Testing a new STARprobe™ Measurement Based Ratio Control Algorithm Using a Dynamic Cell Simulator

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Introduction

In addition to the two main tasks an aluminium reduction cell controller has to perform, namely to keep both the dissolved alumina concentration in the bath and the anode cathode distance (ACD) under tight control, modern cell controllers are also in charge of keeping the bath ratio (or excess AlF_3) concentration under control.

This task has proven to be quite challenging despite the fact that, at first glance at least, it looks quite straightforward. Fluoride evolves out of the cell; a big fraction of that fluoride is captured by the fresh alumina in the scrubber and returns to the cell as part of the secondary alumina feed to it. The part that is not returning to the cell must be compensated by direct AlF_3 feeding in order to keep constant the bath ratio in the cell. The cell controller performs that task using feedback control algorithms based on regular measurements performed by cell operators.

Introduction

Recently Alcoa has develop a revolutionary new technology to measured bath ratio in potroom almost as quickly as you can measure bath temperature. Furthermore, in addition of the excess AlF_3 concentration, the new STARprobe^{TM} can also measures the bath temperature, the dissolved alumina concentration and the cell superheat. That last information can be use as part of the cell control logic as previously presented by Rieck and al.

A dynamic cell simulator can be use to compare the efficiency of the traditional combined bath sample/XRD analysis and bath temperature measurement bath ratio control logic and a new control algorithm based on STARprobes^{TM} excess AlF_3 concentration and superheat measurements.

Performing the AlF_3 mass balance

Using a 300 kA cell as example, the fluoride mass balance can be performed as follows:

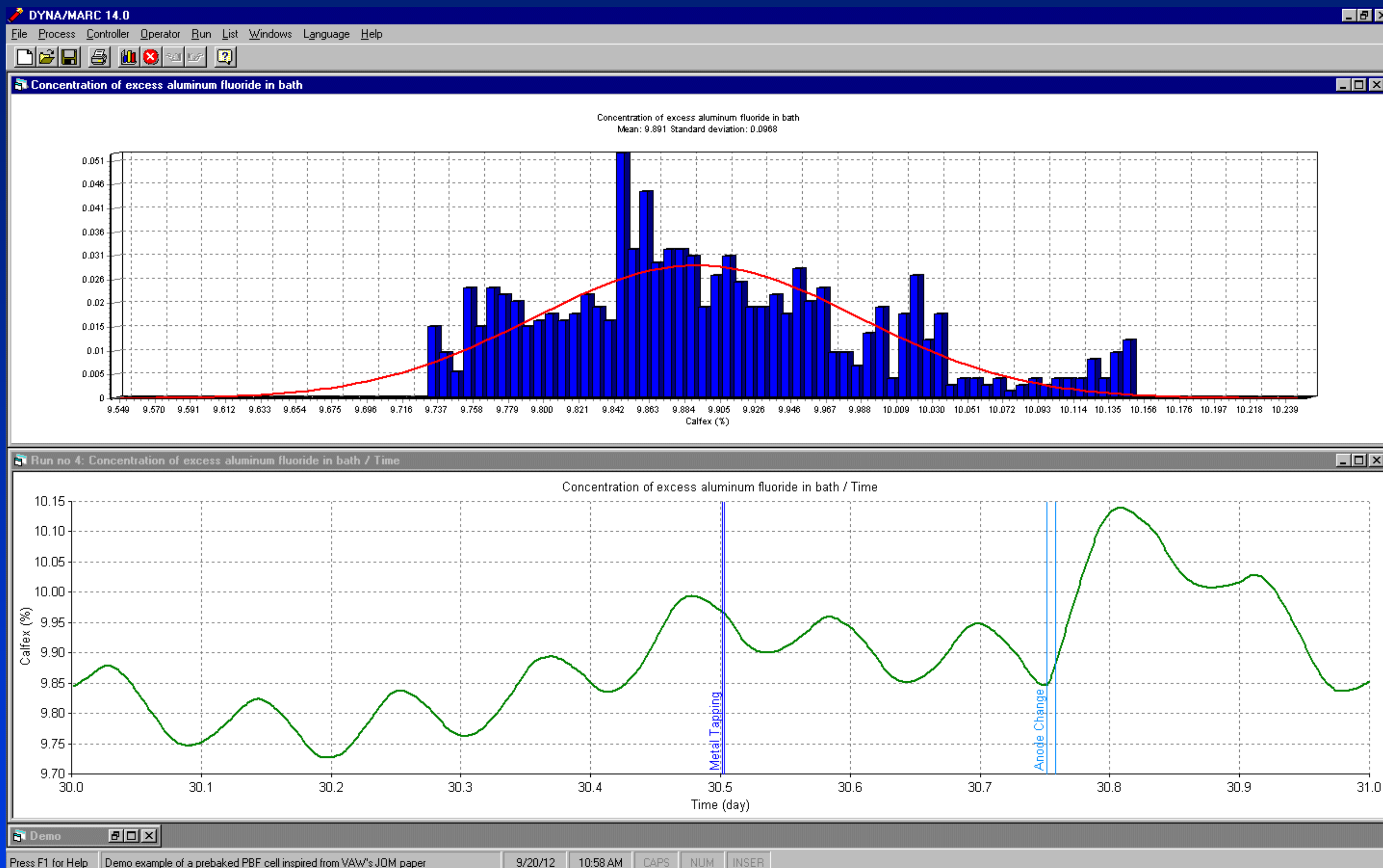
1. **Fluoride evolution rate is calculated to be 33.6 kg F / T Al with the cell conditions selected, namely 10% excess AlF_3, 970 °C and a good anode cover, for a 300 kA cell producing 94.7 kg Al / hr, this represents the equivalent of 4.7 kg of AlF_3 that evolves out of the cell each hour.**
2. **The equivalent of 3.6 kg /hr of AlF_3 is fed back to the cell by the secondary alumina, on average or at the nominal 100% alumina feeding rate.**
3. **This leaves 1.1 kg /hr of AlF_3 that must be directly fed using a point breaker feeder (PBF) under the supervision of the cell controller.**

Performing the AlF_3 mass balance

Considering that the cell contains close to 8 tons of bath and hence about 800 kg of excess AlF_3, this means that if the direct AlF_3 is completely stopped for some reason, it would take about 72 hours for the mass of excess AlF_3 to be reduced by 80 kg and hence the bath excess AlF_3 concentration to drop by 1% to 9%.

