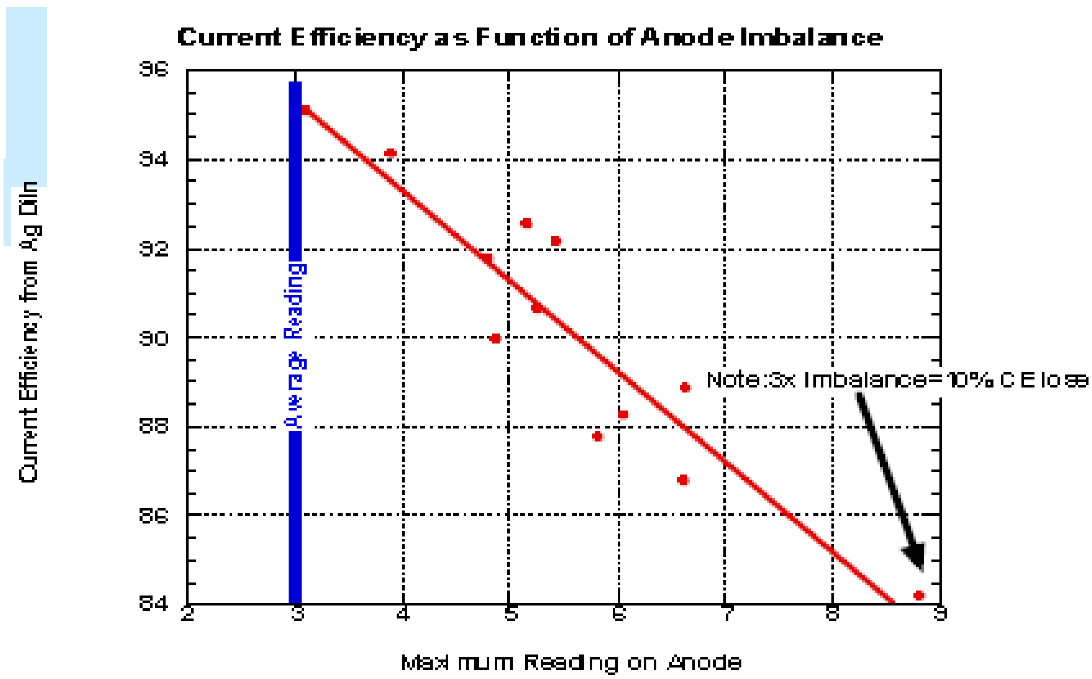

Figure 7. Measurements made by Tarcy on the effect of anode current skewness on CE

We have used these data to estimate the CE loss due to uneven current distributions at the smelter. We have done this using the slope of the line in Fig. 7 and:

a) Plant data made by using the traditional mV drop method.
b) Our data from measurement of the currents using the WIT system.

Using the data from a) we obtain CE *losses* due to uneven current ranging from 0.55% to 1.75%. Using a limited sample of our data from b) we find current efficiency losses ranging from 1.48% to 2.05%. For a modern potline, and current aluminum prices, these CE decreases represent a few million dollars per year of lost revenue that might be avoided if anode currents could be continuously monitored and anodes adjusted when necessary. Of course the repositioning of an anode once it is in place is not trivial; there is at least labor cost entailed in this adjustment. Fig. 8 shows some break-even curves for the adjustment. There are two families of curves in Fig. 8. One family assumes that the imbalance of the currents would persist, but for any anode adjustment; the other family (broken red lines) assumes that the imbalance would last for only three days (due to faster anode consumption of the misplaced anode).

