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NOISE CLASSIFICATION IN THE ALUMINUM REDUCTION PROCESS

Larry Banta, Congxia Dai, Philip Biedler
West Virginia University; P.O. Box 6106; Morgantown, WV 26506

Abstract

Cell "noise" is monitored by virtually all reduction cell control systems, and is generally used as one of the control variables for anode movement. High noise levels are thought to reduce cell current efficiency and are generally combated by increasing anode-cathode distance. However, exactly what constitutes "noise" and how noise is measured varies from controller to controller. Cell control algorithms are universally proprietary and little has been published on the correlation between voltage noise and current efficiency. In this study, three types of frequently observed cell noise are presented, and corresponding noise metrics are proposed. The characteristics and possible causes of the three types of noise are discussed. We show that not all types respond to anode movement, and posit that a better understanding of noise type is necessary for effective control of the cell.

Introduction

This noise classification research is based on data taken from four prebake-anode aluminum reduction cells in potline #3 in the Ravenswood aluminum reduction plant of Century Aluminum Company. The cells are instrumented with a custom data acquisition system which measures cell voltage, cell current and several other variables irrelevant to this paper. The cell voltage V(t) and current I(t) are sampled at a frequency Fs=4.5Hz, and the pseudo resistance R(t) = (V(t)-Vo)/I(t) is calculated as the basic variable for this analysis. Vo=1.65v is the nominal over voltage for the electrochemical reactions in the reduction cell. For the purpose of this work, we will define noise as random and/or uncontrolled fluctuations in the cell resistance.

Bubble Noise

Observation of the resulting signals reveals several distinct patterns of noise. Figure 1 shows what will here be called "bubble" noise. The actual source of this noise is not known conclusively, but it is thought to be at least in part connected to

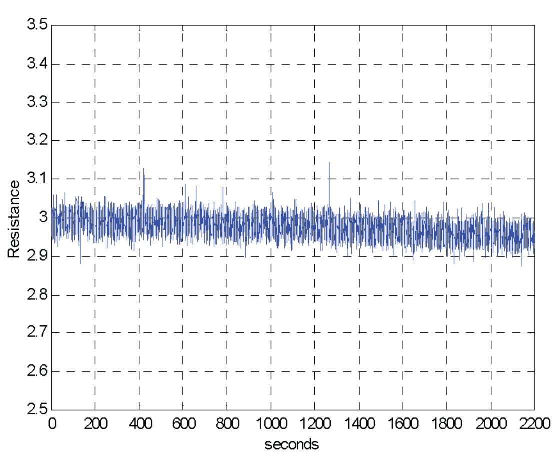

Figure-1. Pseudo resistance with low-level bubble noise

the formation of the carbon dioxide bubbles on the surface of the anode. As bubbles grow, coalesce and are released, the effective area of the anode changes, altering current density and changing the effective cell pseudo resistance in the process. Clearly, the formation of gas bubbles is necessary for the production of aluminum, since the primary forward reactions in the cell are given by [1]:

$$Al_2O_3 + 3C \rightarrow 2Al + 3CO$$

$$2Al_2O_3 + 3C \rightarrow 4Al + 3CO_2$$

Bubble noise is approximately Gaussian in nature, as shown by Figure 2. The histogram on the right has been constructed from the values of (R – Rm) where Rm is the mean value of the pseudo resistance in the sample window. A Gaussian probability density function has been superimposed on the histogram to facilitate comparison.