Considering that relatively slow response time of the cell, it should be rather easy to keep the excess AlF_3 concentration under tight control, but since it is clearly not the case in the great majority of smelters, some other factors must be complicating things.

Daily operations influence on bath ratio



In addition of the irregular AlF_3 addition, the excess AlF_3 concentration variation is influenced by thermal events affecting the AlF_3 evolution like the bath temperature but more importantly by the ledge thickness variation. Figure above shows the daily variation of the concentration of AlF_3 in the bath in absence of control and any AlF_3 mass imbalance. The standard deviation on the average value is about 0.1%.

Sampling frequency and delayed XRD results

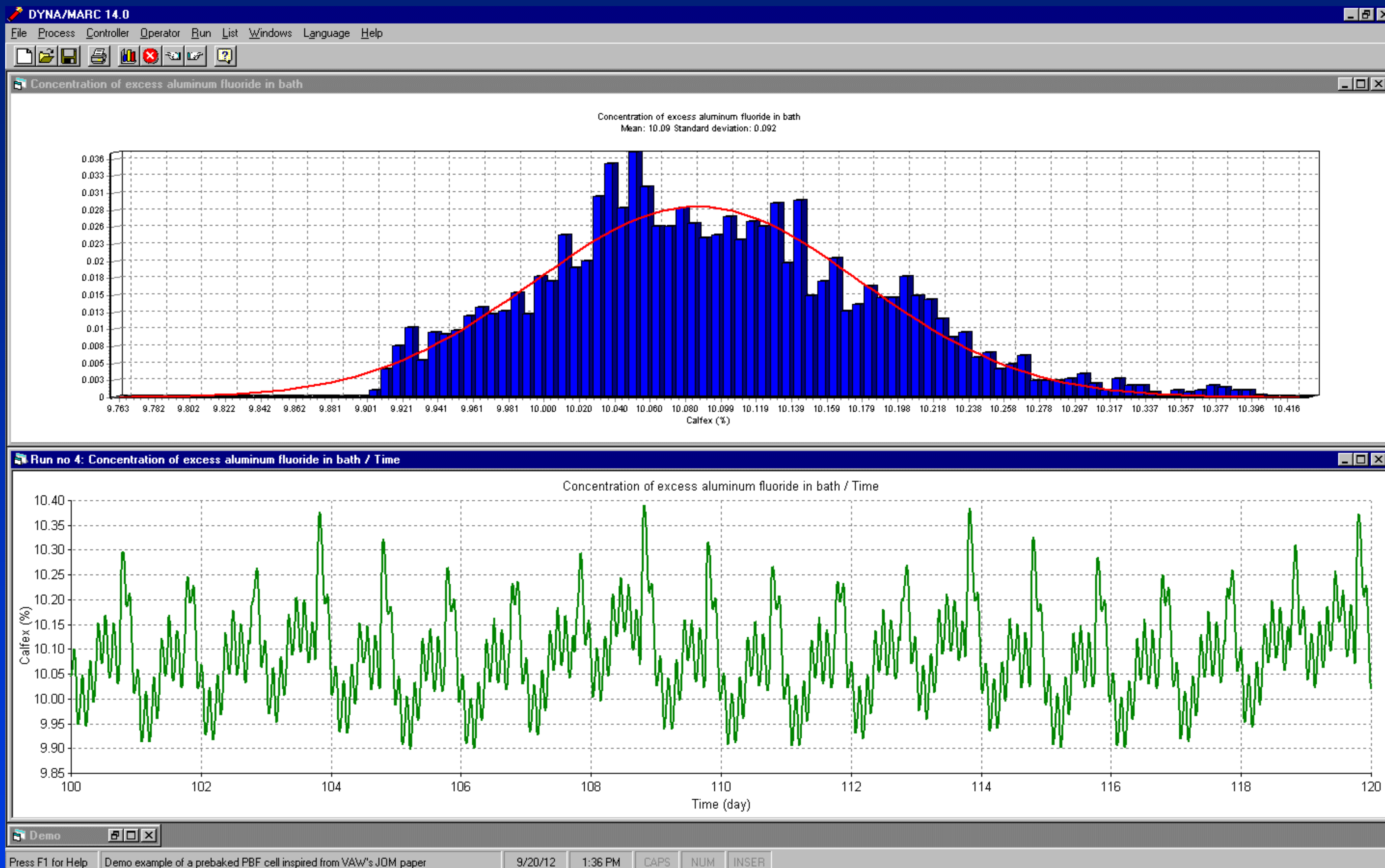


Figure above shows the variation of the AlF_3 for a period of 20 days again without control and any mass imbalance.

