USING A MAGNETOHYDRODYNAMIC MODEL TO ANALYZE POT STABILITY IN ORDER TO IDENTIFY AN ABNORMAL OPERATING CONDITION

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Abstract

A numerical simulation model solves the magnetohydrodynamic equations for the real geometries and busbar arrangements of operating cells. This model predicts the natural frequencies of oscillation of the cell, which can be identified by analyzing anode currents.

The model calculates how an anode change affects the natural frequencies. Measurements were made for a simulated anode change (simply isolating the anode), and for a real change (where material was deliberately allowed to sink and freeze to the cathode). The predicted fluctuations of anode currents were in good agreement with those measured in both cases, the frequency spectrum of the anode current indicating the presence or absence of bottom crust. Thus, analyzing the variations in the anode currents during normal operation can help in identifying the reasons for abnormal operation.

Introduction

General

Often when a pot goes unstable the reason is not immediately obvious. The nature and seriousness of the instability can be conveniently analyzed by recording the fluctuations of the current in an anode rod and then performing a Fast Fourier Transformation (FFT) on the time-variant current values to obtain the natural frequencies and their amplitudes. It would be useful in monitoring the state of the pot and deciding on corrective action if a tool were available that could indicate the nature of the problem in relation to the pattern of these natural frequencies.

One of the commonly known causes of instability is changing an anode, especially when two anodes at the same corner are changed at the same time. If the change is made without due care and attention, cover material falling from the anode can sink and freeze to form a bottom crust over the surface of the cathode, and it is often observed that this aggravates the instability.

A “perfect” anode change (AC) can be simulated by insulating the pair of anodes from the anode beam so that the current they would normally carry is distributed among the other anodes in the pot. Then the anode current fluctuations can be analyzed with the FFT as before. The shift in the FFT pattern from this idealized case to the one where a bottom crust is allowed to form can then be used as an indicator for bottom crust. For the sake of brevity, the simulated AC will be referred to as the “clean” and the one forming bottom crust as the “dirty” AC.

It is however both tedious and time-consuming to make such a test, and it may reduce production; furthermore, a separate test would be needed for each kind of departure from ideal operation. If a numerical simulation model were able to predict accurately enough the change in FFT pattern, then it could be used in conjunction with the observed FFT of the anode current to diagnose problems in operation. It is the object of this paper to demonstrate the successful use of such a numerical simulation in predicting the change in FFT pattern from a “clean” to a “dirty” anode change.

Observations were made on a normally running pot at the ISAL smelter (Icelandic Aluminium Co. Ltd., Straumsvik, Iceland). The pots are arranged end-to-end, and the side of a pot facing the pots carrying current in the opposite direction is referred to as the “inside”, the other as the “outside” of the pot. In the plant a “dirty” AC was made by deliberately allowing material to fall into the bath, and after the pot had fully recovered eight hours later the same anode was insulated from the beam, making a “clean” change. The current distributions in the anodes and in the cathode collector bars were measured, as were the fluctuations in the current of the anode rod in which they were the strongest. The results of the respective numerical simulations were compared with the analysis of these observations.

Reference [1] describes the general nature of this kind of numerical simulation model. The model used here is a combined three-dimensional thermal and magnetohydrodynamic numerical simulation model, various aspects of which are described in references [2] through [8]. This model has found practical application hitherto in reducing anode consumption [9] and in designing hot changes to the external busbar configuration to increase the stability margin and thus allow stable operation at higher levels of current [10], [11]. The last two references concern among others the busbar changes made at the SORAL smelter (Sør-Norge Aluminium A/S, Husnes, Norway), where the current in a set of test pots was successfully increased from 125 KA, the level at which the two lines were operating, to 140 kA.

It is worth mentioning in passing that all the pots in both lines have now (two years later) been retrofitted with the same busbar modification, and are now operating regularly at 150 kA with a current efficiency slightly higher than they had when running at 125 kA before retrofitting.
The Model

Reference [11] describes some important aspects of how the model predicts stability, particularly as regards the interaction of the vertical and horizontal components of the magnetic field with the current. The model determines among other things the velocity of liquid bath and metal, electric and magnetic fields, metal surface contour and ledge shape, and takes account of the following aspects:

- three dimensions
- the shape of both the ledge and the cell cavity
- the liquid bath around the anodes
- pressure fields in both bath and metal

The effect of the external magnetic field is crucial. A simple wire-bar representation is used for the busbar configuration at the ends of the line and for the adjacent potrooms. The current density field is calculated for the pot under investigation during normal operation, and this field is translated in space for the other pots in the line, and also rotated where necessary.

As Figure 1 shows, the pot immediately downstream of the one under consideration is modeled in detail in three dimensions (in the figure, the pot of interest is on the left, and the current flows from left to right).

![Figure 1: The 3D representation of the pot and its downstream neighbor](image)

This is important because otherwise it would not be possible to determine the current distribution in the collector bars, which has a major effect on pot stability.

The metal surface contour is a free interface, which means that the pressure fields are calculated independently on both sides of it. The pressure at all points over the entire bath-metal interface must obviously be the same in bath and metal, so an iterative procedure is required. At each iteration, the complete model is run, i.e. a fresh calculation is made of the velocity, electric and magnetic fields, metal surface contour and ledge shape. The parameter $\psi$ is the difference in pressure between bath and metal at the interface. The point on the interface is found where it is at a maximum and that at which it is at a minimum. Figure 2 gives typical values, the upper line showing the maxima and the lower line the minima. Ten iterations are typically required for the numerical simulation to converge.

![Figure 2: Convergence of the numerical simulation model](image)

Cell stability diagram

The model can be used to derive the stability diagram, which is a plot of the natural frequencies of oscillation in the complex plane, the eigenfrequencies. The real part, the frequency, is plotted on the x-axis, and the imaginary part, the stability criterion, on the y-axis. The stability diagram is described in more detail in [11]. Figure 3 is a typical stability diagram for the ISAL pot on which the measurements were made while it operated normally at 147 kA.

The broken line at -0.006 on the imaginary axis is the stability limit: if the plot of any individual eigenfrequency extends below this line, the pot is noisy and requires corrective action. The value -0.006 is not a theoretical one, but has been established by many observations of normal and more or less noisy pots in various smelters.

![Figure 3: Stability diagram for a healthy pot at ISAL, operating at 147 kA](image)