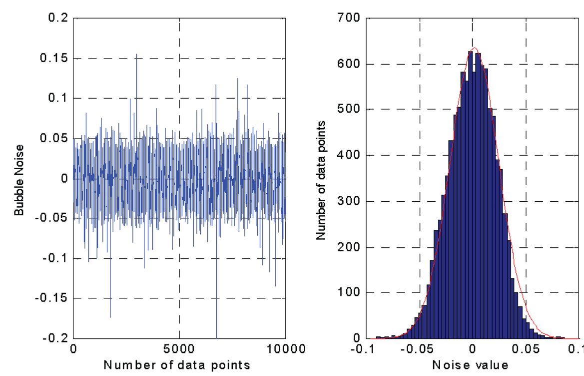

Figure 2: Bubble Noise (left) and its Histogram (right), the enveloping curve on the histogram is a Gaussian distribution with mean zero and standard deviation 0.0234

The intensity of bubble noise can be measured by the variance or standard deviation, with higher noise levels corresponding to higher values of sigma. From the data collected at Ravenswood, the value of sigma ranges from about 0.02 to about 0.04 Note in Figure 3 that the intensity of the noise can vary seemingly spontaneously. No anode movements occurred during this time.

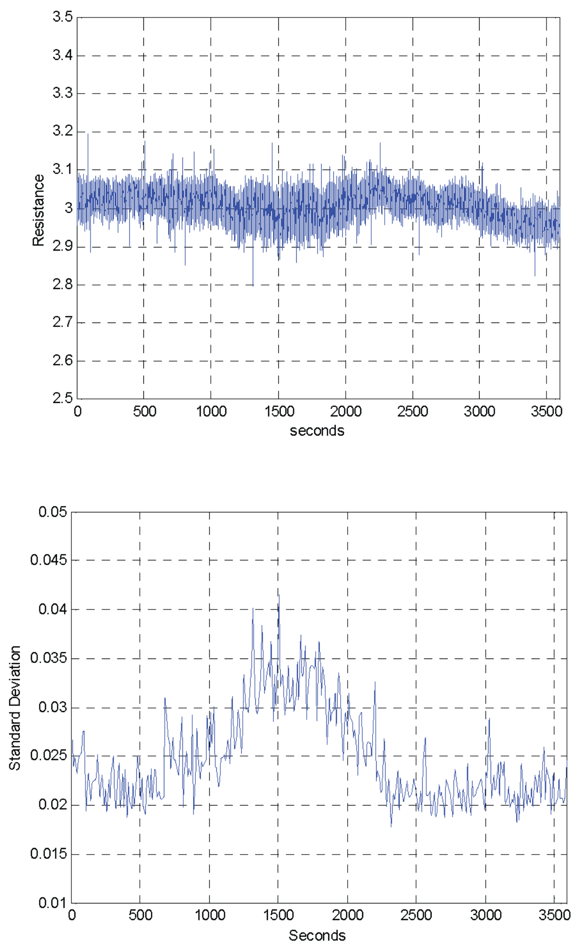

Figure 3 (top): The intensity of bubble noise may increase and decrease without any control action; (bottom): plot of standard deviation of top trace.

Short-circuiting Noise

Besides the bubble noise, two other types of "interesting" noise have been classified from the data. One of them will be called "short-circuiting" noise, and is thought to result from liquid metal splashing against the bottoms of the anodes, causing temporary shorting. This type of noise is characterized by large downward spikes in the pseudo resistance plot, as shown in Figure 4. Note in these plots that the upper envelope of the resistance signal is relatively uniform compared to the lower envelope which is punctuated by very large downward excursions.

Short circuiting may result from one or more improperly set anodes, from interactions between gas bubbles, the metal pad and sidewall freeze, or from other unknown factors. Whatever the exact cause, short-circuiting is most likely detrimental to the cell current efficiency, since the chances of re-oxidation of the liquid metal are increased via the inverse cell reactions [2].

$$2Al + 3CO_2 \rightarrow Al_2O_3 + 3CO$$

$$4Al + 3CO_2 \rightarrow 2Al_2O_3 + 3C$$

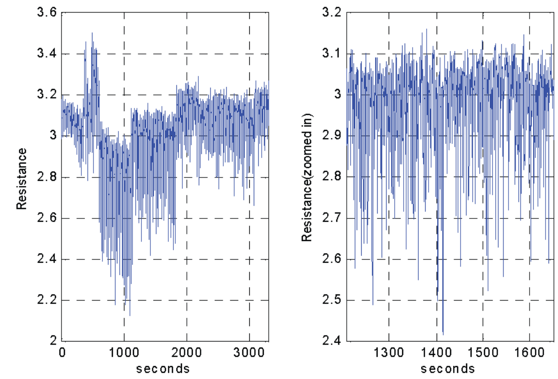

Figure 4: Anode short-circuiting noise is characterized by downward spikes in the cell resistance