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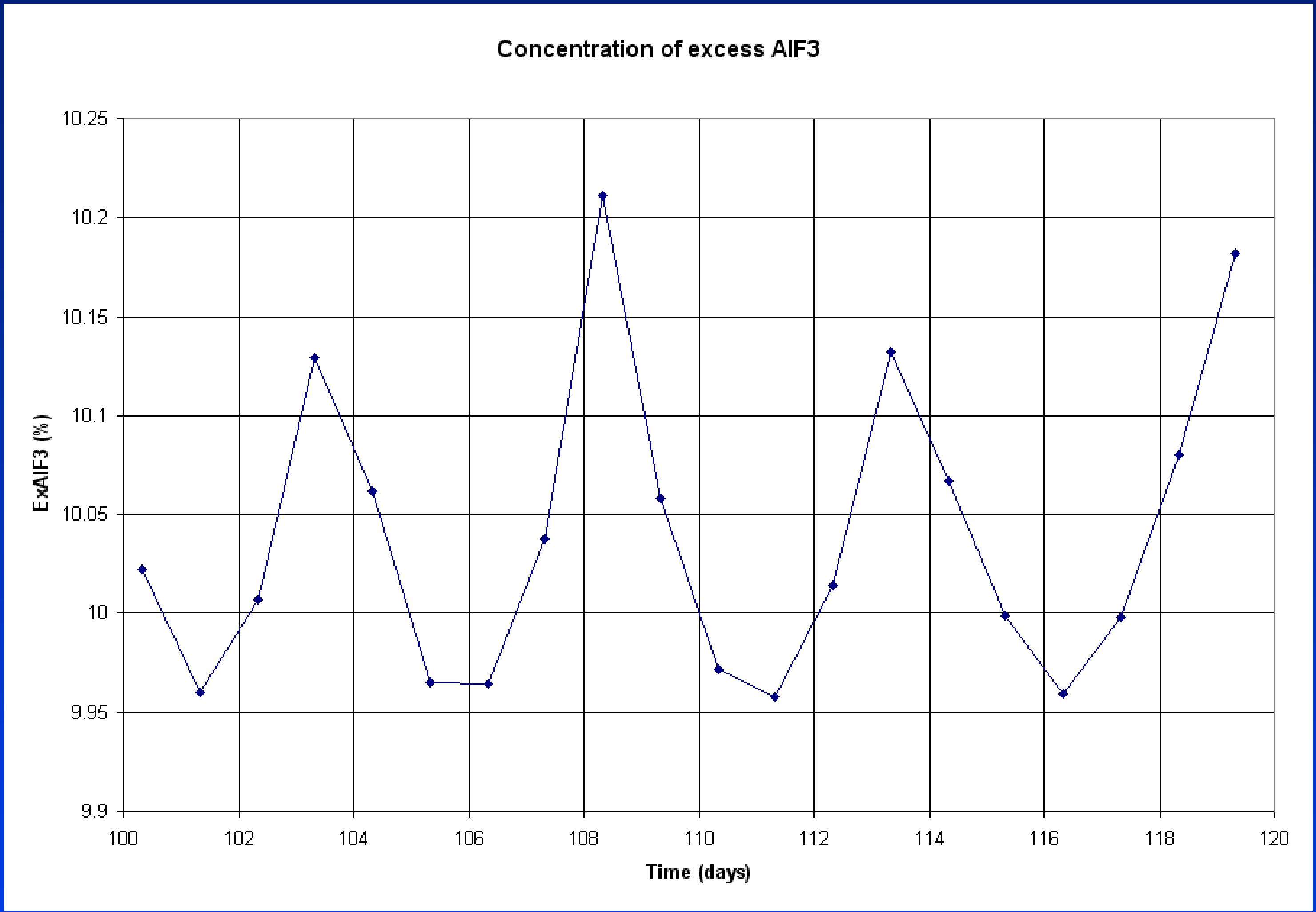
Sampling frequency and delayed XRD results



Corresponding 20 days of excess AlF_3 concentration sampling results assuming no bath sampling noise.

