Magnetic Compensation Loop Design using Transient ESTER/PHOENICS MHD Simulations

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Abstract

Magnetohydrodynamic (MHD) instability or waves at the metal-bath interface in the aluminium reduction cell is the major hurdle for increasing energy efficiency and productivity. The vertical magnetic field and horizontal currents in the metal interact to produce the Lorentz force which is mainly responsible for the growth of the interfacial waves. To stabilize the interface at a smaller anode-cathode distance and higher anode current density, a magnetic compensation loop has been designed without altering the existing busbar system. The effect of magnetic field compensation loops inside, outside, and on both sides of the potline circuit has been evaluated. The bath-metal interface was studied using ESTER/PHOENICS, built specifically for MHD simulations of aluminium reduction cells. Transient simulation of the interface waves was used to study the effect of vertical magnetic field bias from a neighboring potroom. Interface position was tracked with time after introducing the initial perturbation. It was observed that the magnetic compensation loop installed on both sides (tap and duct side) of the potrooms gives the most stable interface.

Keywords: Aluminium reduction cells, Magnetohydrodynamic instability of reduction cells, Magnetic compensation, Horizontal current, Vertical magnetic field, ESTER/PHOENICS.

1. Introduction

Aluminium is produced by electrolysis of alumina dissolved in a cryolite bath at a typical temperature of 950 – 970 °C in a Hall-Héroult cell. Liquid aluminium produced from the reduction process gets deposited on the cathode surface. A liquid-liquid interface exists between the bath on top and aluminium at the bottom. Aluminium and bath are in continuous motion, primarily driven by the electromagnetic Lorentz force. The Lorentz force is generated by the interaction between the electric current passing through the liquids and the magnetic field generated due to the current carrying components in and around the cell. The CO_2 gas is generated as the byproduct of the electrolysis below the anode and also drives the bath. The electric current enters the cell through anodes, passes through the liquid bath, aluminium, carbon cathode, and exits via cathode collector bars. Busbars connected to the cathode collector bars carry the electric current to the next cell. A potline in an aluminium smelter has two potrooms and each potroom has many cells connected in series. The electric current from the rectifier enters through one potroom of the potline and exits from another, forming a closed loop. Aluminium smelters across the world are known to operate at amperages between 60-660 kA, with a cell voltage of 3.5-4.5 V, depending on the design [1]. The specific energy required to produce aluminium can be as high as 14 DC kWh/kg Al [2], or even greater in some smelters. Out of the total energy consumption, 40 – 50 % is required for the electrolysis and the rest is dissipated as heat. The electrical resistance offered by the layer of bath between the interfaces of anode-bath and aluminium-bath is the highest [2] and contributes most to the heat generation in the cells. This layer is known as anode-cathode distance (ACD) and may vary between 25 to 45 mm across different smelters.

To improve overall energy efficiency, a very thin layer of ACD is required. Amperage increase in the potroom is also followed by a reduction in ACD to avoid any major change in internal heat generation. The MHD instability at the aluminium-bath interface is the major obstacle and limits the minimum value of ACD. The MHD instability or waves at the interface may grow upon lowering of ACD, resulting in frequent contacts between the aluminium-bath interface and the anode, thus, allowing the electric current to pass without electrolysis. This loss of current efficiency increases the specific energy required to produce aluminium. Therefore, an aluminium smelter needs upgrades to have better MHD stability which will support productivity increase as well as reduction of specific energy consumption.

MHD instability has been understood as a large wavelength (> 1 m) disturbance [3, 4] of rotating nature [5], which can more clearly be expressed as coupled longitudinal and transverse modes of the wave [6, 7]. Redistributed horizontal current due to the longitudinal mode will interact with the vertical magnetic field to produce a force that excites the transverse mode and vice-versa. The resonating modes interact and feed energy to each other to grow the wave amplitude. Potocnik [6] used a 3D MHD transient model on ESTER to study the interaction of the longitudinal and transverse waves of different harmonics and found a strong relation between (1,0) and (0,1) modes. A bias in the vertical magnetic field, i.e., the non-zero average value over the liquid metal area, due to the effect of neighboring potroom(s) leads to a Lorentz force distribution which is detrimental to interfacial instability [8, 9, 10]. Urata [4] and Potocnik [6], both reported a strong dependence of interfacial stability on vertical magnetic field distribution. Antisymmetric distribution of the vertical magnetic field in the liquids has been recommended for better stability [11].

The interaction of the longitudinal and transverse modes for a uniform vertical magnetic field (B_z) is shown in Figure 1, as explained by Urata [7]. Figure 2 sufficiently illustrates the interaction of waves for an antisymmetric distribution of the vertical magnetic field. The directions of the vertical magnetic field, the horizontal current of the perturbed interface ($j_{i=1,2,3}$), and the perturbed Lorentz force component ($f_{i=1,2,3}$) at the interface are shown in the illustrations.

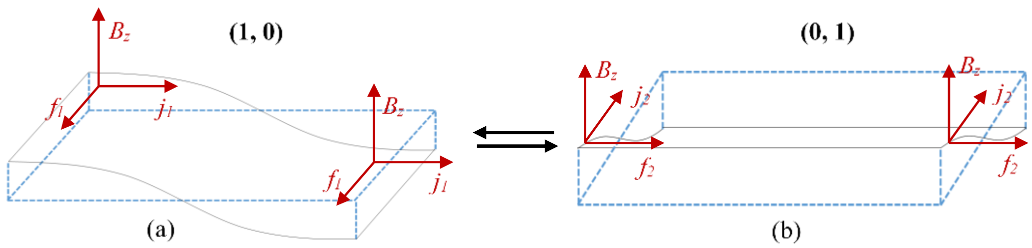

Figure 1. (a) Lorentz force (f_1) along cell width generated due to j_1 and uniform B_z, which leads to the generation of (0, 1) mode, (b) f_2 along cell length generated due to j_2 and uniform B_z, exciting (1, 0) mode.

Figures 1(a) and (b) show (1, 0) and (0, 1) modes at the interface, respectively. In Figure 1(a), the current density increases in the bath layer at the location where the interface comes closer to the anode bottom, resulting in a horizontal current (j_1) in liquid aluminium directed away from the wave crest. The uniform B_z interacts with the horizontal current to produce a component of Lorentz force (f_1) along cell width, due to which the interface gets tilted, resulting in the (0, 1) mode shown in Figure 1(b). The (0, 1) mode at interface generates horizontal current (j_2) along magnetic compensation along the duct-side only, the tap-side only, and the both sides of a potline. The 3D MHD model based on the ESTER/PHOENICS software was used to analyze and compare the interface behavior under perturbed condition. The results of the transient simulation matches closely with the analytical solution of the internal gravity waves. The interfacial oscillation reduces significantly after magnetic compensation, and the amplitude of the waves was the smallest in presence of the compensation loop along the both sides of the potline. Therefore, a magnetic compensation loop installed along duct side as well as tap side of the potline can be a practical solution to counter the effects of neighboring potroom(s) or busbars at increased amperage.

11. References

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