AL14 - The Magnetic Shielding Effect of Steel in an Aluminum Reduction Cell

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Abstract

Since several parts of an aluminum reduction cell are made of steel, their shielding effect on the distribution of magnetic field cannot be neglected. An electromagnetic finite element model of aluminum reduction cell was developed for this purpose. The magnetic fields of an aluminum reduction cell were analyzed with and without the shell and superstructure, cathode current collector bars or floor gratings. The results show that the vertical magnetic field (B_z) is strengthened at the upstream corners and alleviated at the downstream corners by the cathode current collector bars exits. While the shell has strong magnetic shielding effect, the floor grating and anode yokes and stubs have little magnetic shielding effect. On the other hand, the superstructure increases the magnetic field.

Keywords: Magnetic shielding effect, magnetic field distribution in aluminum reduction cell, finite element model.

1. Introduction

In an aluminum reduction cell, the direct current goes from busbars to anode rods, through carbon anodes, molten bath containing alumina and metal and carbon cathode to cathode collector bars. As the electrical current passes through the bath, the alumina is decomposed into molten aluminium (Al) and oxygen (O_2). The oxygen consumes carbon (C) in the carbon anode blocks and forms carbon dioxide (CO_2) which is later released to the exhaust gas system. The current then passes in cathode busbars to anodic busbars of downstream cell in the potline series of cells.

The magnetic field is generated by the electrical current that flows in the reduction cell. The relationship between the magnetic field contribution and its source current element follows the Biot-Savart law. The direction of the magnetic field follows the right-hand rule.

The third Maxwell's equation tells us that there are no magnetic charges, and therefore no sources and sinks for the magnetic field. All the field lines that enter through the surface into a volume enclosed by the surface also exit through another surface of the volume. Magnetic field lines are always closed loops. Unlike electricity, magnetic fields cannot be blocked or insulated, which makes shielding necessary. There is no way to block these field lines. Instead of attempting to stop these magnetic field lines, magnetic shielding re-routes them around an object. This is done by surrounding the device with a ferromagnetic material. Magnetic permeability describes the ability of a material to be magnetized. If the material used has a greater permeability than the object inside, the magnetic field will tend to flow along this material, instead of the objects inside.

Steel shell, superstructure, collector bars and floor grating are ferromagnetic materials in the reduction cell. Their permeability is much greater than that of other materials of the cell. Therefore, the magnetic field generated will tend to flow along those ferromagnetic parts.

The magnetic field produced by superposition of the different fields is responsible for the circulation of the metal, heaving and oscillation of the metal surface. Some of these phenomena have negative effect on the reduction process.

There are many works aiming to alleviate magnetic field by busbar configuration. Qi Xiquan [1] studied the influence of the bypassed cells and end cells on the magnetic fields. Li Mao [2] modeled the busbar configuration in aluminum reduction cells and made optimization with a genetic algorithm. Ziegler and Ruan [3] took partial account of the effect of the steel in automated optimization of the magnetic fields of the end cells.

Stephane Wan Tang Kuan et, al [4] studied the optimization of busbar design at the full smelter scale. A few designs [5-8] have been adopted to compensate for external magnetic fields with side risers. However, little attention has been devoted to the magnetic shielding effects of the ferromagnetic materials. To obtain a preferable magnetic field in the reduction cell, further studies are still necessary.

However, the irregular structure of steel complicates the magnetic field. The computation of ferromagnetic effect on the magnetic field distribution is generally expensive, because it involves a material non-linearity and interactions among the steel structures. The development of computers enables the finite element analysis of more ferromagnetic materials to be covered in the model than ever before.

The purpose of this paper is to investigate the influence of different parts of steel on the magnetic field using a finite element model of the whole cell. It is helpful for further studies on magnetic field optimization by steel configuration.

2. Mathematic Model

To obtain the magnetic effect of the aluminum reduction cell, the electric current and the induced magnetic field should be solved.

The current is solved by the Ohm's law, which governing equation is shown in Equation (1).

$$\mathbf{J} = -\sigma \nabla V \tag{1}$$

where:

J Current density vector, A/m2,
V Electric potential, V,
σ Electrical conductivity, S/m.

For the whole cell, the current is conserved as Equation (2):

$$\nabla \bullet \mathbf{J} = 0 \tag{2}$$

Hence, using Equation (1) substitute **J**, Equation (2) turns into Laplace equation:

$$\nabla \bullet (\sigma \nabla V) = 0 \tag{3}$$

The initial magnetic field is calculated by Biot- Savart's law:

$$\mathbf{H}_g = \frac{1}{4\pi} \iiint_{vol} \frac{\mathbf{J} \times \mathbf{r}}{r^3} d(vol) \tag{4}$$

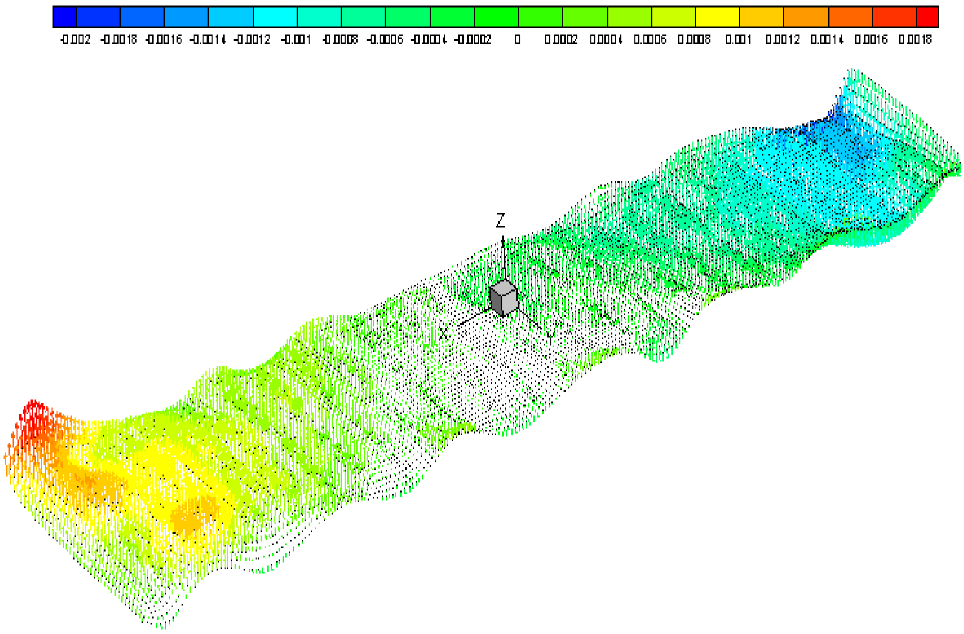

Figure 7. The direction and magnitude of B_z with ground grating in the model.

6. Conclusions

The magnetic shielding effect of the steel parts was analyzed. The results showed that each part has different magnetic shielding effect for the aluminum pad in the cell. If there were no steel in the cell, the magnitude of B_z would be relatively large. Most of the magnetic field generated by the outside busbars is shielded by the shell and little is shielded by the ground grating. The collector bars have some influence on B_z at four corners of the cell. The yokes and stubs have little influence on the magnetic field. However, the superstructure brings more magnetic lines through the metal pad.

In order to lower the B_z in the metal pad, more efforts could be directed on the design of the shell and superstructure for a given busbar system.

7. References

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