Magnetic Field Improvement in Electrolytic Cells by Shielding

Nitin Kumar Tiwari[1], Bibhudatta Mohanty[2], Shubham Kurvey[3] and Dagoberto Schubert Severo[4]
1. Chief Operating Officer, Metal
2. Innovation Head
3. Assistant Manager, Innovation Cell,
Vedanta Aluminium Ltd, Jharsuguda, India
4. Director, Caete Engenharia Ltda, Porto Alegre, Brazil
Corresponding author: shubhamsanjay.kurvey@vedanta.co.in

Abstract

Magnetohydrodynamics (MHD) plays an important role in the performance of aluminium electrolysis cells. The magnetic field is generated by the electrical current that flows in the reduction cell. The vertical component of magnetic field (Bz) is responsible for MHD instability in the cell. Unlike electricity, magnetic fields lines cannot be blocked or insulated but only deformed or redirected, which makes magnetic shielding a valuable option for reducing the local Bz magnitude, by concentrating the field lines inside the shield material.

A ferromagnetic shielding plate (“Kavach”) was designed using Finite Element modeling, to be employed in Vedanta cells in order to reduce the Bz field located at the cell corners, inside the metal pad. This is the critical location of the vertical magnetic field for this technology. Several trials have been conducted in the live cells using the Kavach shield, where the magnetic field was measured inside the metal by a tri-axial magnetic field probe. These trials included several options of the shielding plate in the cell compared with the no-plate situation.

Long term trials have also been carried out resulting in voltage noise reduction. This shows that the Kavach has played a significant role in reducing the instability of the cells and thereby improving its performance.

Keywords: Magnetic field, Magnetic Kavach, Cell noise, Magnetic field improvement.

1. Introduction

In the aluminium reduction cell, the electrical current is responsible for the electrolytic reduction of alumina to molten aluminium in a molten electrolyte bath. The direct electrical current (DC) that flows in the busbar network, anodes, bath, liquid metal, cathodes and collector bars is responsible for the generation of a very complex and high intensity magnetic field. This magnetic field coupled with the electrical currents in the bath and metal are responsible for the liquid metal movement by electromagnetic (Lorentz) forces. The most important component of the magnetic flux density (interchangeably referred to as “magnetic field” in this work, unless explicitly mentioned otherwise) regarding magnetohydrodynamic (MHD) instability is the vertical one, Bz. Having this component as low as possible is one of the potential strategies to achieve a stable and energy efficient cell.

Around every conductor carrying electrical current, a magnetic field is produced in circular field lines oriented as shown in Figure 1. The magnetic field vector is tangent to the circle and its direction is determined by the right-hand rule.

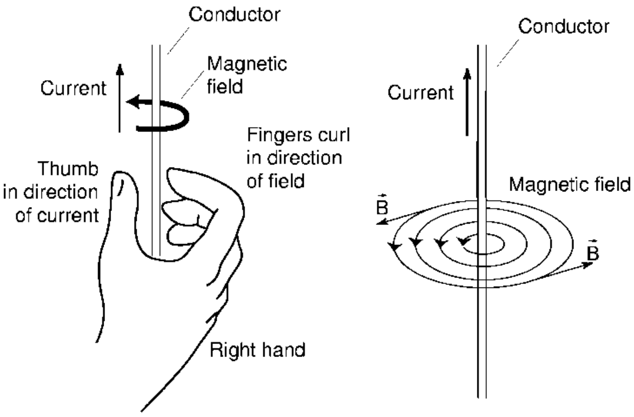

Figure 1. Right hand rule for magnetic field direction around a conductor [1].

Gauss´s Law for magnetic fields states that the total number of magnetic field lines going out of any closed surface is equal to zero, thus the magnetic flux always exists in closed paths [2]. The field lines are continuous and will find a way back to their origin. Therefore, there is no shield or material that will block magnetic fields, the field lines can only be distorted and/or redirected.

The magnetic field lines can be redistributed by concentrating them inside a ferromagnetic material. Reducing the magnetic field in a specific region requires inserting a shield of appropriate material that will change its spatial distribution. The shield causes a change in the behavior of the field, diverting the magnetic lines away from the shielded region. When the shield is inserted, the resulting magnetic field shape is dependent on the shield geometry and the material parameters [3].

