Development and Industrial Application of NEUI600 High Efficiency Aluminum Reduction Cell

Yungang Ban, Jihong Mao, Yu Mao, Jing Liu, and Gaoqiang Chen

Abstract

As the high amperage aluminum reduction technology is developed in a complicated system, designers should draw special attention to structural optimization, environmental protection and energy saving while overcoming multiple core technical difficulties. NEUI has successfully eliminated a great number of technical bottlenecks hindering the development of high amperage aluminum reduction technologies, such as pot MHD stability technology, 3D thermal-electric field simulation technology, dynamics simulation technology of pot gas flow, etc., and has also developed the NEUI600 aluminum reduction technology, which has been put into extensive application. As of May 2017, 6 NEUI600 potlines with total capacity of 2210 kt/a have been put into commercial operation, the pot voltage can be maintained within the range of 3.90–4.05 V based on actual need. NEUI600 high amperage aluminum reduction technology has become an energy-saving and environment-friendly electrolysis technology with the lowest investment.

Keywords

NEUI600 aluminum reduction cell • Physical field simulation • Industrial application

Introduction

As a professional engineering and research institute in light metals metallurgical industry, NEUI is always giving top priority to the development of core technologies. With the help of advanced technology, talent advantages and domestic and international cooperation, NEUI has successfully developed NEUI600 aluminum reduction cell technology and already put it into commercial operation.

Shandong Weiqiao Aluminum & Power Co., Ltd. as the world's largest aluminum production enterprises, has been the pursuit of the most advanced technology for industrial upgrading, in order to implement science and technology enterprises, cost-leading development strategy.

During the period from 2010 to 2013, both NEUI and Weiqiao carried out sufficient technical exchange and optimization of the NEUI600 technology, the optimal construction plan was established. In September 2013, the construction of NEUI600 aluminum reduction potline was started. December 2014, Weiqiao has put the first NEUI600 potline into commercial operation with the capacity of 300 kt/a. This article will focus on the development process and industrial application of NEUI600 high efficiency aluminum reduction cell technology.

Development of NEUI600 High Efficiency Aluminum Reduction Cell Technology

Electrical Optimization of Cathode Busbar

The cathode busbar of aluminum reduction pot has a basic function of current transfer for potlines. For this specific equipment however, busbar shall also be designed to meet the following functions and requirements:

- Proper compensation for magnetic field inside a pot.
- The deviation of current out of cathode flexible busbar shall be controlled in a certain range.
- Rational current density shall be maintained to ensure the most reasonable safety and economy.
- Rational current density of short-circuit busbar must be maintained during pot shut down condition to ensure the safety under special circumstances.

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- Rational current distribution of short-circuit busbar must be maintained during pot shut down condition to minimize the impact on the neighboring pots.
- Simple structure, easy to produce and construction.

Based on above principles, NEUI gives top priority to the safety in busbar performance and also takes extreme conditions into full account in electrical design of cathode busbar of 600 kA potline. The electric balance of the ring busbar is affected by very complicated factors such as busbar location and shape, heat radiation and dissipation between busbars, heat radiation with the pot body, and heat exchange with pot body, etc. Therefore, busbar thermoelectric coupling calculation must be performed to obtain relatively accurate busbar current distribution. With the assist of the advanced ANSYS simulation software, NEUI performs calculation on thermoelectric busbar coupling so that the above basic requirements can be met and good busbar techno-economic parameters can be achieved. The thermoelectric busbar coupling calculation results are partially shown in Fig. 1.

Optimization of Magnetic Field Distribution

As described above, reduction pots not only conduct electricity but also serve as a compensator for magnetic field. The magnetic field compensation means to offset the magnetic field formed by potline, countercurrent of neighboring potroom and the pot busbar by proper configuration of the ring busbar structure, so that an ideal magnetic field distribution inside the pot can be achieved. Because of the complexity of the reduction pot busbar structure and numerous ferromagnetic substances' impact on the magnetic field, solving Maxwell equations with ANSYS software has become a common measure for accurate calculation of magnetic field in a pot. However, the way of modeling scientifically, correctly setting boundary conditions and calculation domain, as well as accurately inputting material properties have been playing a key role in obtaining precise magnetic field results [1]. Based on the distribution features of the potline and pot structure, NEUI has determined scientific modeling methods and material parameters after many times of deliberation and testing to ensure the correctness of calculated results. Model units are partially shown in Fig. 2. Simulation of vertical magnetic field of molten aluminum in a certain pot is described in Fig. 3.

