In Situ Alumina Feed Control

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Replacement of the pseudo-resistance variable by the more robust predicted voltage variable is recommended for potline process control. The predicted voltage variable has a greater sensitivity for accurate detection of in situ bath alumina concentration. An alumina ore feed control strategy employing the predicted voltage variable is described.

INTRODUCTION

One of the useful purposes of pseudo-resistance ($R_p$) computations is the inference of low alumina concentration in an aluminum reduction cell during a tracking cycle. Pseudo-resistance is computed via

$$R_p = \frac{(V - V_{ext})}{I}$$

(1)

where $V$ is cell voltage, $I$ is line amperage, and $V_{ext}$ is the extrapolated voltage at zero amperage (intercept value). $V_{ext}$ is employed as a constant whereas in fact it is not. Pseudo-resistance is more useful than raw cell voltage as a control variable because many cell voltage changes are a consequence of fluctuating line amperage and anode/cathode distance (ACD) changes produced by anode bridge adjustments. Smaller and more subtle cell voltage changes can occur more slowly as a consequence of bath chemistry and bath temperature changes with the notable exception of the short period before an anode effect. $R_p$ is sensitive to unavoidable errors in the selection of $V_{ext}$. In this paper, the use of a variable called predicted voltage ($V_p$) as a more robust indicator of alumina concentration covering the entire range of typical alumina concentrations is proposed. $V_p$ can be computed as follows:

$$V_p = R_p \cdot I_R + V_{ext}$$

(2)

where $I_R$ is a constant reference line amperage which is the same as or close to the average targeted line amperage. By substituting (1) into (2) it becomes clear that the sensitivity of $V_p$ to errors in $V_{ext}$ is decreased:

$$V_p = (V - V_{ext}) \cdot (I_R / I) + V_{ext}$$

from which

$$V_p = V \cdot (I_R / I) + V_{ext} \cdot (1 - I_R / I)$$

(3)

Since $(I_R / I)$ is very often close to one, the sensitivity of $V_p$ to errors in $V_{ext}$ is very small when this happens. Comparison of this result with Equation 1 shows that $R_p$ does not have a compensating effect to errors in $V_{ext}$. It also follows from Equation 2:

$$\Delta(V_p) = \Delta(R_p) \cdot I_R + \Delta(V_{ext})$$

(4)

A given change in $V_p$ is not equivalent to a corresponding change in $R_p$ without knowing the change in $V_{ext}$ which is not accurately measurable in a potline environment.

ANALYSIS OF PSEUDO-RESISTANCE AND PREDICTED VOLTAGE VARIABLES

Error Comparison of $R_p$ versus $V_p$

The Achilles heel intrinsic to $R_p$ computations is the inability to dynamically measure an accurate value of the extrapolated intercept value ($V_{ext}$) at any given moment in a potline environment. It has been established that $V_{ext}$ does fluctuate if the bath alumina level is changing. The 95% confidence interval for extrapolated values of $V_{ext}$ can be large, as illustrated in Figure 1 where a simulated data array of 41 points was generated with an amperage dispersion from 165 to 175 kA. The impressed “true” value of $V_{ext}$ was set at 1.650 to generate cell voltage and
line amperage values that maintained impressed values of a constant \( R_p \) of 15.29 and a constant \( V_p \) of 4.250. The only errors were \( \pm 0.10\% \) randomized errors impressed upon both volts and amps. Linear regression of volts versus amps produced the intercept, \( V_{ext} \), where the slope was multiplied by 1,000 for an estimate of \( R_p \). Regression slope and intercept values were used on \( I_R = 170 \) to generate the estimate of \( V_p \). The 95\% confidence intervals for a simulated best case scenario are:

\[
V_{ext} (1.607–1.718); \text{"true" value} \ = \ 1.650 \\
R_p (14.89–15.55); \text{"true" value} \ = \ 15.29 \\
V_p (4.250–4.251); \text{"true" value} \ = \ 4.250
\]

These are sobering results which dampen exuberant confidence in the dynamical accuracy for any given estimate of \( V_{ext} \) and \( R_p \). The amperage dispersion of 170 \( \pm 5 \) kA in this example is extreme since the majority of potlines do not experience frequent amperage changes of this scale. Most dynamical estimates of \( V_{ext} \) in typical potlines today by linear regression methods would not be credible since line amperage fluctuations are most often small. This simple example might well generate renewed and greater relative confidence in the estimate of \( V_p \) as a control variable since unavoidably significant errors in \( V_{ext} \) at any given moment produce relatively smaller errors in \( V_p \) compared to \( R_p \).