Bath sampling noise problem

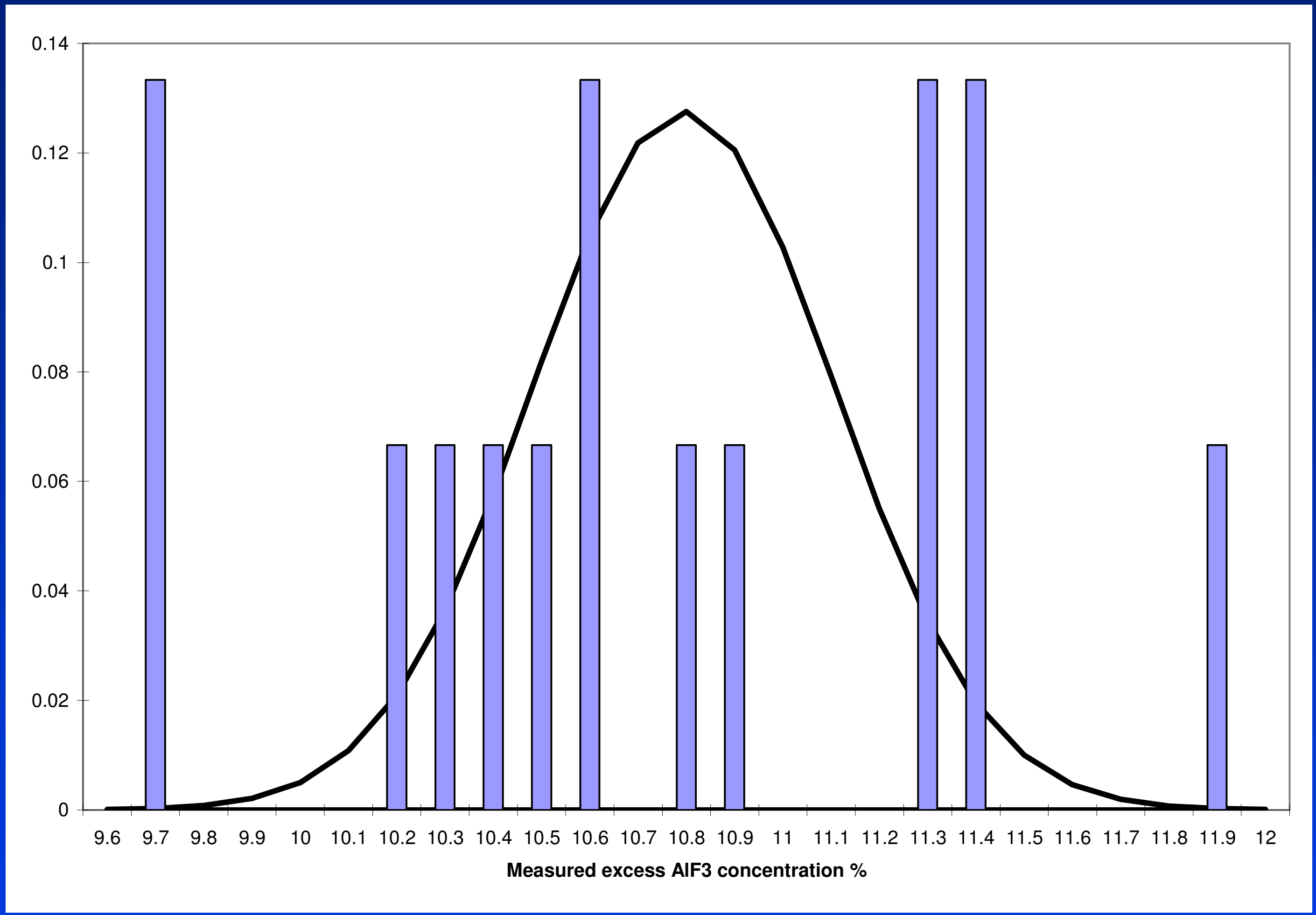


Figure above highlights the relative variability or lack of strict repetitivity of the measurements which in turn highlight the lack of homogeneity of the bath. The standard deviation of that bath sampling noise has been