The best shape for magnetic shields is thus a closed container surrounding the shielded volume as shown in Figure 2 (left). In a flat shield, as shown in Figure 2 (right), the magnetic field lines which intersect the flat shield will be compressed into the shield, leaving less magnetic field lines on the side behind the shield. However, note that while there is an area near the shield which has lower field intensity, the area near the edge of the shield has higher field. The magnetic fields of large radius are unaffected. The wider the shield, the larger the shielded area, both in width and depth.

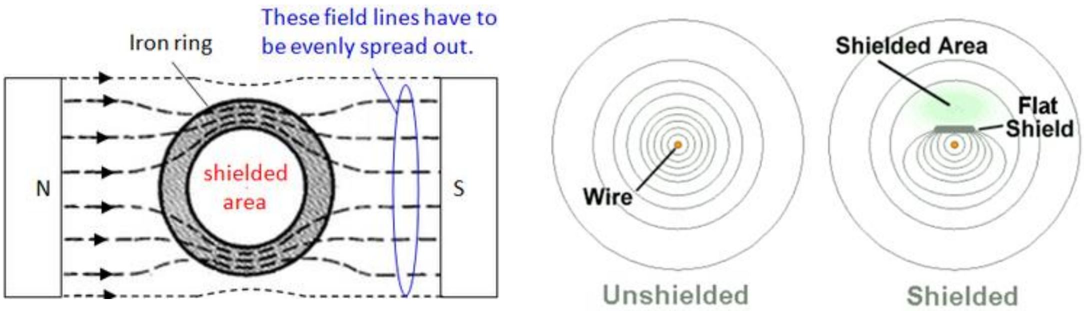

Figure 2. Left: enclosed shielded area [4], Right: opened shielded area [5].

The effectiveness of this type of shielding depends on the material's magnetic permeability. This property 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 inside the object. Permeability is also a measure of a material's ability to concentrate magnetic flux density. The higher it is, the better the shielding device.

Magnetic saturation is the state reached when an increase in applied external magnetic field **H**, (H), cannot increase the magnetization of the material further, so the total magnetic flux density **B**, (T), remains the same. Saturation is a characteristic of ferromagnetic materials that contains iron, nickel or cobalt.

There are many works on studying ways to reduce or to change the magnetic field to an optimum configuration by busbar design. The design principles of an optimum magnetic field are presented by Kjar *et al.* [6]. Also, some authors like Yiwen Zhou *et al*. [7] investigated the influence of the steel parts on the magnetic field. However, very few information could be found about using ferromagnetic materials as magnetic shield in aluminium reductions cells.

This paper discusses about the use of a ferromagnetic shielding plate ("Kavach") in improving the stability of the electrolytic cell operating at 340 kA. The Kavach was placed in live cells and lead to significant improvement in noise and average voltage reduction of the cell.

2. Finite Element Modeling

A Finite Element model of Vedanta aluminum reduction cell was developed, in which, geometrically, both anode and cathode assemblies, bath, molten aluminum pad, side ledge, lining, shell, framework of superstructure, operating floor grating and busbar system are included – Figure 3. The electromagnetic models of the Vedanta cells were run in the presence and absence of magnetic shielding. The vertical component of magnetic field was significantly reduced in the Kavach vicinity, as shown in Figure 4. Modeling studies shows that in the presence of Kavach, B_z can be locally reduced by 8–10 G.