Simulation of MHD Stability

For high amperage aluminum reduction pots the magnetic field distribution can only indirectly characterize the MHD stability, rather than evaluating MHD stability directly. Facts also prove that only rational magnetic field distribution cannot ensure the MHD stability [1]. Therefore, after optimizing magnetic field design, the MHD software must be used to calculate its MHD status. The simulation of MHD of NEUI600 cell is shown in Figs. 4 and 5.

As Figs. 4 and 5 show, the NEUI600 cell has an evenly distributed velocity field of molten aluminum and the value of interface deformation less than 10 mm, featuring more flow rings and low flow speed. All those factors contribute to an important guarantee for MHD stability in a pot.

Simulation of Thermal Field and Lining Optimization

Good energy balance is the precondition for stable production of aluminum reduction cells. With increasing cell

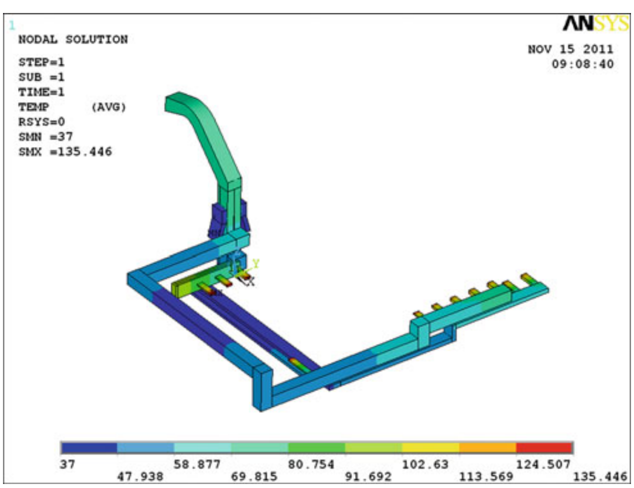

Fig. 1 Thermoelectric busbar coupling calculation results

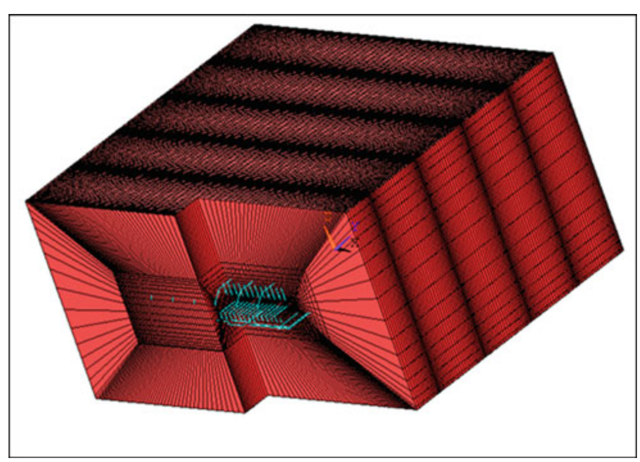

Fig. 2 Section of partial model unit of magnetic field

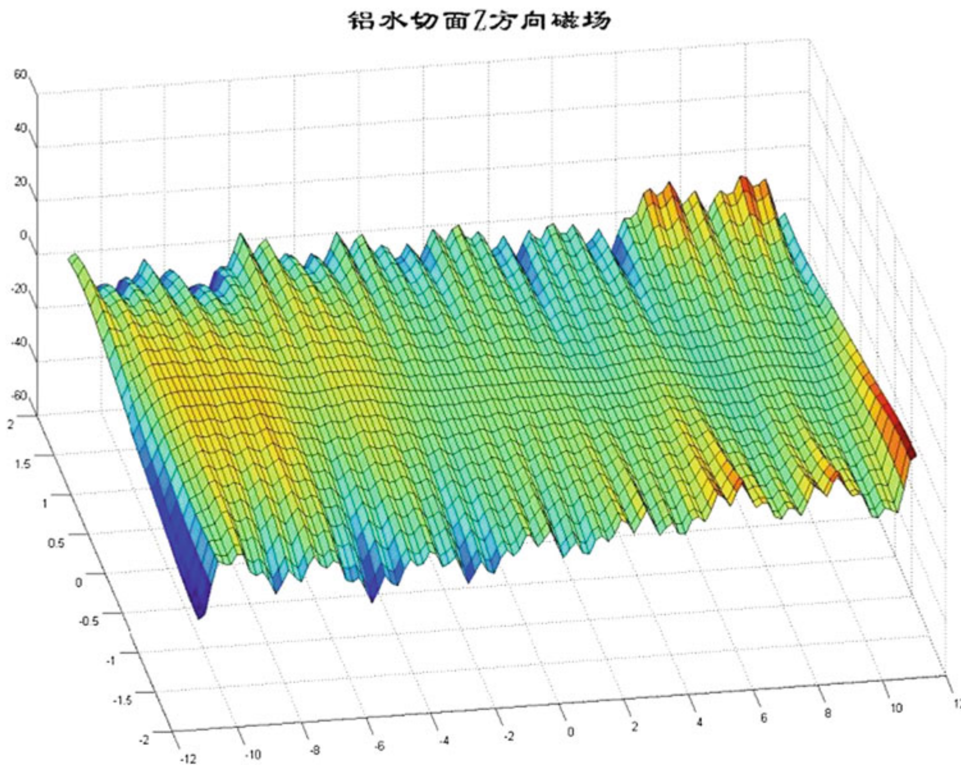

Fig. 3 Distribution of vertical magnetic field of molten aluminum in NEUI600 Cell

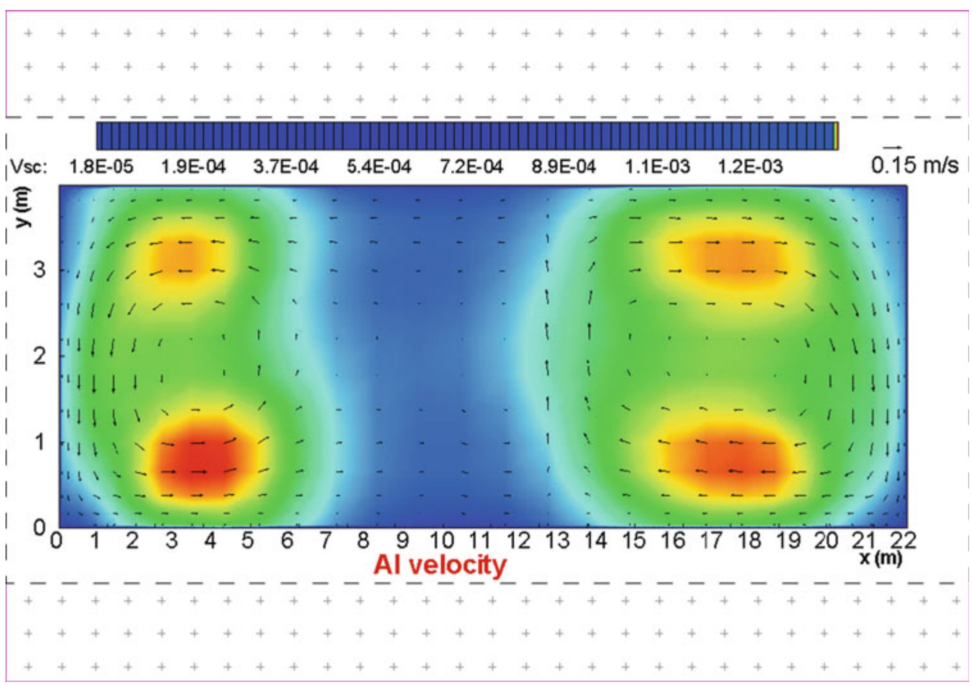

Fig. 4 Simulation result of velocity field of molten aluminum in NEUI600 Cell

capacity, the heat dissipation load of specific surface area of a cell is also increasing gradually. Therefore, the key issue for designers is to ensure the energy balance of extra high amperage cells and achieve rational ledge shape and lining temperature distribution. NEUI has performed repeated simulations to NEUI600 cells with self-developed ANSYS-based 3D thermo-electronic simulation software, and has finally determined an optimized lining structure for