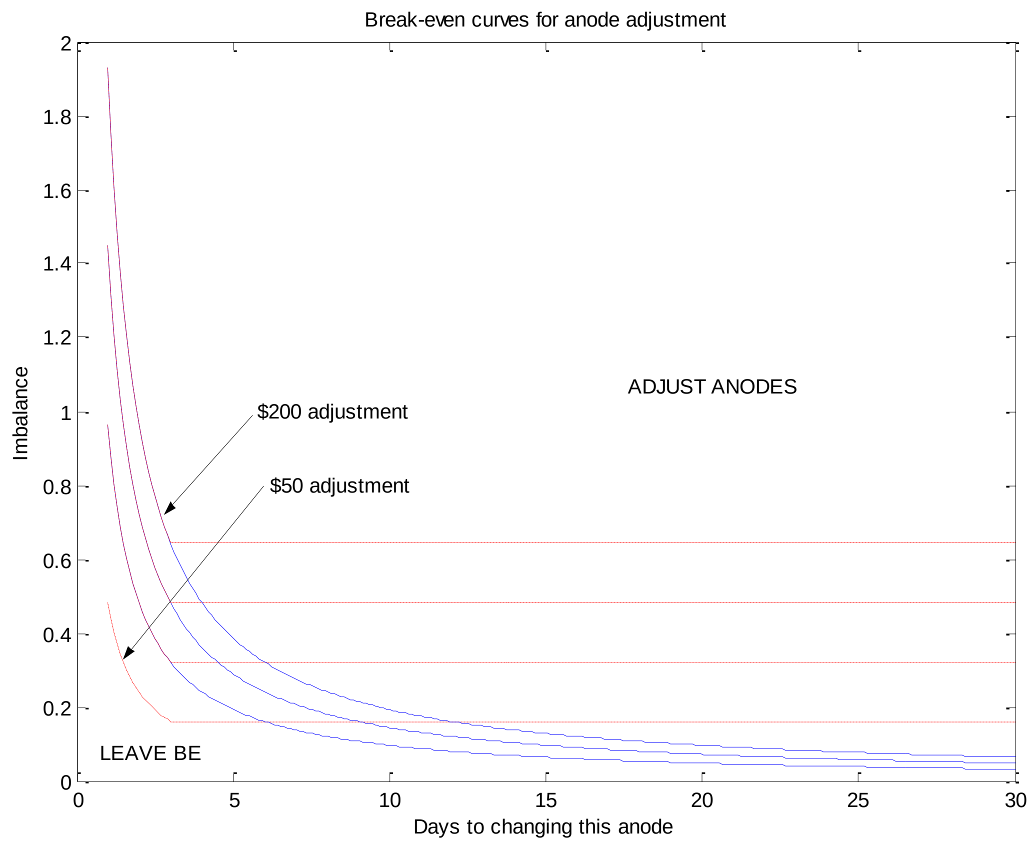

Figure 8. Break-even curves telling whether an anode should be adjusted in position or left alone. Blue solid line for persistent imbalance; red broken line for three day imbalance.

The curves of Fig. 8 are drawn for a range of costs ($50-200) for an adjustment and for anodes of various ages. "Imbalance" is the ratio of the excess current in the anode with the maximum current to the average current (e.g. imbalance = 1 means that the offending anode is carrying twice the average current). These curves will shift around as the cost of alumina and the metal price vary, but are easy to recalculate. They suggest that anode adjustment will frequently be economic.

Conclusions

Our work over the past few years has shown that anode currents can be continuously monitored by a non-contacting system that measures the magnetic fields produced by the anodes. The master-slave system that has evolved during this work appears to be robust and will show substantial economies of scale once slaves are bought in thousands and masters in hundreds. The benefits available from such anode current measurements include early warning of anode effects so they may be shortened, or even avoided altogether, and improvements in current efficiency.

Acknowledgement

This investigation was supported by the US EPA, through August, 2010, under contract EP-D-10-046; thereafter it has been supported by the US DOE under contract DE-EE0003500 and by cost sharing from Alcoa. The authors thank Alcoa also for the opportunity to do measurements on Alcoa smelters. Assistance from Lyle Cunningham, Tom Tillotson and David Binge of Alcoa is particularly acknowledged.

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