

## Millivolt Anodes - New Technology Opportunities for Better Pot Control

**Benoit Verreault<sup>1</sup> and Renaud Santerre<sup>2</sup>**

<sup>1</sup>Vice President, Maestria Solutions, Chicoutimi, Québec, Canada

<sup>2</sup>Aluminium Reduction Technology Advisor (retired from Rio Tinto Alcan),

Consultant, Saguenay, Québec, Canada

Corresponding author: benoit.verreault@maestria.ca

### Abstract

Uniform anode current distribution is the basis of stable pot operation and better efficiency. The most common method to control the anode current distribution is to measure voltage drop between two points on each anode rod, the so-called anode millivolt (mV) drop, with a fork. The trend to increase cell size makes global sensing of the cell behavior not sufficiently powerful. Various localized cell phenomena may affect operation and may induce interesting signal pattern characteristics on a probed anode. In order to make this measurement more reliable, rapid and automatic, Maestria Solutions, in collaboration with Rio Tinto Aluminium, has developed Millivolt Anodes (mVa) tool, including a lightweight fork, automatic recording of the anode mV, pre-programmed sequence of measurements and automatic modern data transfer to the computer. This tool has been in use in several smelters, some of them have been using the previous generation of the tool for over 25 years. In this paper, new technology opportunities mainly based on real time analysis, data transfer and integration will be discussed. Actual results of the new versions of these tools will be shown.

**Keywords:** Anode current distribution measurement; Millivolt Anodes (mVa); anode setting.

### 1. In Search of Current Efficiency

Current Efficiency (CE) is an important cell parameter that measures which fraction of the electric current results in aluminum production. Proper use of anode signal can be a great process control tool for improving it.

The industrial cell is a complex system where all parameters are closely interrelated. Incremental improvements can be made by managing marginal contributing factors when you can identify their probable origin.

Recently, a considerable interest has been noted in the literature in detection of local cell conditions based on individual anode current measurements [1], which fits well with the global trend of Data Mining, the statistical analysis of large pools of data to find hidden correlations so called Big Data [2]. We vision a great potential of such applications in aluminium smelters considering it is getting easier each year to collect and process a lot of data. We will concentrate on one path of application we know works well and can be implemented without major investment from operators.

Uniform anode current distribution is basic for stable pot operation and best efficiency. Obviously, the smelter staff needs to monitor it by some means. The most common method to monitor the anode current distribution is to measure the voltage drop between two points on each anode rod with a fork, the so-called anode millivolt (mV) drop. We can easily postulate that all the aluminium smelters do this measurement on a more or less regular schedule, but not all reach the maximum possible payback by doing it.

The trend to increase cell size or to increase the amperage of older cell designs makes global sensing of only one measurement element for the whole cell, not sufficiently powerful to really

understand the various variations happening inside the cell. Moreover, another trend is amperage creeping of an existing smelter, which is one of the most cost efficient ways to increase the specific production, and is really a success story for many aluminum smelters when well done. One way to increase amperage is to reduce the anode-cathode distance (ACD). So, close monitoring of each anode becomes more and more critical; no need to detail how the current efficiency is very sensitive to ACD variation, especially when it gets very low where instability and drift can make the goal of increasing CE very hard to reach.

Thereby, typical problems following amperage increases are the loss of current efficiency (CE), increased frequency of anode problems, increased anode effect frequency, and increased cathode wear resulting in shorter cell lives. It is well documented that many abnormalities encountered in cell operation are often preceded by some patterns occurring in the current distribution.

Many various local cell phenomena may affect operation and may induce interesting signal pattern characteristics on a probed anode. Diagnosis and correction of operating cell event history help to build a knowledge base that can be put in relation with the anode signal measurement, looking for anode kicking, anode spike, anode setting accuracy, bubble and MHD noise, etc...

Maestria Solutions has developed Millivolt Anodes (mVa) tool; including a lightweight fork, automatic recording of the anode mV, pre-programmed sequence of measurements and automatic modern data transfer to the computer. This tool has been in use in several smelters, in some cases for over 25 years. This tool can be easily integrated at low cost into actual operation team doing the work on the aluminium cells. In diagnostic mode, the tool does a part of the job done by an on-line continuous current monitoring which needs to be installed on each anode of all cells, at a very high installation, maintenance and operation costs.