Metric for anode short-circuit noise

Anode short-circuiting noise can be mitigated by raising the anodes. Prompt detection and correction of the shorting condition is desirable. Generally, shorting will drive the variance of the signal to levels well beyond those achieved by bubble noise alone, so high signal variance could serve as an indicator of short-circuiting, but it is desirable to have a more specific metric for the short-circuiting phenomenon. One such metric is here defined as the "shorting-circuiting ratio", SR(t). A sequence of noise data is taken, and the sample mean over that sequence is calculated. Each data point is compared with the mean. The number of points greater than the mean, Nabove(t), and the number less than the mean, Nbelow(t) are computed and compared to find the short-circuiting ratio:

$$SR(t) = \frac{N_{above}(t)}{N_{below}(t)}$$

For normally distributed noise, Nabove(t) approximately equals Nbelow(t), and the short-circuiting ratio SR(t) is close to 1.0. However when the anode short-circuiting noise occurs, the large downward spikes draw the mean value down, making Nabove(t) greater than Nbelow(t), and making SR(t) greater than 1. High values of SR(t) indicate more and larger downward spikes, resulting from intense anode short-circuiting noise. Figure 5 shows a pseudo resistance signal with high levels of anode short-circuiting noise and the corresponding plot of the short-circuiting ratio. Note that as the pot anodes were raised both the short-circuiting noise and the short-circuiting ratio declined.

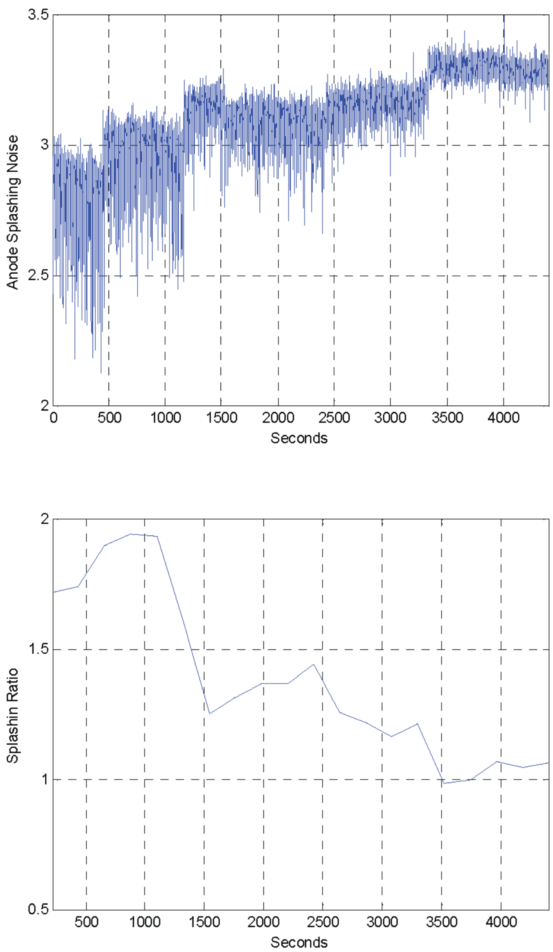

Figure 5 (top) Cell resistance curve showing anode short-circuiting noise. Note flat top and downward spikes on trace. (bottom): Short-circuiting Ratio metric for the top trace.

Metal Pad Roll

A third type of noise also results in high signal variance, but is distinct in origin from the short-circuiting noise. This is the well-known metal pad roll, and resistance signals caused by this process are shown in Figure 6. At coarse time resolution, the metal pad noise looks much like high-intensity bubble noise, evenly distributed about the mean. But zooming the time scale reveals the characteristic sinusoidal shape of the metal pad waves.