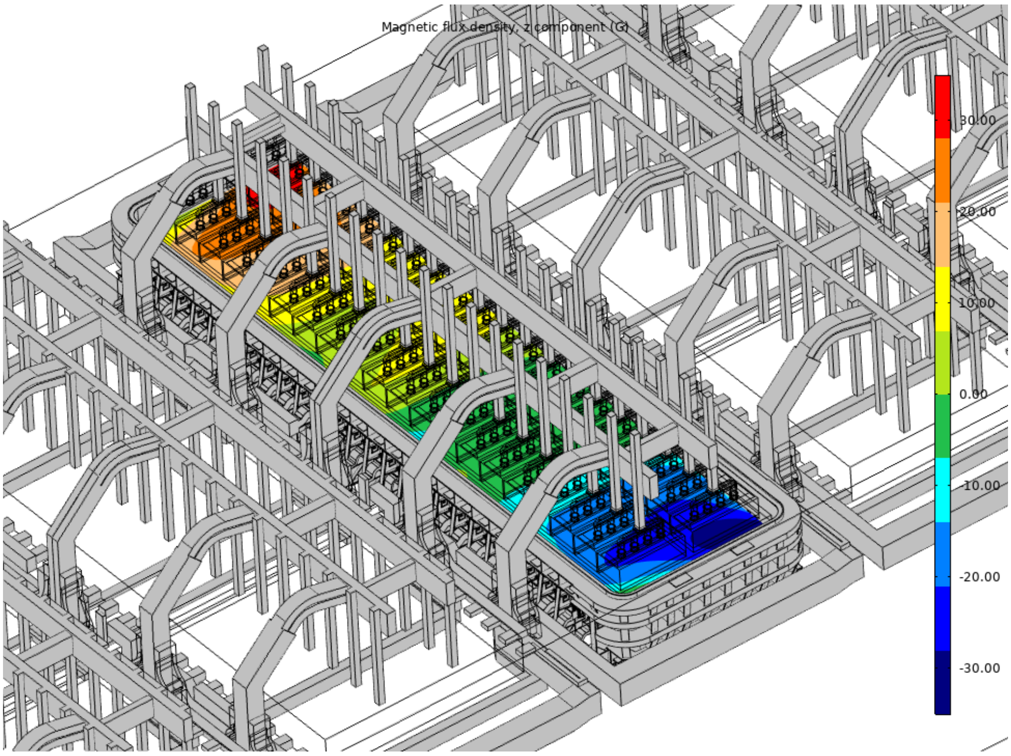

Figure 3. Existing cell electromagnetic model showing Bz, [G], at the middle of metal pad.

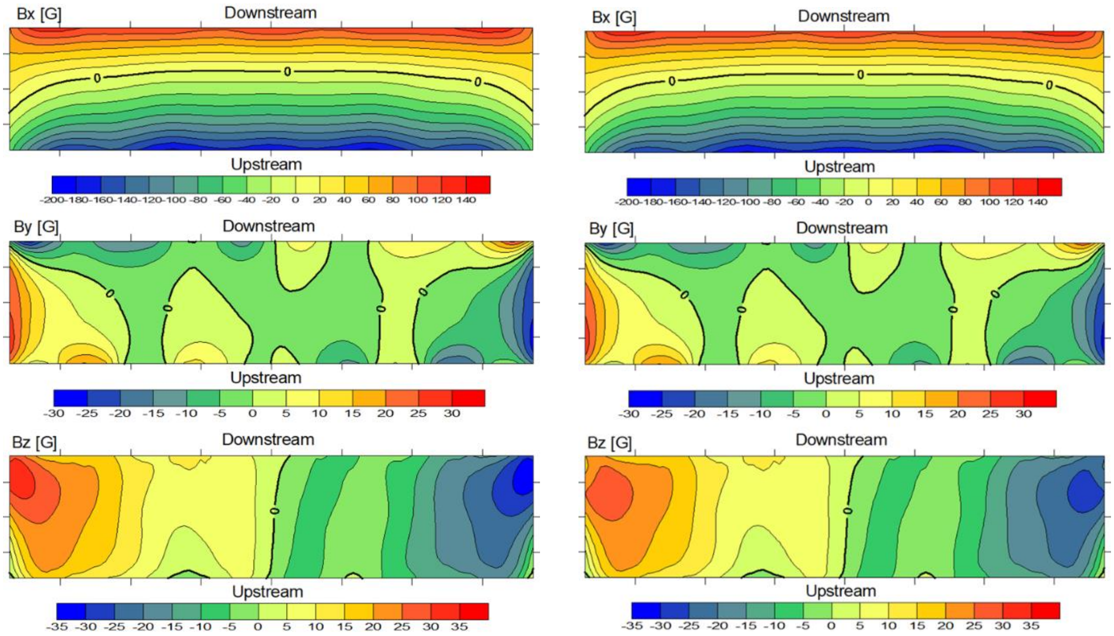

Figure 4. Magnetic field components in the middle metal pad. Left: existing cell, Right: with shielding plates (Kavach).

3. Industrial Trial

In order to validate the modeling results for the reduction of Bz inside the cell, several trials were performed in live electrolytic cells using the Kavach. The shielding assemblies were fabricated in-house using ferromagnetic materials in different shapes and sizes.

In the trial phase, after placing the Kavach in the cell, most of the critical cell parameters such as noise, average voltage, excess AlF3, metal level and bath temperature were tracked daily as shown in Figures 5, 6, 7 and 8, respectively. After 4–5 days of Kavach placement in the cell, significant reduction in noise (8–10 mV) of the cell was observed. Also, during this phase, average voltage of the trial cells was reduced by 35–40 mV.