evaluated to be around 0.5 % which is 5 times greater than the process noise generated by daily events (ref: ICSOBA 2012).

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Bath sampling noise problem

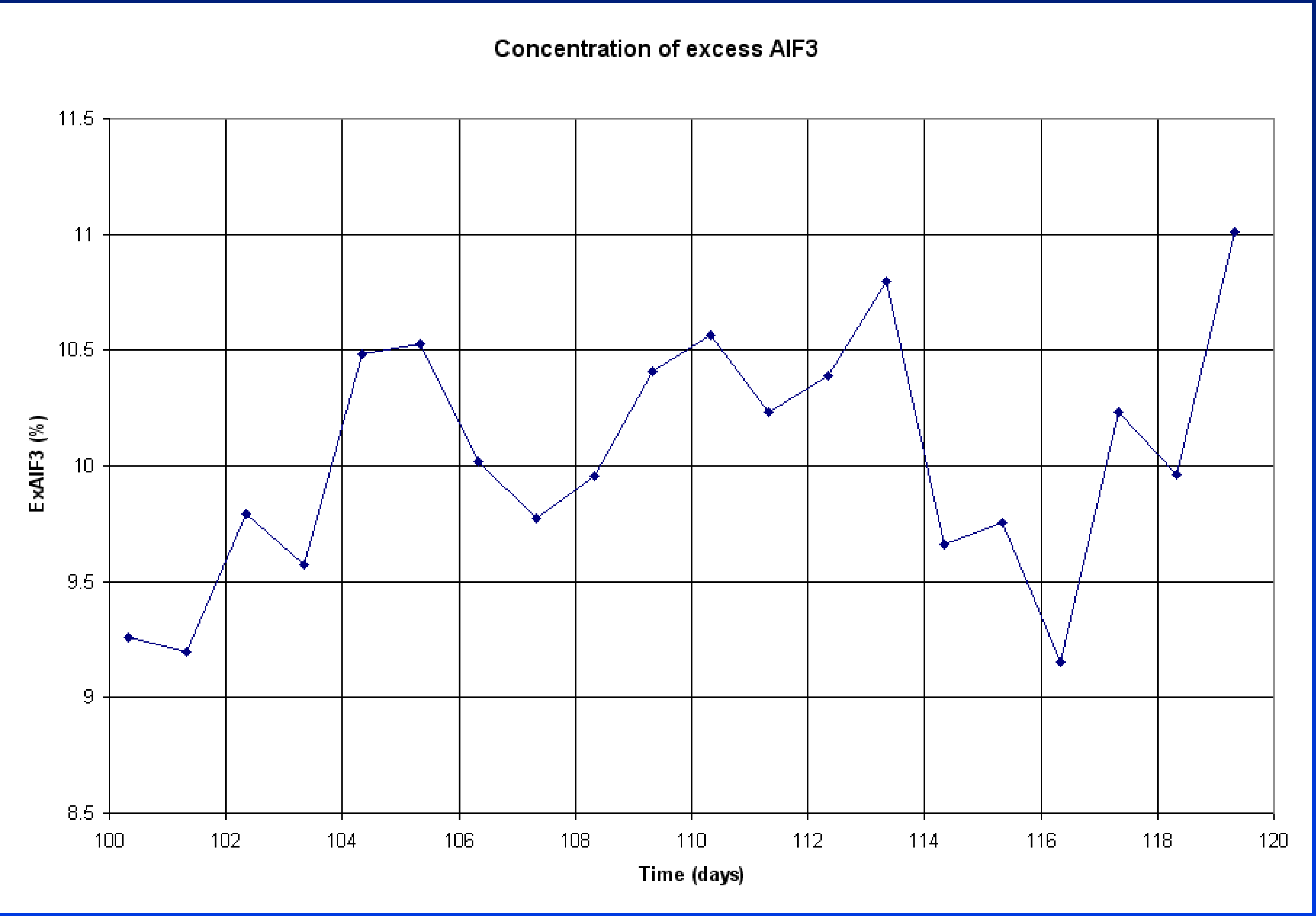
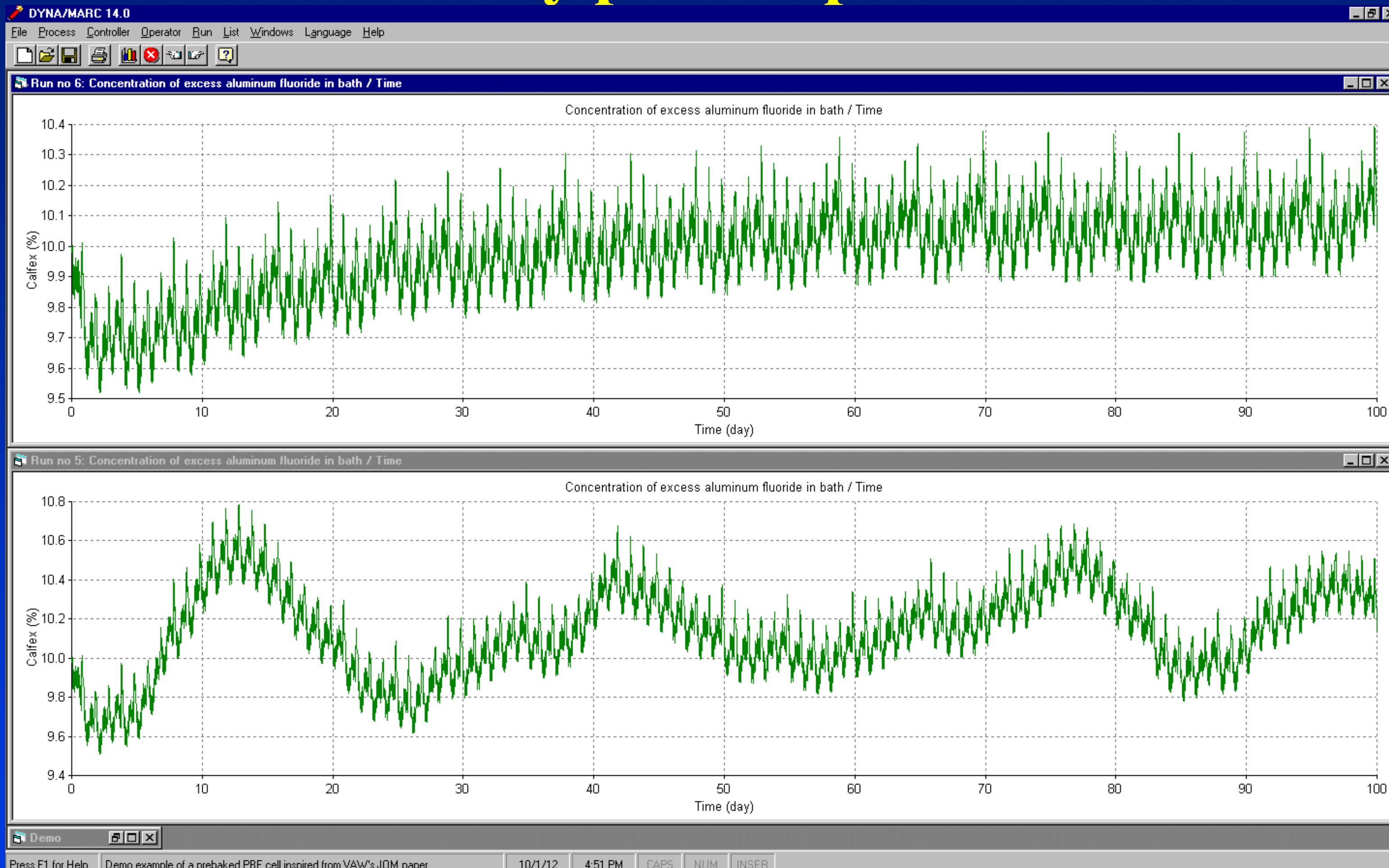