The Ravenswood pots have a natural period ranging from about 15 seconds to 45 seconds, depending on the wave mode. The metal oscillation frequency at other facilities will vary with pot design and operating conditions, and the intensity will vary with the effectiveness of the magnetic compensation in the pot line. Figure 7 shows that the frequency of oscillation can vary within one pot as conditions change. Figure 7a shows that the controller attempted to extinguish the noise by a series of anode moves over a two-hour period. Note that the anode moves do not appear to have been effective in reducing the noise, at least in the short term. Figures 7b shows that the period of the oscillations changed from T = 18 seconds to T = 31 seconds, however. The time scales on the magnified traces correspond to those on the top trace, showing how the excerpts correlate with the larger picture.

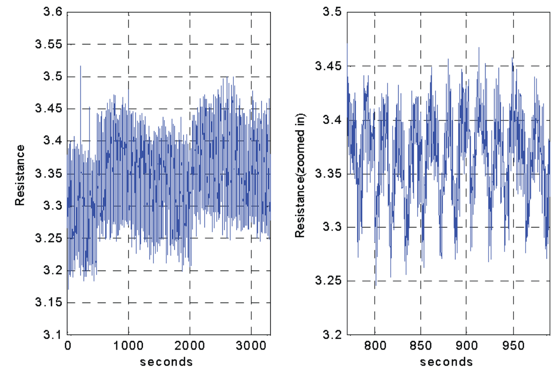

Figure 6: Metal pad motion noise can look much like high-intensity bubble noise (left). Magnifying the time scale reveals the sinusoidal pattern characteristic of metal pad roll.

The metal pad motion is also believed to degrade the current efficiency, because it can promote remixing of metal with the electrolyte and can effect transport of the metal to the reaction zone where the inverse reaction can occur [3]. It is not clear from the data at hand, however, that raising the anodes is an effective way to damp metal pad oscillations. In fact, anode movements and the fluid disturbances they cause are suspected to excite metal pad roll in some cases. Metal pad roll is often observed in the time periods immediately following metal tapping operations, for example. To date, the measurements in this research have all been passive—the commercial pot controller commands all anode moves based on its internal algorithms, and the data acquisition system merely observes the results. With passive data, it is impossible to prove causality. New experiments are being designed to allow further investigation of strategies for metal pad oscillation control.

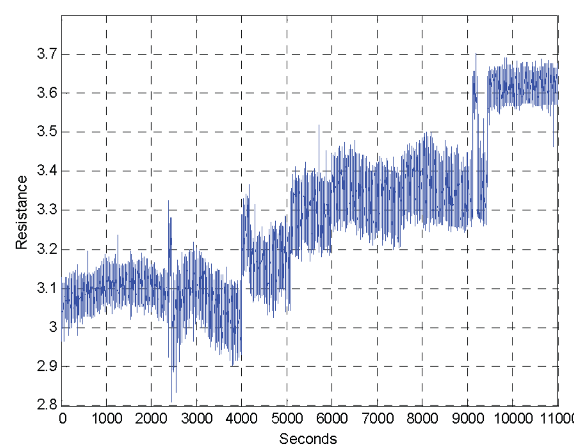

Figure 7a: Metal pad motion noise, and the controller's attempts to suppress it by anode raises.

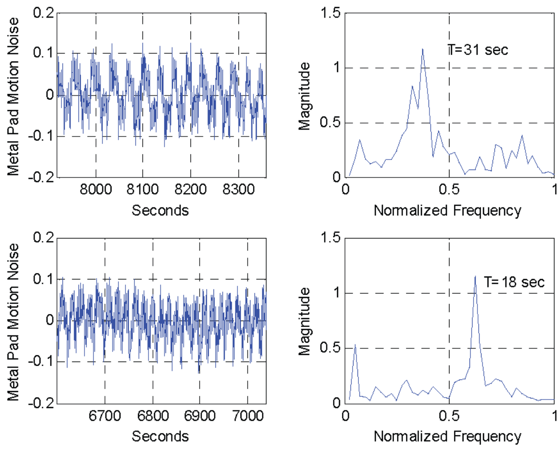

Figure 7b: Expanded traces and their Fourier spectra from two points in the data shown in 7a. A significant shift in the oscillation frequency occurred.