In order to validate whether the noise reduction effect is due to the plate or the regular potroom activities, shielding assembly was removed from the cell for 1 week as shown in the Figure 7. It was observed that after the removal of shielding assembly, the cell noise increased drastically and the cell became unstable, thereby proving that the noise reduction in the cell was due to the placement of Kavach.

It was also found that the Kavach doesn't have any negative impact on the other cell parameters. In fact, most of the cell parameters such as bath temperature and cell voltage were improved during the trial phase – Figures 5 through 8.

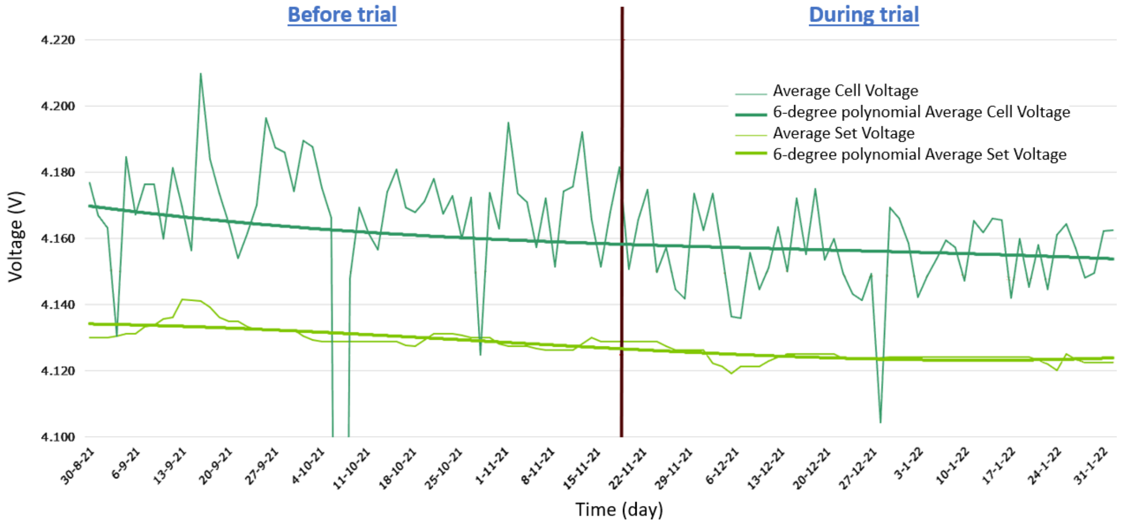

Figure 5. Voltage comparison before and after the placement of shielding plate, (V).

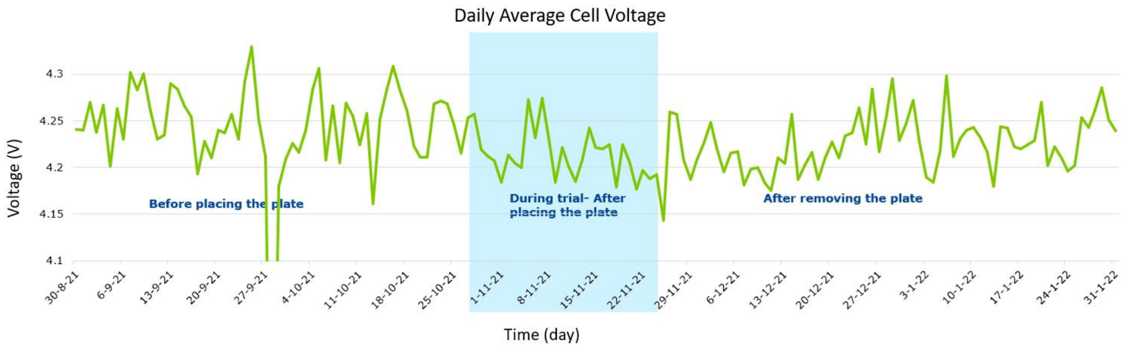

Figure 6. Voltage comparison after removal of shielding plate, (V).