Figure above shows the results of bath sampling performed on the 20 days period when a 0.5% standard deviation white noise is added to the noise free results

Simulated process response using standard control without any process perturbation

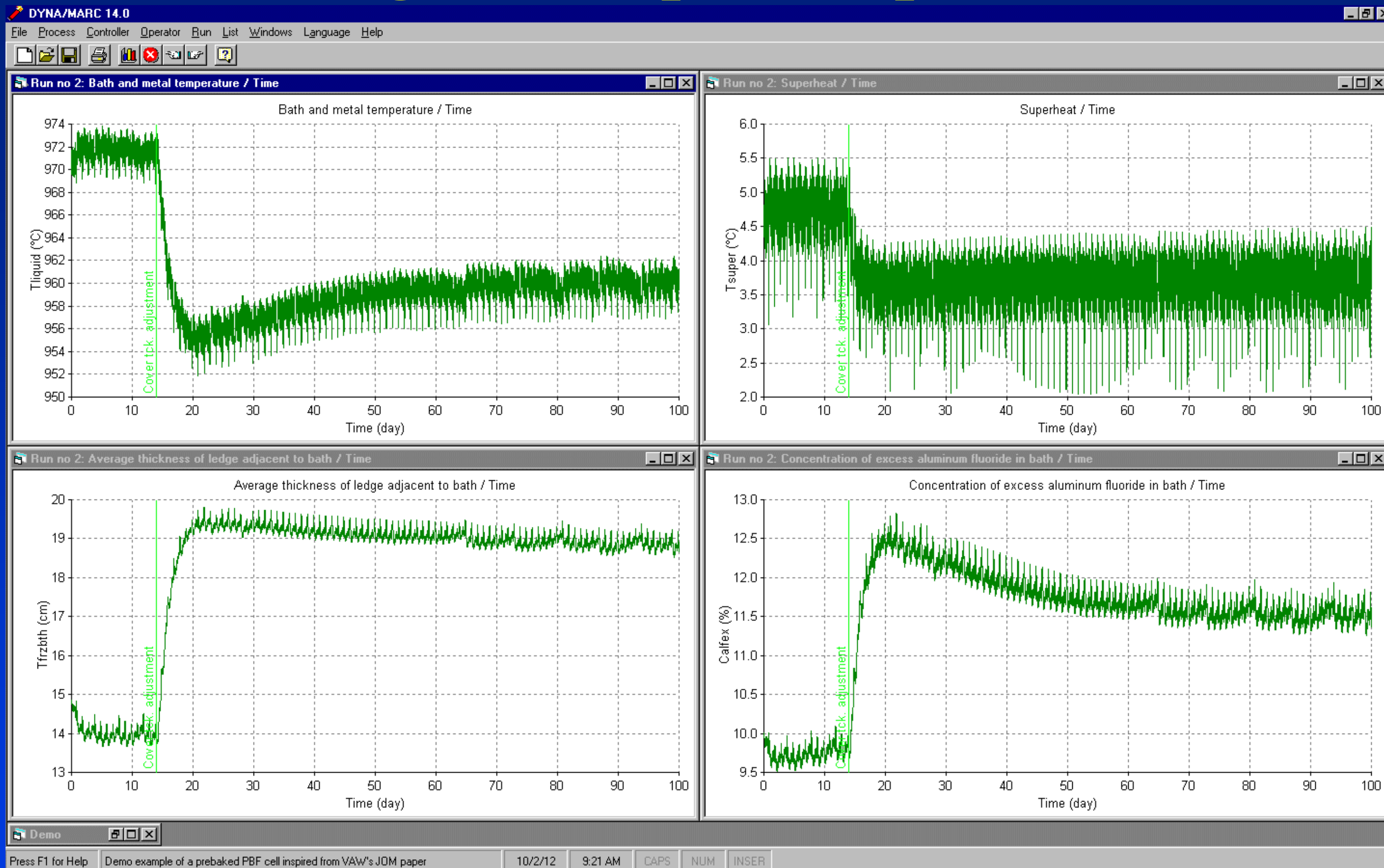


Simulation of the process without perturbation; top without control, bottom with feedback control, 10% target concentration: XRD results, once per day, 1 day delay, 0.5 kg/hr% proportional band and -0.1 kg/hr°C proportional band for temperature.

Simulated process response using standard control with a significant process perturbation

In order to more seriously test the stability of the feedback control loop, a major perturbation is added to the simulation. On day 14, about half of the anodes cover material is removed in doing so increasing the anode panel heat loss by about 30 kW from 230 kW to 260 kW.

Simulated process response using standard control with a significant process perturbation



As we can see in figure above, as a natural response, the cell must reduce its cathode heat loss of the same amount by reducing its superheat by about 1 °C and increasing its ledge thickness by about 5 cm. As a result, of this extra ledge formation, the excess AlF_3 increase by about 2% and remains close to 12% if the direct AlF_3 additions remain unchanged.

Simulated process response using standard control with a significant process perturbation

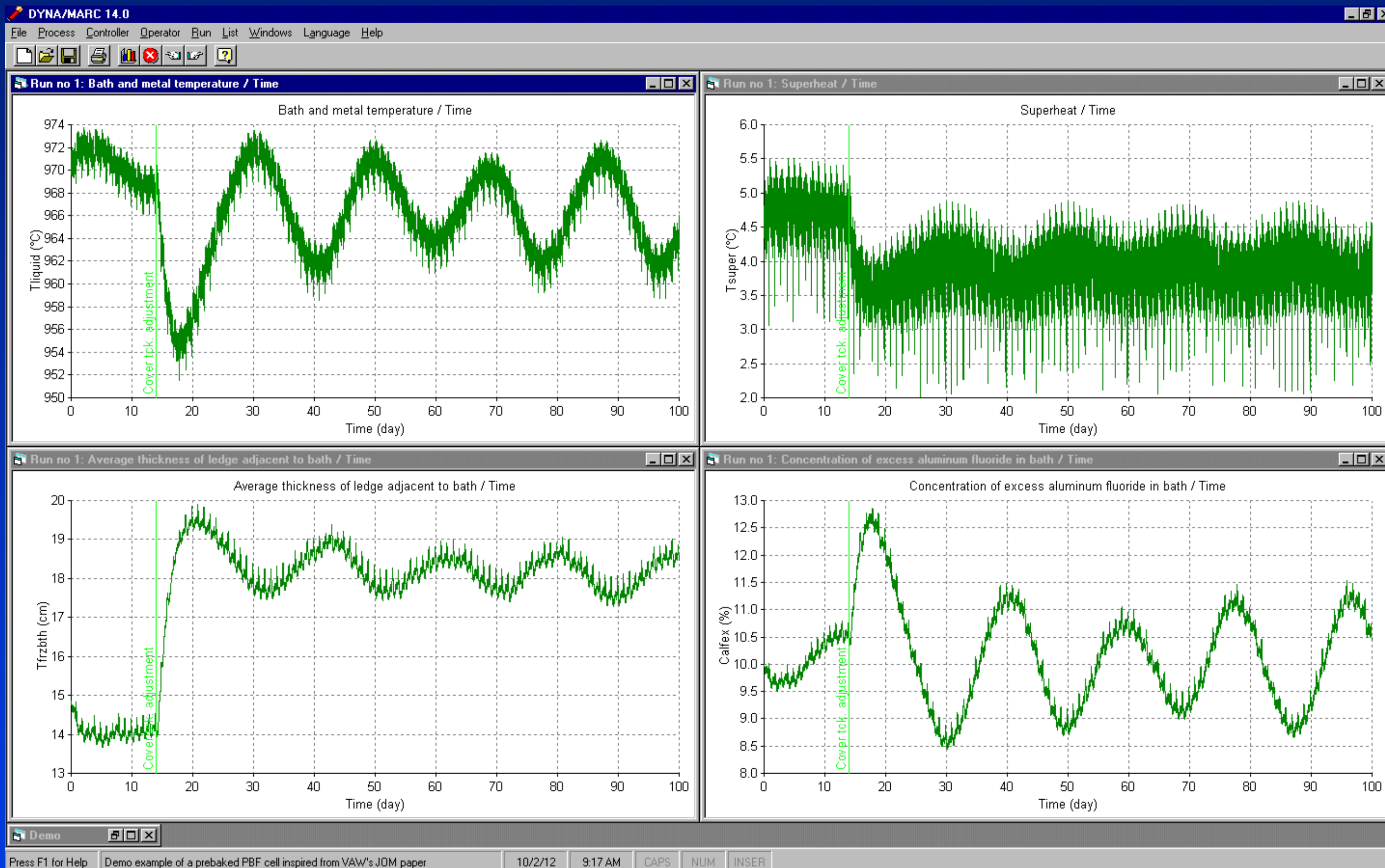
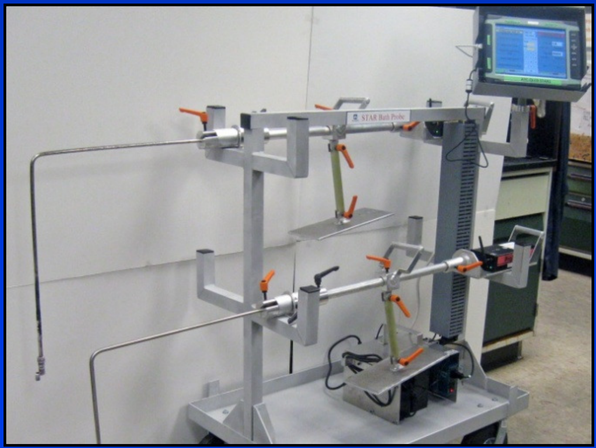