Uniform anode current distribution is the basis of stable pot operation and best pot performances. Some people consider that 80 % of the cell operation problems are caused by anodes. Even though this can be viewed as an exaggeration for some, it is well known that the anodes are a primary source of potential problems in real operation. Therefore, it is logical to monitor closely the anode behavior in order to detect and correct any irregularity early.

The general concept for individual anode current measurements is to regularly monitor the values and trends of the data sets and to deduce various local cell conditions by matching patterns for known process behaviors, where the proper statistical analysis helps to guide the corrective actions. Starting with Statistical Process Control (SPC) method, the data can be scrutinized in many ways; and by using some smart ways to highlight specific pattern occurring in the data set, it becomes a great diagnostic tool.

A good operation to be monitored closely is the anode setting, well known as disturbing the cell operation for several hours after setting, if not several days. The anodes are set to a certain target height with respect to the old anode butt for proper operation of the cell. Anode setting accuracy in typical operational condition is influenced by many factors. Even in the best situation, it is quite common to have some margin of error in the actual height adjustment. Operators have typically found the following pattern:

- Anode set too low has the following consequences:
  - High current flow in this anode,
  - Prone to cracking carbon, causing bad connection in cast iron-carbon contact,
  - Early instability as metal waves increase, higher noise,
  - Computer adds resistance modifiers,
  - Detrimental to current efficiency, reduces aluminium production.
- Anode set too high has the following consequences:

- Low current flow in this anode,
- Longer time to heat up,
- Local bath freezing, side ridge formation under the anode,
- Risk of setting anode on side freeze with down bridge moves,
- Current increase in the other anodes, instability, noise,
- Resistance modifiers added.

The new Maestria mVa unit uses Bluetooth for communication that enables bidirectional communication with an external device. When doing the actual measurement around the cell, it is not mandatory to be in communication with the computer; the fork is storing the data for transfer when the operator gets back near a computer later on at the end of the run. It has a battery that can make the system running typically for a few weeks on one charge, depending on the amount of usage in the potroom. Also, individual Light Emitting Diodes (LEDs) give extra information to guide the operator in determining a normal or abnormal measurement; it even allows seeing if an anode is unstable, using customizable software trigger parameters. This is especially useful after anode change. Another LED gives feedback of a good reading to the operator. The measurements can be downloaded via Bluetooth for history and analysis on a PC and process control software.

A well-trained operator can easily do one cell in less than one minute. It can be implemented easily into the day to day routine already done by the smelters on their potline. The payback overcomes greatly the required change.

Hence, there is less time of exposure of workers and thus better health and safety benefits; the ultra-light design allows quick operation and reduces exposure.

It was found that a great accuracy is needed to really make appear a small change in the measurement that is symptom of an unwanted phenomenon appearing or starting to appear in the cell, which by a side effect is reflected by a subtle difference in the anode signal. It is not easy for on-line continuous measurement systems to reach that level of precision.

Through the years, millions of measurements taken in many smelters on thousands of cells show that those techniques work. The operation gains and increases of current efficiency confirm that the system offers a very good solution for better anode control in an aluminium smelter, just to recall that 1% CE improvement is documented in some smelters [3]. Many abnormal or even potential faulty situations can be detected early. The system has been useful as a diagnostic tool to avoid operational drifts when creeping amperage, and has helped to maintain good process control. The new version with the built-in sophisticated electronics and software can also be closely adjusted to each smelter technology. Some new functions enable quick detection of various noise patterns occurring in the cell, helping the operator at the cell to apply quickly the proper corrective action. We will introduce also this year new analysing tools that will simplify the statistical data manipulation to be applied to the measurements generated by the system and that will make it easy to push the critical information needed for the operation directly in the process control system.

## **2. Treatment of the mV Data**

As anyone knowing rules of the art, reducing the variability of the anode current distribution and of the anode setting improves the overall cell performances including the current efficiency, the energy consumption and the environmental emissions.