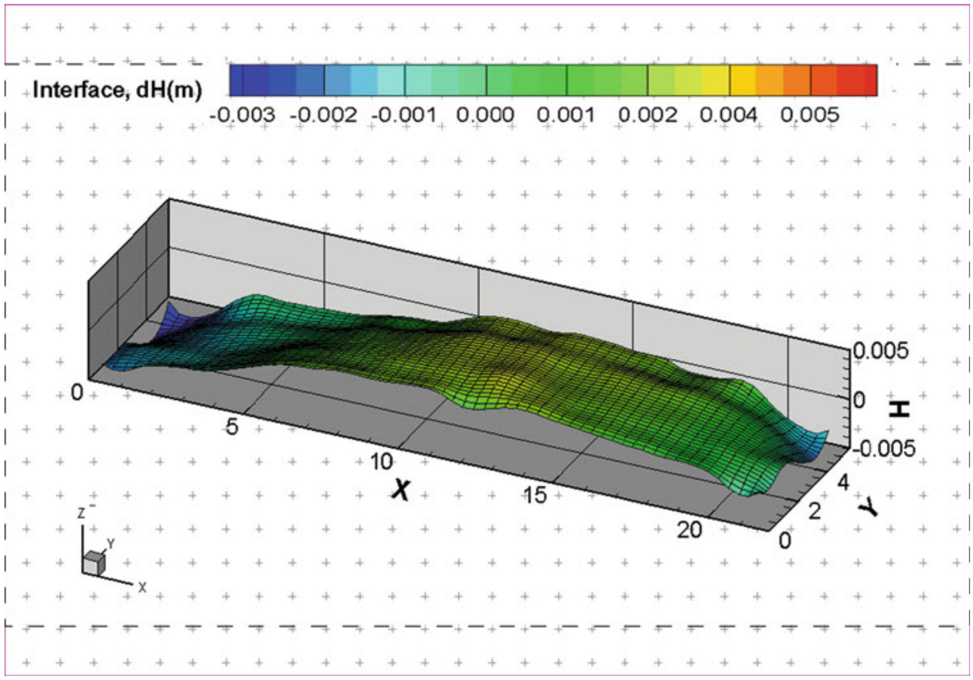

Fig. 5 Simulation result of interface deformation of NEUI600 cell

600 kA extra high amperage cells. At the same time, this structure has certain shrink ability and can absorb lining expansion as much as possible on the premise of ensuring the energy balance. Figure 6 shows the simulation results of thermal field in the NEUI600 cell.

As Fig. 6 shows, the position of every isotherm meets the requirements for temperature distribution within lining materials.

Simulation and Optimization of Stress Field of Pot Shell and Superstructure

- Pot Shell Structure

Needless to say, the solid steel pot shell has great importance to the reduction pot, but the rigidity of pot shell is also associated with material selection. During pot shell design,