Figure above presents the results obtained using the standard control described above. After the change of superheat, the 970 °C temperature target is no longer compatible with the 10% excess AlF_3 target, this combined with the 1 day offset between the AlF_3 feedback and the temperature feedback generates a cyclic response characteristic of somewhat unstable feedback control.

The new STARprobe™

The STARprobe™ is a portable device that takes real time measurements of bath properties, such as Superheat, Temperature, Alumina concentration and bath Ratio or acidity (STAR), in electrolysis cells. This synchronicity of measurements is a most important step forward in improving the control and efficiency of electrolysis cells.



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The new STARprobe™

Same Replaceable Probe tips

The new STARprobe™

Probe Head (Box)

The new STARprobe™

Tablet PC

The new STARprobe™

Considering the great advantages of the STARprobe™, Alcoa has decided to share the technology with the rest of the aluminium industry starting from 2012. In this regard, Alcoa has just appointed STAS, a well recognized leader in the aluminium industry (www.stas.com), to commercialize the new STARprobe™ analyzing system.

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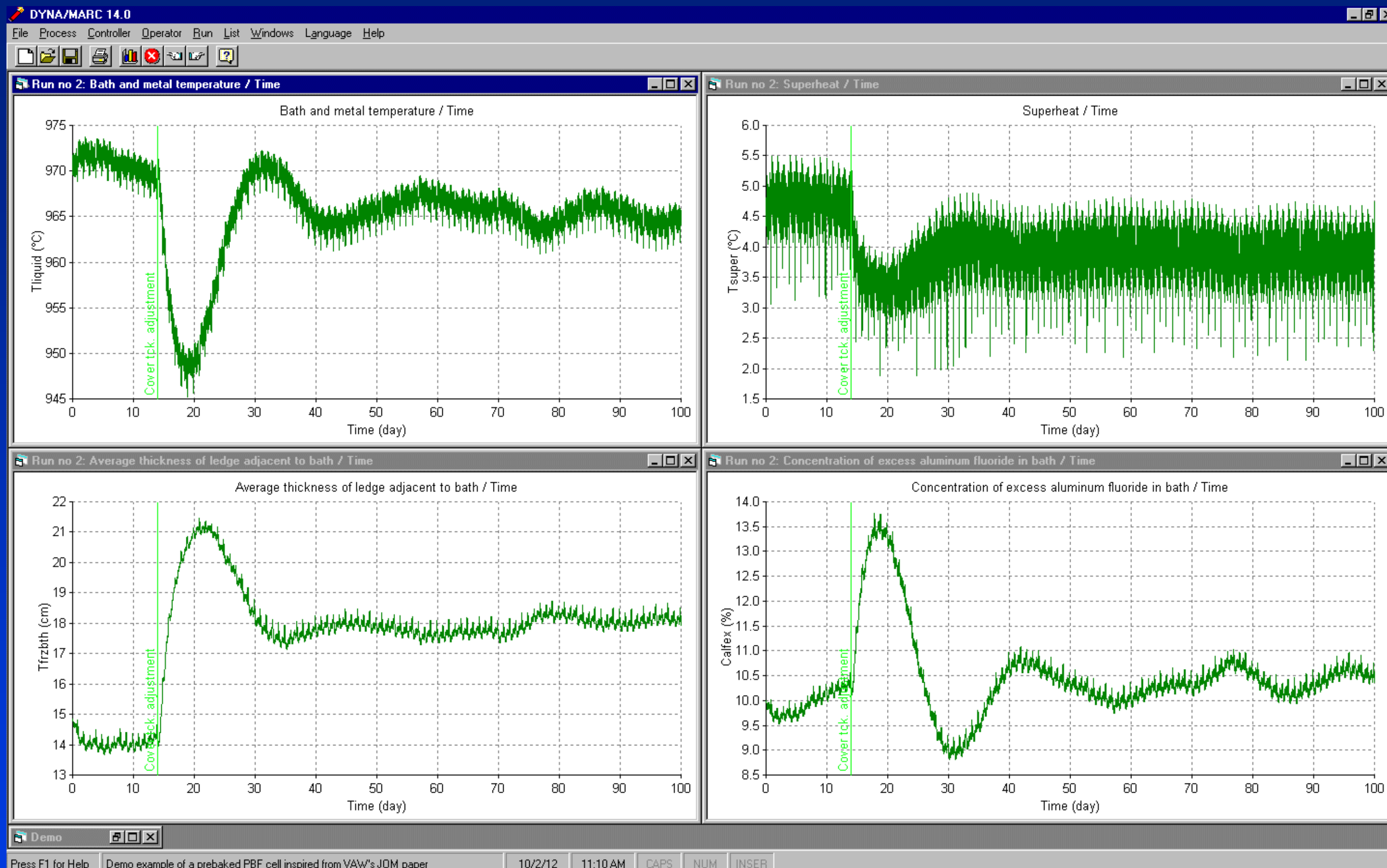
Simulated process response using STARprobe™ measurements based control with a significant process perturbation

The exact same major perturbation is use to test the efficiency of a STARprobe™ measurements based feedback control loop. The same 1 day measurement frequency is used and the same 0.5 kg/hr% proportional constant for the AlF_3 feedback loop. Obviously in this case however, the measurement results are available without delay.