In some smelters, standard operating procedures require to carry out on all pots the anode mV on regular basis, mostly every shift or every day, to control the uniformity of the anode current distribution and the anode setting accuracy. The systematic mV measurement of all the anodes

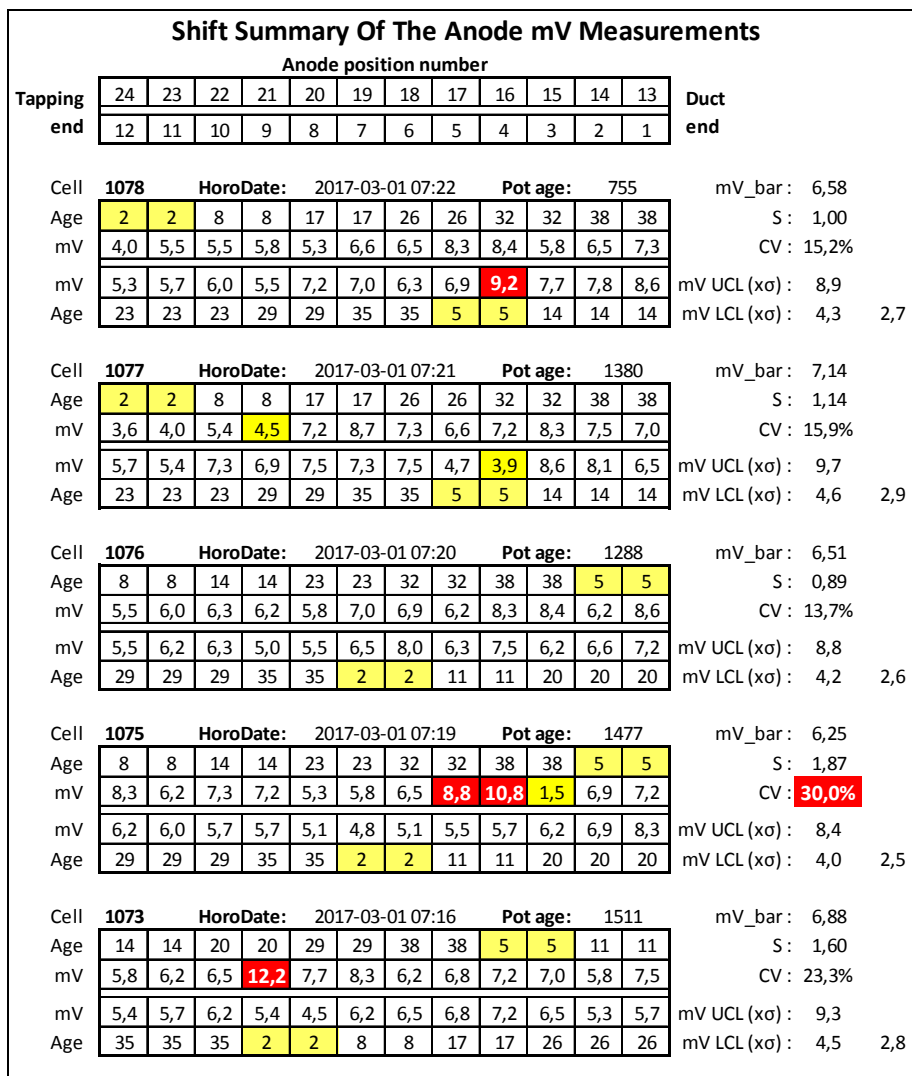
of the cells generates a huge amount of data that needs to be analyzed by proper statistical technics.

Maestria Solutions is developing innovating techniques for extracting useful information from this mass of data. Some are presented below as examples from real data collected and supplied by Rio Tinto.