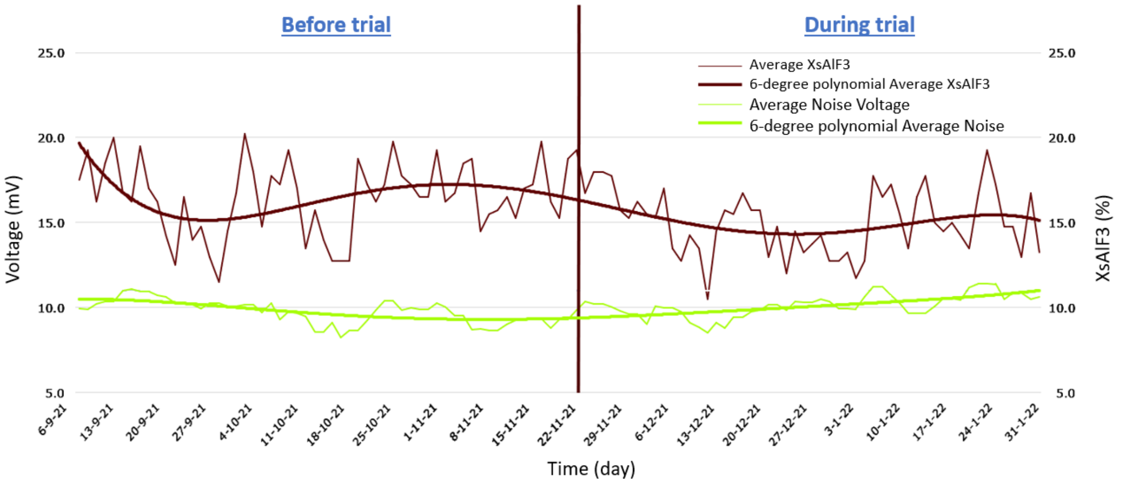

Figure 7. Noise, (mV), and excess AlF3, (%), comparison before and after the placement of shielding plate.

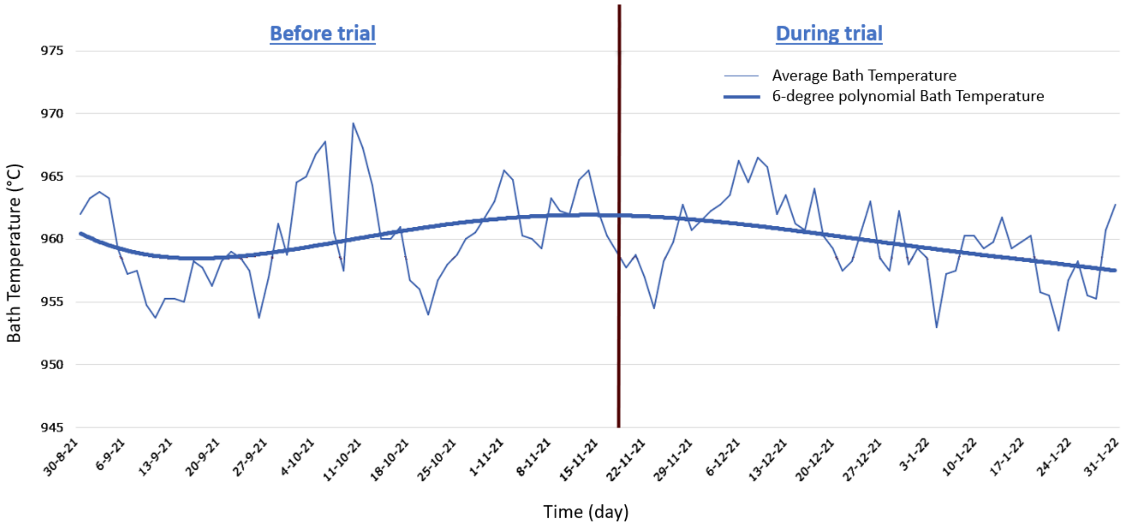

Figure 8. Bath temperature, (°C), comparison before and after the placement of Kavach.

4. Experimental Results and Discussion

The magnetic field shielding trial was conducted in 6 unstable electrolytic cells of the Vedanta Smelter. During the trial phase, critical process parameters of the electrolytic cell such as noise, average voltage, bath temperature, excess AlF3 were tracked daily. The data of critical process parameters of the electrolytic cell was compared for the duration of 6 months before and during the trial period, as shown in Table 1 and Table 2. It can be observed that critical cell parameters such as voltage and cell noise improved significantly after the placement of Kavach in the unstable cells. Noise of the unstable cells was reduced by 7.9 mV on average, whereas the average voltage of the cells was reduced by 35 mV.

Table 1. Performance comparison of magnetic shield Kavach trial (6 cells).

Parameters	**Before Trial**	**During Trial**	**Improvement**
Voltage set (V)	4.154	4.145	0.009
Average voltage (V)	4.217	4.182	0.035
Overvoltage (V)	0.062	0.038	0.024
Noise (mV)	19.7	11.8	7.9
Bath temperature (◦C)	963	962.1	0.9
Excess AlF3 (%)	9.2	9.8	0.60

Table 2. Pot wise improvement in parameters.