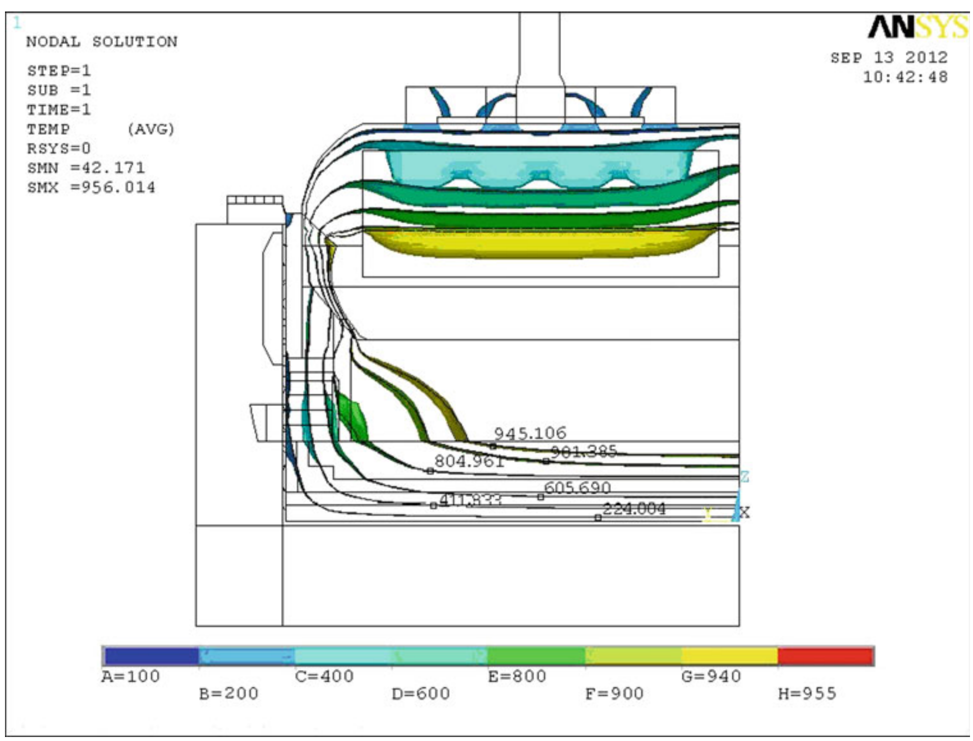

Fig. 6 Simulation result of heat field in NEUI600 cell

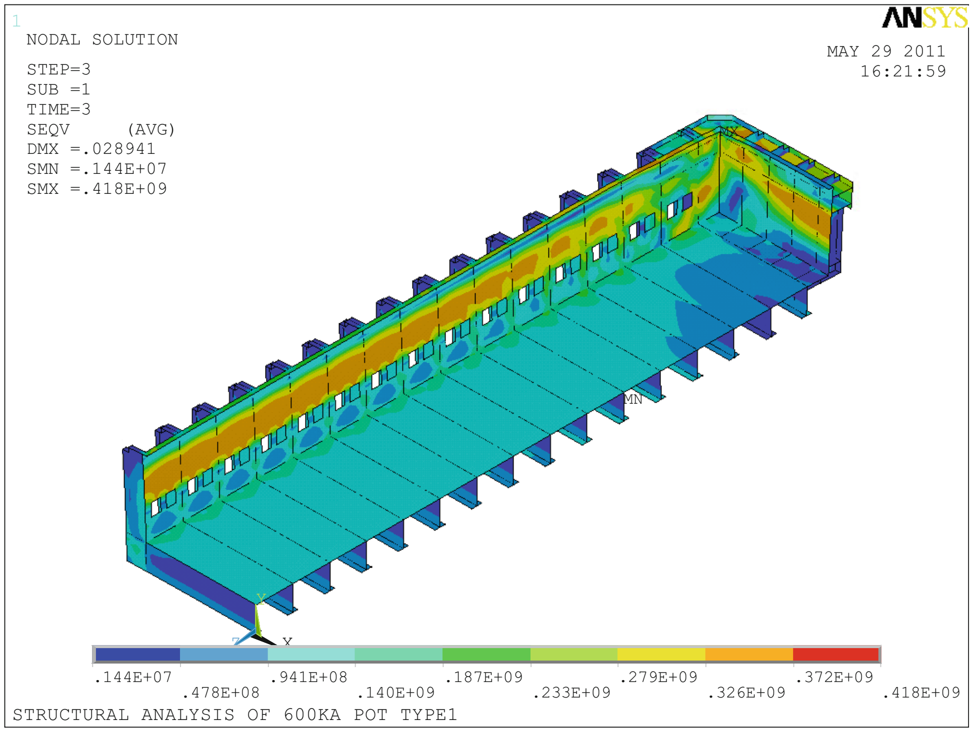

Fig. 7 Calculations of NEUI600 pot shell stress (Plastic Stage)

NEUI has set a clear objective, had the two factors combined, adopted advanced simulation software for optimized simulation of pot shell and performed analysis and calculation to heat stress coupling field of shell structure in all stages of NEUI600 cell service life, including the time before and after pot preheating and start-up, after operating for 2–3 years and till the end of potlife. Results showed that within pot shell's service life, the maximum node displacement of integrated welded shell structure of a NEUI600 cell is 59.1 mm, indicating that the shell deformation is within rational and safe range. In addition, the total steel consumption for pot shell with the same strength has reduced by 5–10%. The simulation results of NEUI600 pot shell are partially shown in Fig. 7.

- Bearing Superstructure

With the increase of cell length and on the precondition of ensuring strength and deformation, to minimize steel consumption has become the top priority. NEUI has redesigned the bearing superstructure in the aspects of superstructure heat dissipation, equipment installation, simple structure, and optimized steel selection, etc., and finally created an optimized pipe truss type bearing structure. The stress ratio distribution and deformation results of NEUI600 cell superstructure are shown in Figs. 8 and 9 respectively.

According to the calculation results, the maximum deflection under maximum load measures about 34 mm, which falls in the required value range. Additionally, the specific current steel consumption reduces by 9.2% compared to NEUI400.

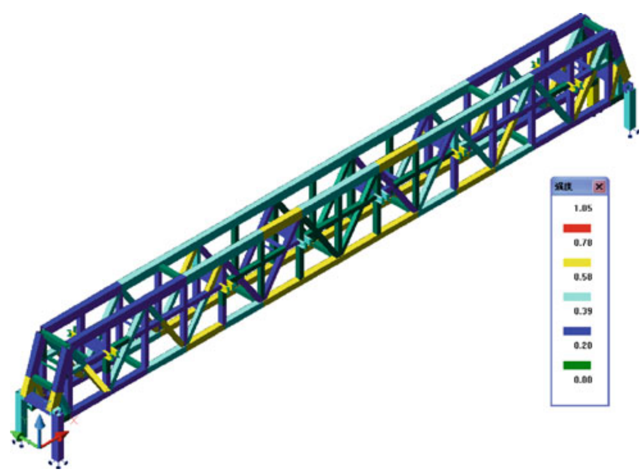

Fig. 8 Maximum stress ratio distribution of upper truss member of NEUI600 cell

Simulation of Gas Flow Field Inside Pots and Optimization of Gas Collecting Structure