### **2.1. Detection of Anodes and Cells Needing Attention**

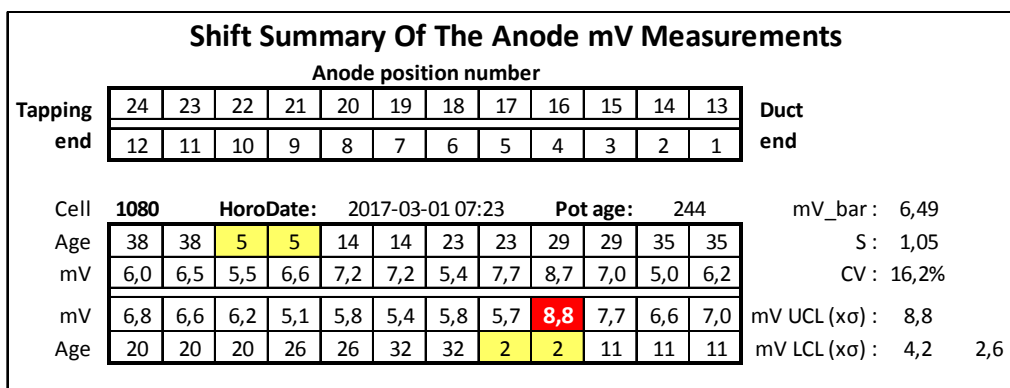
Some smelters scan the mV drop in all anode rods of their cells at the beginning of the working shift. With proper statistical analysis, the data collected can be used for detecting anodes needing attention, with mV being abnormally high or abnormally low and to detected cells having an anode current distribution abnormally uneven.

Figure 1 below is an extract of an example of screen that can be supplied to the operator after he has downloaded the mV data he has just collected. In this extract, the anode current distribution of the cell 1075 is abnormally uneven (Coefficient of Variation (CV) = 30.0 %) and would need to be investigated. The mV of anode 21 in cell 1073 and of the anode 4 in the cell 1078 are abnormally high and would also need attention. The Maestria mVa tool in diagnostic mode facilitates quick analysis of various noise patterns occurring in the cell, helping the operator at the cell to quickly identify the proper corrective actions.



**Figure 1. Identification of anodes and cells needing attention.**

Figure 2 shows an example of a 24 h old anode (2 12-h shifts) carrying abnormally high current, which would need attention.



**Figure 2. High current in the 24-h anode.**

Naturally, if necessary, those pieces of information could be presented to the operator in various formats instead of the cell layout format as above.

## 2.2. Summary of the mV Collected

At the operator level, the mV collected are analyzed in such a way to identify which anodes and cells need attention during his shift as described in the previous section. But at the plant level, there is also useful information that can be extracted in various groupings as per operator, per Pot Tending Machine (PTM), per potroom, per potline, for the whole plant, etc...

As an example, Figure 3 presents the statistics that can be generated every shift of measurements at the whole plant level.

Shift Summary Of The Anode mV Measurements			
2017-03-01, day shift			
Typical CV of the anodes "Other" in cells :	15,1%	Nb of $\sigma$ pour UCL & LCL of CV_cell :	2,33
Typical S of the CV_cell :	5,7%	CV_cell UCL :	28,4%
		CV_cell LCL :	1,9%
Avg. CV_cell :	14,9%	Current pickup of the anodes 24h :	85,5%
S CV_cell :	6,4%	CV mV of the anodes 24h :	18,4%
Nb of cells measured :	287	Nb of anodes 24h :	121

Figure 3. Statistics for SPC charts.

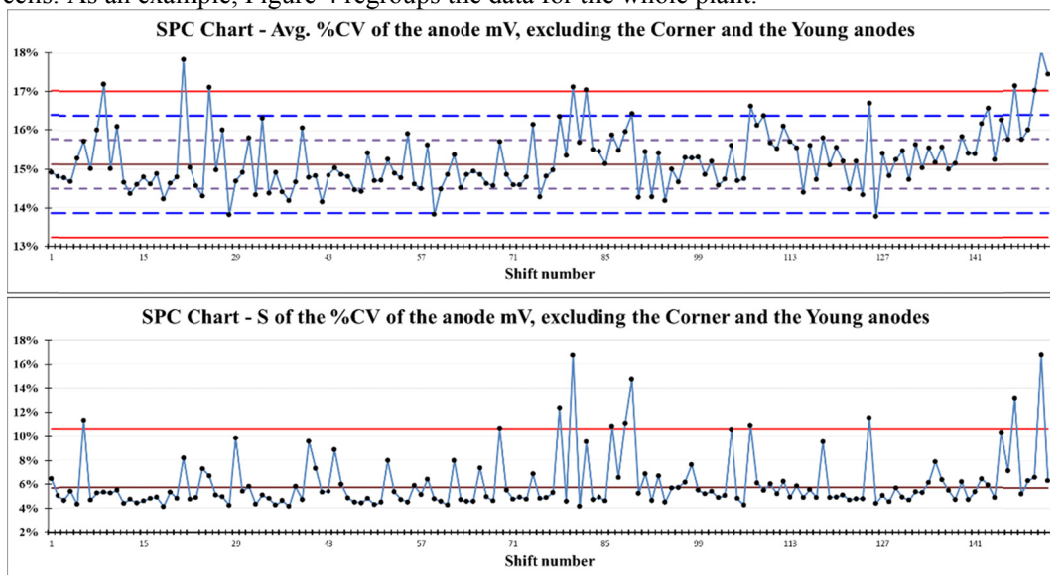
These summarized data could be very useful as input for the process control and for the continuous improvement process.