Another example advocating \( V_p \) as a more suitable variable for potline control purposes is presented in Table I. Although there are only two data points for the sake of simplicity, the purpose of this idealized exercise is to demonstrate the slope error comparison of \( R_p \) versus \( V_p \). Although "true" values of the variables are never known, the results in Table I show clearly the resulting hypothetical errors if a constant working value of \( V_{ext} = 1.650 \) is chosen when in fact the "true" but unknowable values are different. Since the time slope is employed to estimate or predict bath alumina levels, the results demonstrate the superiority of \( V_p \) for in situ alumina prediction since the slope error of \( \pm 0.5\% \) is relatively much smaller in an absolute sense than the \( R_p \) slope error of \( \pm 38.3\% \). Since \( V_{ext} \) decreases as both \( R_p \) and \( V_p \) increase (and vice versa), a pernicious effect is exerted on the accuracy of the \( R_p \) time slope. The \( V_p \) time slope is affected not nearly as much by unknown changes in \( V_{ext} \).

\( R_p \) slope values prove most reliable only when the alumina concentration is sufficiently low that the \( R_p \) slope and rate of change of slope is large enough to detect a depleted alumina condition. However, it is possible to accurately measure and track in situ alumina concentrations using \( V_p \) throughout the entire operating alumina concentration range, not just when low levels of bath alumina have been reached. An ability such as this may well open the way for a new approach to improved alumina ore feed control.

An additional comparison of \( R_p \) versus \( V_p \) employs the total differential to determine the \( \text{max/min intrinsic error} \) (\( dw \)) for any given data point:

\[
\begin{align*}
\text{If } w &= f(x,y,z), \text{ then } dw &= (\partial w/\partial x)dx + (\partial w/\partial y)dy + (\partial w/\partial z)dz \\
&= \left(\partial R_p/\partial V_{ext}\right)\Delta V_{ext} + \left(\partial R_p/\partial V_p\right)\Delta V_p \\
&= \left(\partial V_p/\partial I_R\right)\Delta I_R + \left(\partial V_p/\partial V_{ext}\right)\Delta V_{ext}
\end{align*}
\]

(5)

\[
\begin{align*}
d(R_p) &= \left[-(V-V_{ext})/I_R\right]dI \\
&\quad + \left[1/I_R\right]dV - \left[1/I_R\right]dV_{ext}
\end{align*}
\]

(6)

\[
\begin{align*}
d(V_p) &= \left[-(V-V_{ext})/I_R\right]dI \\
&\quad + \left[1/I_R\right]dV - \left[1/I_R\right]dV_{ext}
\end{align*}
\]

(7)

For example:

\[
\begin{align*}
V &= 4.250 \text{ and } \Delta V = \pm 0.002 \\
I &= 175.0 \text{ and } \Delta I = \pm 0.2 \\
V_{ext} &= 1.650 \text{ and } \Delta V_{ext} = \pm 0.05 \\
I_R &= 170 \\
R_p \pm \Delta(R_p) &= 0.01486 \pm 0.00031 \\
\text{error} &= \pm 2.1 \\
V_p \pm \Delta(V_p) &= 4.176 \pm 0.006 \\
\text{error} &= \pm 0.1
\end{align*}
\]

There is more than an order of magnitude difference that separates the intrinsic errors of \( R_p \) and \( V_p \) in this example.

The case for advocating the replacement of \( R_p \) by \( V_p \) seems a strong one. There is a considerable amount of mathematically induced intrinsic error from any given choice for a constant value of \( V_{ext} \) in the computation of extrapolation dependent \( R_p \). This error is relatively lacking by a wide margin when interpolation dependent \( V_p \) is computed and in fact vanishes when the operating line amperage \( I_R \) is the same as the reference line amperage \( I_R \).

**Table I. \( R_p \) versus \( V_p \) Hypothetical Comparison**

<table>
<thead>
<tr>
<th>Min.</th>
<th>&quot;True&quot; volt</th>
<th>&quot;True&quot; amp</th>
<th>&quot;True&quot; ( V_{ext} )</th>
<th>&quot;True&quot; ( R_p )</th>
<th>&quot;True&quot; ( V_p )</th>
<th>Working ( R_p )</th>
<th>Working ( V_p )</th>
<th>Working ( V_{ext} )</th>
<th>% error</th>
<th>true slope</th>
<th>working slope</th>
<th>% error</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4.2000</td>
<td>171.00</td>
<td>1.620</td>
<td>15.088</td>
<td>4.1849</td>
<td>14.912</td>
<td>4.1851</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4.1785</td>
<td>169.00</td>
<td>1.615</td>
<td>15.169</td>
<td>4.1937</td>
<td>14.962</td>
<td>4.1935</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( I_R = 170.00 )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>true slope</td>
<td>working slope</td>
<td>% error</td>
</tr>
<tr>
<td>( R_p ) (( \mu )l/min)</td>
<td>0.0162</td>
<td>0.0100</td>
<td>-38.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>( V_p ) (mv/min)</td>
<td>1.76</td>
<td>1.68</td>
<td>-4.5</td>
<td></td>
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