With the increase of cell length, it is also important for designers to know how to realize a rational pressure gradient inside cell hood, so as to ensure the highest gas collection efficiency. Under the principles of simple structure, small

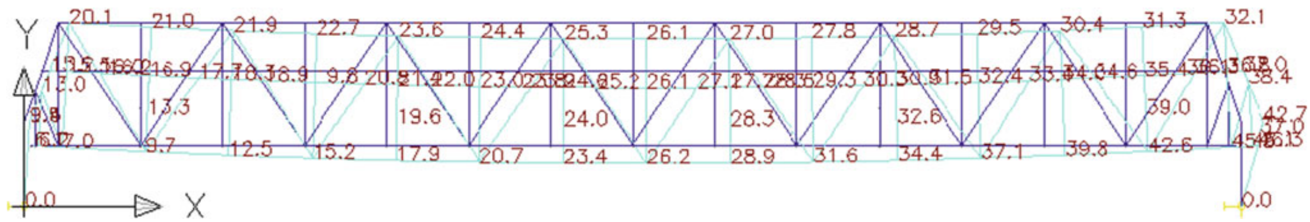

Fig. 9 Deformation results of NEUI600 superstructure (showing deformation factor: 10 times)

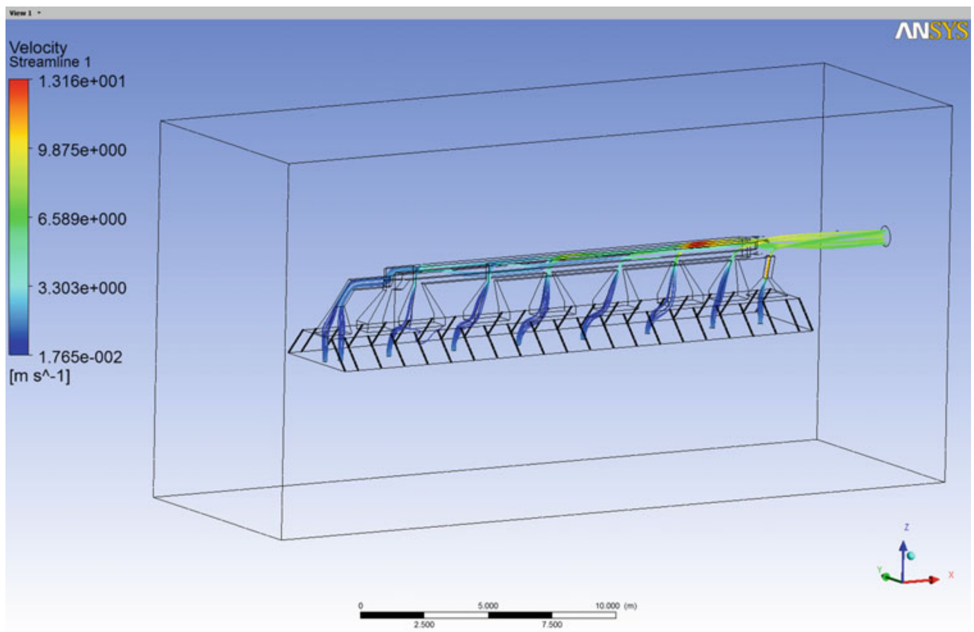

Fig. 10 Inlet stream line chart for pot's gas collection

pressure gradient and less energy demand, NEUI divides the reduction cell into multiple sections horizontally for separate gas collection. At the same time, to reduce the gas emission during process operation, an auxiliary exhaust system is designed to increase the exhaust suction rate. Based on the above idea, CFD software was adopted to simulate the gas flow characteristics inside the cell and then optimize the best negative pressure distribution in the cell [2]. It has been proven that both sectional gas collection and double exhaust system can play an important role in reducing gas emission and improving gas collection efficiency. Figures 10 and 11 show partial simulation results of pot superstructure.

Pot Control System

The reduction pots developed by NEUI adopt embedded PLC intelligent pot controller manufactured as per PLC standards. Electrical performance of hardware, communication interface, software programming, etc. is all standardized in the PLC system. Hardware is connected with the system by standard PLC and software that can be connected include standard "configuration software" such as AB, Siemens, Kingview, Touch Screen, etc. This system can be programmed with standard ladder diagram, function block and statement. The integration of hardware is substantially improved and software programming is simple and convenient with more powerful calculating function. The software programming only involves adding new functions on original basis without the need to further study details on given programming modules. The system has already been put to application in several domestic smelters with good control effect.