## 2.3. Historical Analysis – SPC Charts

The examples of SPC charts below have been built with 2½ months of real data collected every 12-h shift on a few hundred cells.

### 2.3.1 Follow-up of the Uniformity of the Anode Current Distribution

Figure 4 presents an example of SPC chart for tracking the anode current distribution that can be built to support its continuous improvement or for early detection of a drift within a group of cells. As an example, Figure 4 regroups the data for the whole plant.

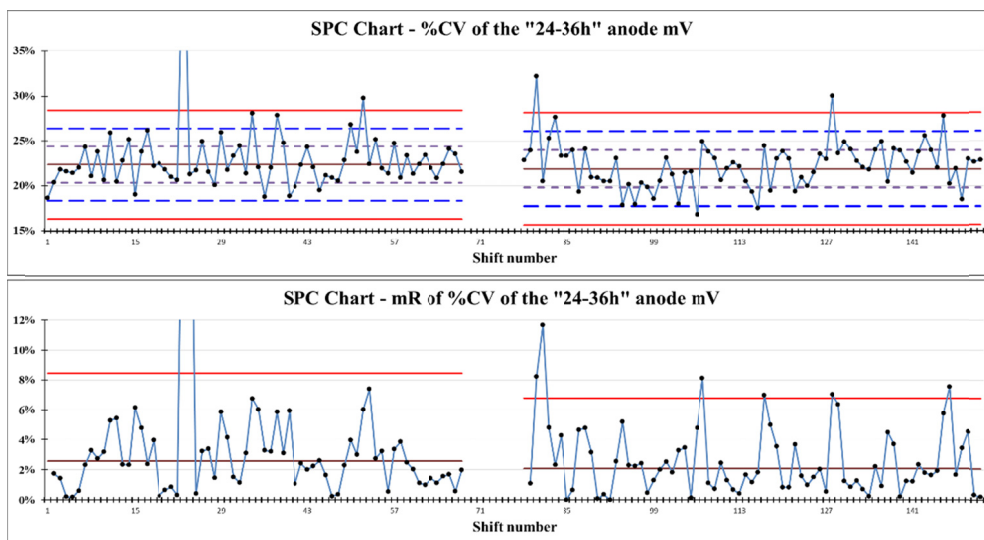


**Figure 4. Average CV<sub>cell</sub> and S of “Other” anodes (Corner and the Young anodes excluded).**

**2.3.2 Follow-up of the Variability of the Anode Setting**

In addition of the corrective actions done by the operators for addressing abnormalities in new anode setting, minimizing the variability of the setting is of primary importance for good behavior and good performances of the cells.

Figure 5 presents an example of SPC chart for tracking the variability (Coefficient of Variation - CV) of the anode current at approximately 24 or approximately 36 hours after setting that can be built to support continuous improvement of anode setting or for early detection of a drift within a group of cells. As an example, Figure 5 regroups the data for the whole plant.