<u>Metric for metal pad motion noise</u>

It was noted that the metal pad roll is linked to the physical attributes and operating condition of the cell. This means that for any cell design, there exists a range of oscillation frequencies which the cell can sustain, and which will appear on the pseudo resistance trace. It is relatively simple to apply Fourier spectrum analysis to the metal pad motion noise. To measure the intensity of metal pad motion, it is proposed to use the area under the Fourier spectral power density curve over the frequency range of interest. This metric will be called the Roll Index (RI). Figure 8 shows how the RI varies with time as a trace moves through a period of high metal pad motion that was triggered by a metal tapping operation.

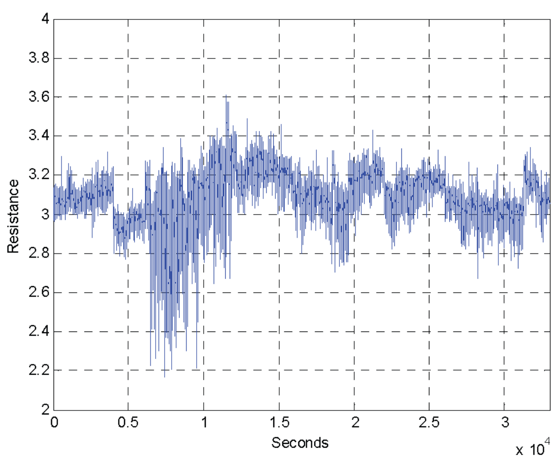

Figure 8a: Resistance signal exhibiting transition from quiet operation to metal pad roll and back to quiet operation.

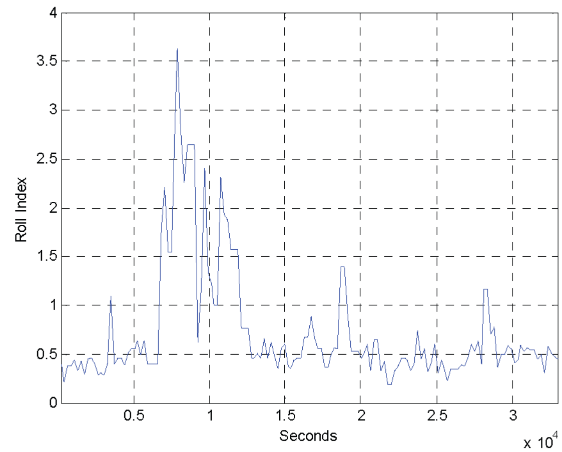

Figure 8b: The Roll Index is the signal power in the frequency range of f = 1/15 to f = 1/45 seconds, and indicates intensity of metal pad roll.

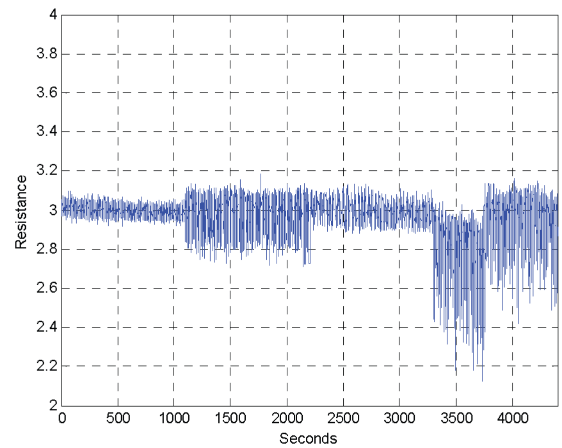

Figure 9a: Composite signal exhibiting different types of noise. From 0-11 = bubble noise, 1100-2200 = short-circuiting, 2200-3300 = metal pad roll, and 3300-4400 = both roll and short-circuiting noise.