In addition, the measured superheat is also used in a separate feedback loop where the target cell resistance is adjusted based on the offset between the target superheat and the measured superheat.

The measured superheat is also affected by a very significant bath sampling noise. That bath sampling noise was estimated to have a standard deviation of about 2°C in previous study so a 2°C standard deviation white sampling noise was added to the simulation.

Simulated process response using STARprobe™ measurements based control with a significant process perturbation



Simulation of the process with a significant perturbation; feedback control, 10% target concentration: STARprobe™ measurements once per day, 0.5 kg/hr% proportional band and daily 0.1 micro-ohm target resistance correction due to superheat offset from target.

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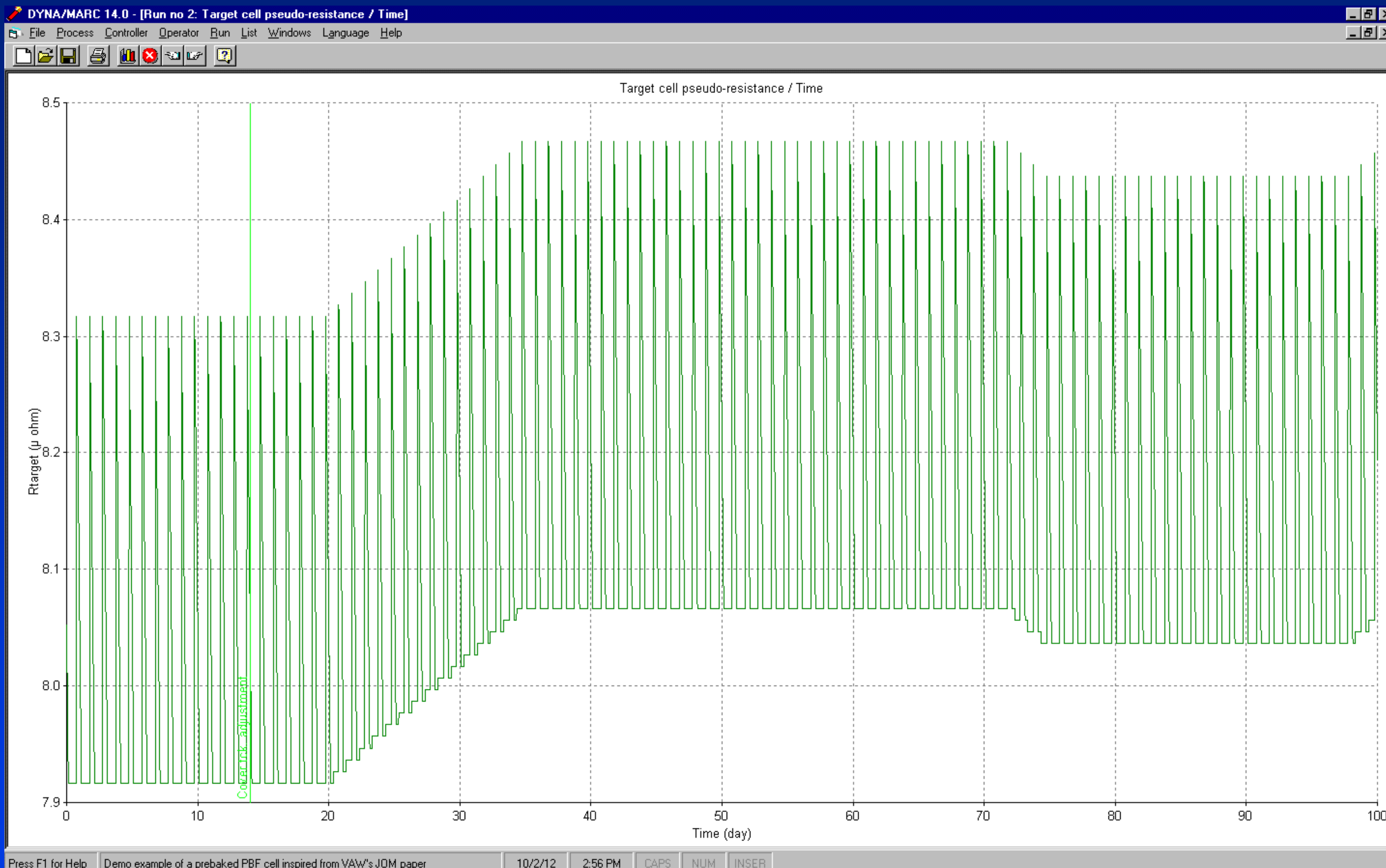
Simulated process response using STARprobe™ measurements based control with a significant process perturbation



Evolution of the cell target resistance (there is a 0.4 micro-ohm change of target resistance each day during the anode change event).

Conclusions

- A new control logic scheme based on independent control of the excess AlF_3 and the cell superheat made possible with the revolutionary new STARprobe^{TM} measurement tool was demonstrated to be superior to the standard single feedback control loop using two target variables namely the excess AlF3 and the operating temperature to control a single control action namely the direct AlF_3 additions.
- The author hopes that this demonstration study highlights the value of using the new STARprobe^{TM} measurement instead of bath samples/XRD analysis and separate temperature measurements to perform bath ratio control.
- The STARprobe^{TM} developed by Alcoa is now available to the hole aluminium industry through STAS (http://www.stas.com/en/starprobetm.html).

Conclusions

- The author also hopes that this demonstration study highlights the value of using a dynamic cell simulator to optimize existing cell controller algorithms or to test new ones without putting real cells at risk.
- The Dyna/Marc cell simulator used in this study is available to the whole aluminium industry through GeniSim Inc. Version 14 supports adding the observed bath sampling noise to the AlF_3 measurements and using STARprobe™ measurements instead of bath samples/XRD analysis to perform bath ratio control.