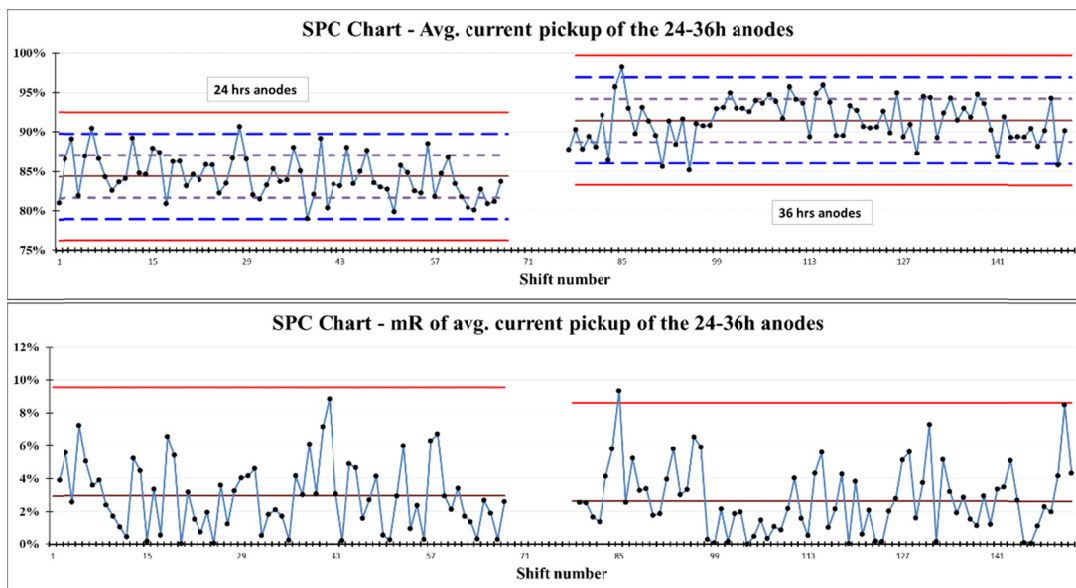


**Figure 5. CV and Moving Range (MR) of the 24 – 36-hour old anode mV**

As one can see, this type of representation is useful for identifying periods with high variability (high Coefficient of Variation) of the anode setting and other periods with lower variability; which is powerful for tracking improvements.

**2.3.3 Follow-up of the Accuracy of the Current Pickup**

Following the accuracy of the pickup of the current in the new anodes are also of prime importance. Figure 6 below presents an example of SPC chart for tracking the variability of the current pickup of the new anodes at approximately 24 or approximately 36 hours after setting.



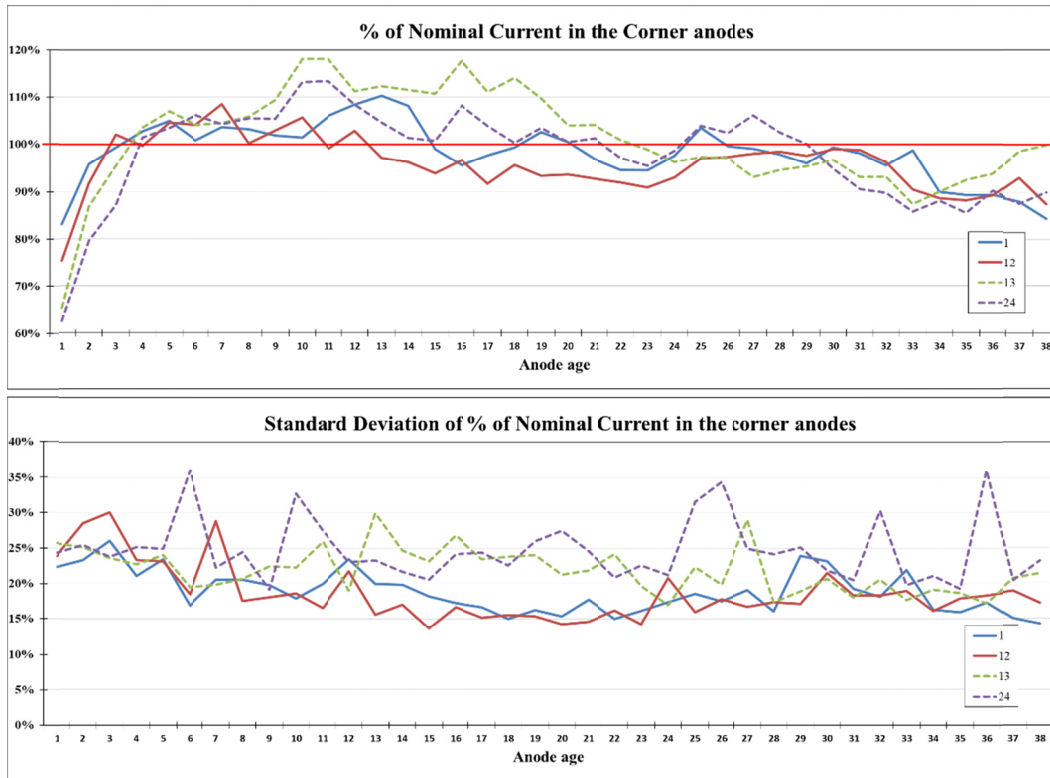
**Figure 6. Average current pickup and MR of the 24 – 36-hour old anodes.**