Industrial Application of NEUI600 Technology

Given the widespread application and advanced indexes of NEUI high amperage aluminum reduction technologies, the NEUI600 has drawn great attention in the industry soon after its successful development. After in-depth research and technical verification, a plant in Weiqiao smelter has decided

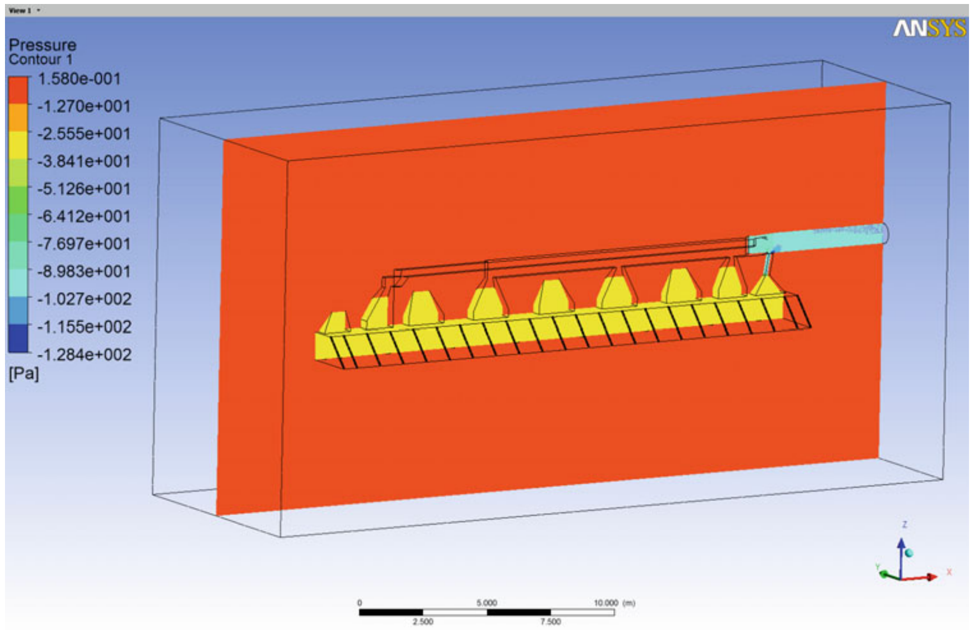

Fig. 11 Pressure field of vertical section for pot's gas collection

to adopt NEUI600 technologies in its two newly installed potlines, which has been operated for nearly 3 years.

Preheating and Start-Up

Due to the large capacity of the cell and the substantial increase in the productivity per unit area, the difficulty for preheating and start-up of NEUI600 cell are also greatly increased. In order to successfully complete the smooth preheating and start-up of the NEUI600 cell, the technical team of Weiqiao smelter has repeatedly demonstrated and improved the preheating and start-up procedure to determine the optimal scheme. NEUI600 cell preheating using a coke layer leveling, two shunt and other proprietary technologies, the technologies have the advantages of a low impact on impulse voltage fluctuation, current distribution and temperature control etc.

Figure 12 shows the preheating temperature increase curve of the typical NEUI600 cell, and the average temperature rise during preheating is 8–10 °C/h. The whole preheating process was safe and smooth.

Operation and Management After Start-Up

In the stage after start-up NEUI600, the height of aluminum was gradually increased by adjusting the technical parameters, gradually reducing the pot working voltage, bath temperature, height of bath and CR, and established the regular cell cavity. The measuring results showed that the ledge thickness of NEUI600 cell is nearly 11 cm at long-side, and

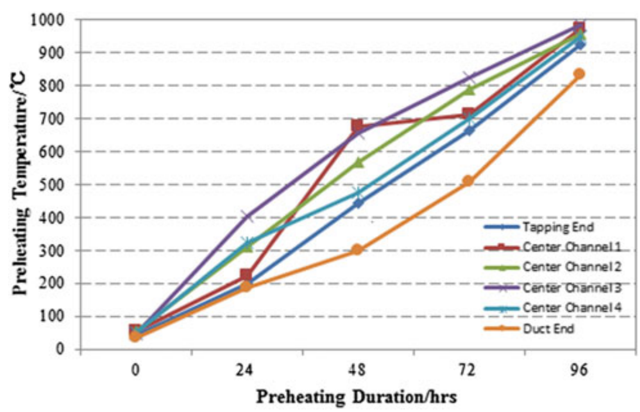

Fig. 12 Measured temperature during preheating emission of NEUI600 cell

ledge thickness in different position is nearly the same, which conducive to the smooth production of NEUI600 cells.