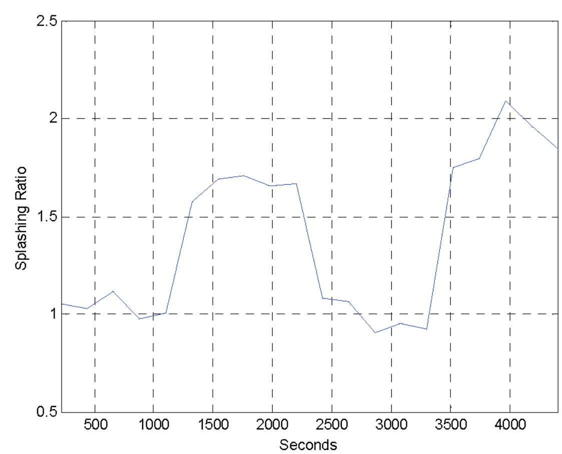

Figure 9b: Short-circuiting Ratio trace for signal in Figure 9a.

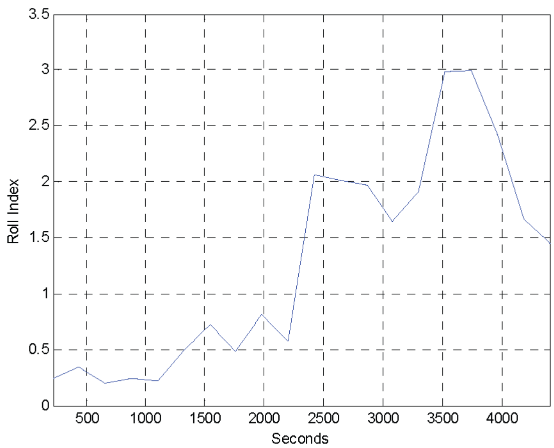

Figure 9c: Roll Index trace for signal shown in Figure 9a.

Selectivity of the metrics

For control purposes, it is desirable to have the metrics be selective of the type of noise incident in the signal. Figure 9 demonstrates that the proposed metrics are highly selective for the chosen noise types. The top trace shows a composite signal consisting of periods of pure bubble noise, short-circuiting noise, metal pad roll and a combination of short-circuiting and metal pad roll. The second trace shows the Short-circuiting Ratio (SR) and the third trace shows the Roll Index (RI). Note that for the initial bubble noise, both the SR and the RI are low. During the second part of the trace, where the short-circuiting noise is dominant, the SR is high, but the RI remains low. In the third segment, the RI jumps up to indicate high metal pad roll, but the SR drops back because there is not much short-circuiting noise present. In the last segment both types of noise are present, and both the SR and the RI exhibit elevated values.

Conclusions

This study on classification of noise signals in the aluminum reduction process shows that different types of noise have totally different characteristics and causes, and therefore, reflect different working states of reduction cells. Bubble noise is caused by the release of gas bubbles, which is a necessary process for aluminum reduction. Thus even high intensity bubble noise should not trigger noise control measures such as anode moves. Both anode short-circuiting noise and metal pad roll noise indicate conditions which can cause a reduction in current efficiency. Therefore, the conditions which cause these two types of noise should be suppressed as quickly as possible. Metal short-circuiting noise can be effectively suppressed by raising the anodes. It is desirable to raise the anodes only as much as is necessary to suppress the noise, since increasing the anode-cathode distance also increases the energy per pound of metal. On the other hand, it is not clear that anode raises are very effective means of quenching metal pad roll. In fact, there is some indication that metal pad roll can be instigated by anode movement, since it is frequently observed following metal tapping operations. It is thus useful to have a method for separating noise by type, to avoid commanding inappropriate control actions.

In this paper, methods and metrics have been proposed to discriminate metal short-circuiting noise from metal pad roll noise or normal bubble noise. The metrics appear to demonstrate both sensitivity to various noise levels and selectivity for the target noise type. The algorithms have been tested on historical data from four prebake anode cells at Century Aluminum in Ravenswood, WV. Experiments are being planned to verify relationships and test control algorithms based on these metrics.

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