As ones can imagine, this type of follow-up can detect if there is a change in the pickup of the current in the new anodes (or a problem with the off-set for setting the new anodes).

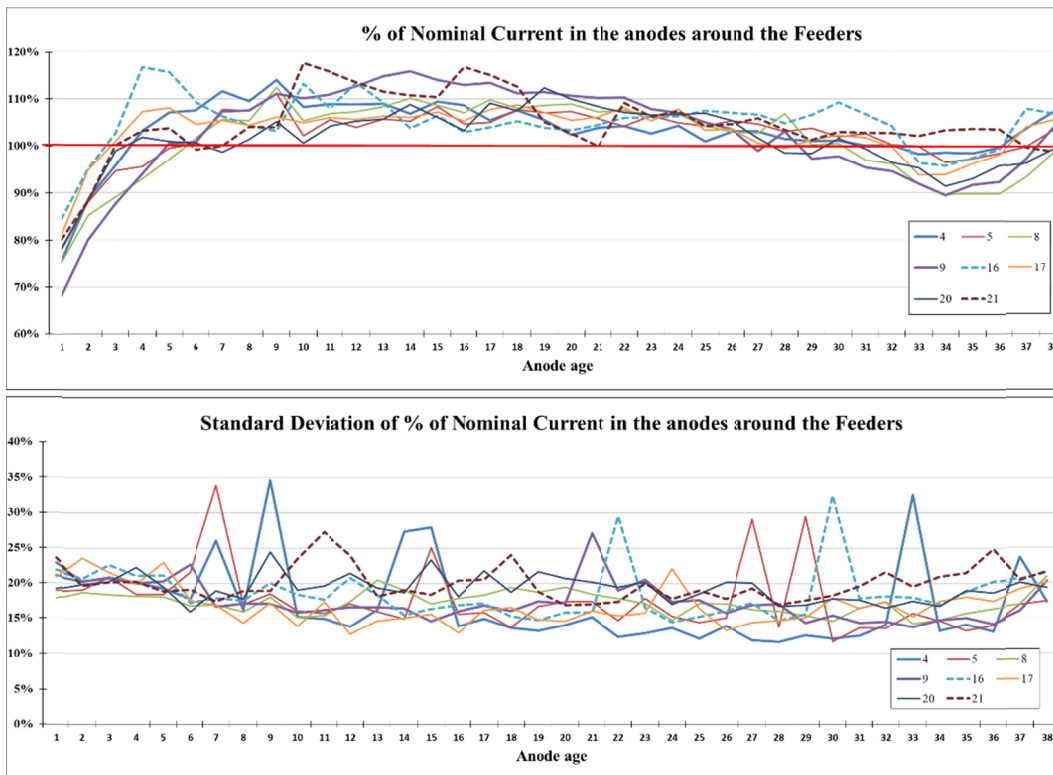
#### **2.4. Evolution of the current during the life of the anodes**

As a bonus, all those data can be used for analyzing the evolution of the current in each individual anodes throughout their life. Figures 7, 8 and 9 below present the evolution and the variability of the current in all the anodes; per groups of anodes as corners, around the feeders, and the remaining ones.