Operation and Management in Production Period

During the normal production period, the high efficiency and high productivity is taken as the criteria in order to achieve the lowest cost of production. Stable technical conditions and the regular cavity is the core to maintain the appropriate pot working voltage, height of aluminum, lower bath temperature and CR, and low AE frequency [3]. Table 1 shows the technical parameters for the NEUI600 cell at normal production period.

Table 1 Technical parameters for NEUI600 aluminum reduction pot at normal production period

Name of parameter	Unit	Parameters
Average cell working voltage	V	3.95–4.05
Amperage of potline	kA	600–602
Height of aluminum	cm	26 ± 1
Height of bath	cm	20 ± 1
CR	–	2.35 ± 0.1
Bath temperature	°C	955 ± 5

Table 2 Main technical and economic parameters of NEUI600 potline

Name of indexes	Unit	Parameters
Current Efficiency	%	≥ 93
DC Energy Consumption	kWh/t-Al	≤ 12,750
AE Frequency	times/pot·day	≤ 0.01
Gross Anode Consumption	kg/t-Al	≤ 470
Fluoride Consumption	kg/t-Al	≤ 14
Hooding Efficiency	%	≥ 98.5
Purification Efficiency of GTC	%	≥ 99.5
Dust Emission	kg/t-Al	0.97
Total Fluoride Emission	kg/t-Al	0.52

Main Technical and Economic Parameters

The potline has been operating smoothly for nearly 3 years since the NEUI600 potline putting into commercial operation at the end of 2014. The advanced technical and economic parameters were obtained as shown in the Table 2.

In addition, NEUI600 also has a prominent economic advantage, compared with 400–500 kA cell technology, investment of NEUI600 technology can be lowered by 10%, and the operating cost of labor is lower than nearly 10%. Figure 13 is the NEUI600 potline in Weiqiao smelter.

Fig. 13 NEUI600 high efficiency aluminum potline in Weiqiao smelter

Conclusion

With the successful production of first NEUI600 potline, NEUI large capacity aluminum reduction cell technology are quickly recognized by the aluminum industry and put to widespread application. It has been proved that NEUI has reached the most advanced level internationally in core technologies of cell design, and has also made remarkable strides in pot's overall structure optimization and emission reduction. The first NEUI600 potline has been operating smoothly for nearly 3 years, has obtained excellent technical and economic parameters, compared to 400–500 kA technology has significant economic advantages. As of May 2017, there are 9 potlines using NEUI600 technology with the total capacity 3490 kt/a, among them 6 potlines has been put into commercial operation with capacity of 2210 kt/a. NEUI600 has gradually become the most important and efficient cell technology in China's aluminum industry.

Acknowledgements From development to the successful implementation of NEUI600 cell technology, both NEUI and Weiqiao have made a significant contribution. In the technical development process, the organization of the project by Lv Dingxiong, Deng Wenqiang, Mao Jihong, Li Quanlin, Yang Qingchen and Du Zhengguang, who also provide specific technical guidance for development and application of NEUI600 technology. The research and development of busbar structure and MHD stability technology are mainly completed by Mao Jihong and Mao Yu. The simulation of thermal balance of cell mainly completed by Dr. Ban Yungang. The design and simulation of cell ventilation structure are mainly completed by Chen Gaoqiang. The design and simulation of pot shell structure and bearing superstructure are mainly completed by

Liu Jing and Huang Kuisheng. The development of pot control system is mainly completed by Dr. Wang Dequan. NEUI600 pot preheating, Start-up and operation management mainly by Li Quanlin, Du Zhengguang and Liu Jianfei, etc. The above experts have made great contribution to the success of NEUI600 technology.

References

1. Qi Xiquan, Liang Xuemin, Lv Dingxiong etc. "Successful Commercial Operations of NEUI400 Potline", Light Metals 2010, TMS (The minerals, metals & materials society) 2010, 359–363.
2. Technical Report on Technology Development and Industrial Application of NEUI600kA High Efficiency Aluminum Reduction Cell, Northeastern University Engineering & Research Institute Co., Ltd. (Internal technical information document), 2015, 05.
3. Yungang Ban, Xiquan Qi, Yu Mao etc. "Baking Start-up and Operation Practices of 400kA Prebaked Anode Pots", Light Metals 2010, TMS (The minerals, metals & materials society) 2010, 369–373.