Parameter (Improvement)	**55XX**	**58XX**	**61XX**	**61XX**	**15XX**	**27XX**
Voltage set (V)	0.009	0.008	0.010	0.012	0.011	0.014
Average voltage (V)	0.034	0.040	0.030	0.044	0.030	0.028
Overvoltage (V)	0.024	0.034	0.018	0.032	0.123	0.013
Noise (mV)	14	5.5	5	4.9	11.9	5.8
Bath temperature (◦C)	0.950	0.920	2.3	2.6	14.6	2.4
Excess AlF3 (%)	0.698	0.575	0.670	0.6	3.1	0.9

The magnetic field components in the electrolytic cell were measured in the presence and absence of Kavach. The measuring device is shown in Figure 9 and consists of a tri-axial probe that is immersed inside the metal pad. Magnetic field components are then recorded.

Figure 9. Magnetic field measurement in the operating cell.

It was observed that the Bz component of magnetic field was reduced by 8–10 G on average in the presence of Kavach (at the measured point located at downstream corner). The measurements provided successful validation of the electromagnetic models, as shown in Table 3. Different arrangements types (1, 2 and 3) of the Kavach were trialed in order to achieve maximum local reduction in magnetic field. Different arrangements were categorized on the basis of composition of ferromagnetic materials employed as well as geometry.

Table 3. Vertical Magnetic Field (Bz) Comparison, [G].

Arrangement Type	Modeling	Measurement
No Shielding	-29.9	-26.8
Arrangement Type 1	-27.6	-21.8
Arrangement Type 2	-20.0	-19.6
Arrangement Type 3	-19.1	-17.2

5. Conclusion

Magnetic field improvement in electrolytic cell by shielding is an innovative approach for improving the stability of the electrolytic cell, thereby reducing the specific power consumption by around 110 kW h/ton Al, which is yet another initiative towards Vedanta vision of decarbonization. Patent has also been filed for this breakthrough initiative as magnetic field shielding using Kavach, when applicable, has economic advantages when compared to the different operational practices for stabilizing the electrolytic cell in the aluminium industry (such as increasing ACD or adding shunts to reduce cell current). The major advantages of using Kavach in electrolytic cell are its cost-effectiveness and portability. The use of the Kavach allowed the trialed cells to be operated at a lower noise level while MHD stability is improved.

In addition, the results showed that due to the local improvement in vertical magnetic field of the electrolytic cell, various critical parameters of the electrolytic cell such as bath temperature, excess AlF_3, average voltage, noise have been improved significantly, thereby also improving the overall performance of the pot.

Up to this date, Kavach trials have been performed well for the unstable and noisy cells. In the next phase, trials will be performed on stable cells in order to verify if the average voltage can be reduced without affecting their stability.

Acknowledgement

The authors would like to thank our unit leaders Mr. Sunil Gupta (CEO), Mr. Nitin Tiwari (COO-Metal) and all the members of the potline team, Vedanta Aluminium Limited, Jharsuguda for their continuous support in conducting these trials.

6. References

1. Kai Grjotheim and Halvor Kvande, *Introduction to Aluminium Electrolysis*. 2nd Edition, Düsseldorf, Aluminium-Verlag, 1993.
2. Korada Umashankar, *Introduction to Engineering Electromagnetic Fields*, Singapura, World Scientific, 1989.
3. Salvatore Celozzi, Rodolfo Araneo and Giampiero Lovat, *Electromagnetic Shielding*, John Wiley & Sons, Inc., Hoboken, New Jersey, 2008.
4. 4. Magnetic Shielding, http://www.excelatphysics.com/magnetic-shielding.html, (accessed on 30 July 2022).
5. What is the best way to shield magnetic fields from wiring? https://lessemf.com/shielding-faqs, (accessed on 30 July 2022).
6. Anthony Kjar, Jeffrey Keniry and Dagoberto Schubert Severo, Evolution of busbar design for aluminium reduction cells, *8th Australasian Aluminium Smelting Technology Conference*, Yepoon, Australia, 3–8 October 2004.
7. Yiwen Zhou, Shouhui Chen and Qingjie Zhao. The magnetic shielding effect of steel in an aluminum reduction cell, *Proceedings of 38th International ICSOBA Conference*, 2020, *Travaux* 49, 691–701.