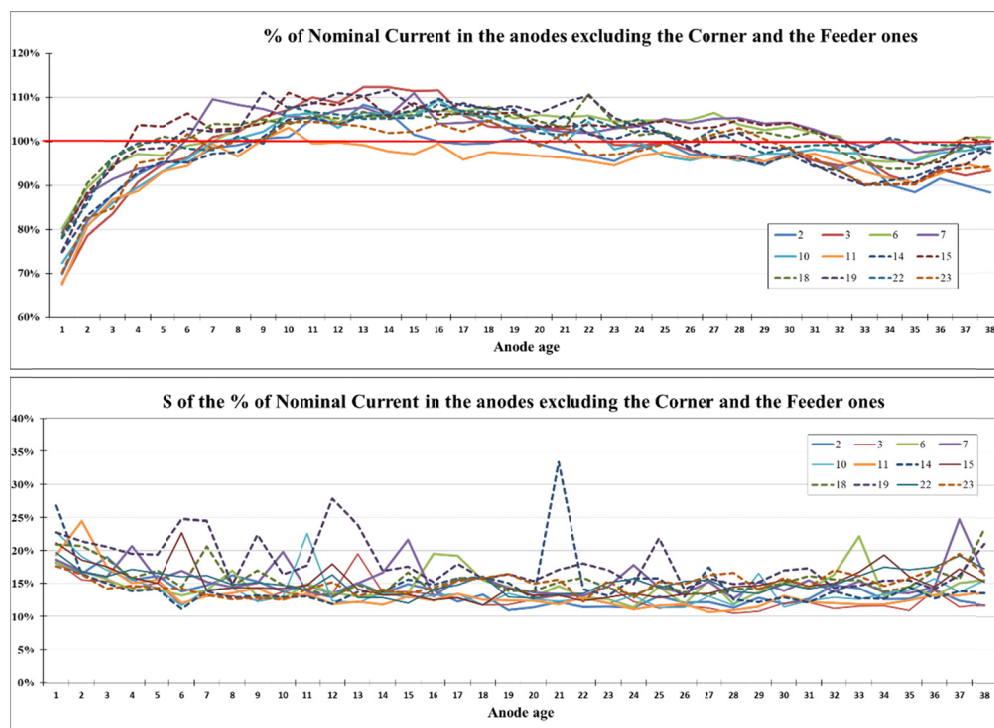
Ones can observe some differences between anodes: different speed of current pickup, different level of overshooting above the nominal current, lower variability in the anodes excluding the corners and around the feeders, etc... Those would be useful to identify room for improvement.



**Figure 7. Average and Standard Deviation (SD) of the nominal current during the life of the corner anodes. Anode age is in 12-h shifts.**



**Figure 8. Average and SD of the nominal current during the life of the anodes around the feeders. Anode age is in 12-h shifts.**



**Figure 9. Average and SD of the Nominal current during the life of the anodes excluding the Corner and the Feeder ones. Anode age is in 12-h shifts.**

### 3. Conclusions

In the aluminium smelting process, knowledge related to diagnosis and correction of operation abnormalities is based on rules of the art, but primary source of information is based on actual data of the operation, a real demonstration of the statement: Measure to Control - Benchmark to Improve. Stable anode current distribution is known to be of primary importance and one of the first elements of good cell operation. Applying an easy tool and an easy method for anode current distribution measurements, mVa of Maestria Solutions, will help pot operation staff in day to day follow-up of the cell behaviour and in determination of required actions for optimum pot performance. Some smelters have found great success with the tool and the method for many years. Without having to put a lot of instrumentation in potlines, with mVa tool it is possible to make very good short term diagnostics for anode current outliers and longer term diagnostics, such as potline drift from optimal anode current distribution parameters.

### 4. Acknowledgement

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### 5. References

1. Yuchen Yao et al., Detection of local cell conditions based on individual anode current measurements, in *Light Metals* 2016, 595-600.
2. Claude Vanvoren et al., Data connectivity, a key feature of the smelter of the future, *Proceedings of 34<sup>th</sup> International ICSOBA Conference, Travaux* No. 45, Quebec City, Canada, 3 – 6 October 2016, Paper KN01, p2 (Presentation pdf available from ICSOBA).

3. Benoit Verreault et al., Millivolt Anodes and Cicero - new tools for better pot and potline control, *Proceedings of 33<sup>rd</sup> International ICSOBA Conference, Travaux* No. 44, Dubai, UAE, 29 November. – 1 December 2015, Paper AL11, 589-597.

