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Development of NEUI500kA Family High Energy Efficiency Aluminum Reduction Pot ('HEEP') Technology

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Abstract

Based on the successful development and application experiences of NEUI400kA family high energy efficiency aluminum reduction pot ('NEUI400 family HEEP') technology, through the physical field measuring & analysis and with the proprietary 'Physical Field Numerical Simulation and Analysis Software Package for Aluminum Reduction Pots', by continuously following its own high amperage reduction pot development mode of incorporating the numerical simulation technology with experiences, NEUI has developed the NEUI500kA family high energy efficiency aluminum reduction pot ('NEUI500 family HEEP') technology. Comparing with NEUI400 family HEEP, the simulation results showed that the technical parameters that affecting the MHD stability, current balance, pot lining structure, gas collection system and the superstructure etc. are more excellent.

1. Introduction

In order to meet market demands both home and abroad, based on the successful development and application of NEUI400 family HEEP technology, NEUI has proceeded develop NEUI500kA family HEEP technology by continuously following its own high amperage reduction pot development mode of incorporating the numerical simulation technology with experiences.

In what follows, is an introduction about NEUI400 family HEEP, and the following is an introduction about the key technologies of NEUI500 family HEEP.

1.1 Development and Application of NEUI400 Family HEEP

NEUI has created a high amperage aluminum reduction pot development mode of incorporating the numerical simulation technology with accumulated experiences. Assisted by the 'Physical Field Numerical Simulation and Analysis Software Package for High Amperage Aluminum Reduction Pots' redeveloped by NEUI based on the software platforms including ANSYS, MHD and CFD, etc, and the expert team which has experienced the whole development course of the high amperage aluminum reduction technologies in China, NEUI was the first in China to have developed the NEUI400 family HEEP technology. Comparing with the 300kA family reduction pots, key technologies of the NEUI400 family HEEP technology including MHD stability, thermal balance, ventilation system and steel structure, etc., have been improved obviously. Since the first NEUI400(I) HEEP potline with the capacity of 230,000t/a was put into operation in August, 2008, NEUI400(II-IV) HEEP potlines with the capacity of 250kt/a, 250kt/a and 300kt/a have been put into production successively in Linfeng Aluminum and Power Co., Ltd, Shandong Nanshan Aluminum Industry Co., Ltd and Jinning Aluminum Co., Ltd, and more excellent techno-economic indices have been achieved.

1.2 Verification of the Physical Field of NEUI400 Family HEEP by Measurement

After the commercial operation of NEUI400 family HEEP, Materials and Metallurgy School of Northeastern University respectively measured and analyzed the physical field of NEUI400(I) HEEP in Henan Zhongfu Industry Co., Ltd. and NEUI400(III) HEEP in Nanshan Aluminum Industry Co., Ltd. in Jan., 2009 and Jun., 2010. The comparison results showed that the physical field of NEUI400 HEEP was in compliance with their numerical simulation results, which verified the advancement and reliability of NEUI400 family HEEP technology.

1.3 Operating Parameters of NEUI400 Family HEEP

All NEUI400 family HEEP potlines have achieved excellent techno-economic indices after being put into commercial operation. Table I is a typical comparison between the operating parameters and design parameters of NEUI400 family HEEP.

Table I. Comparison between Design Parameters and Operating Parameters of NEUI400 Family HEEP

	Design parameter	Operating parameter
Amperage (kA)	400±10%	400±15%
Anode effect frequency (effects/pot·day)	≤0.05	<0.015
Average cell voltage (V)	4.06	3.85
DC energy consumption (kWh/t-Al)	<12900	<12500
Hooding efficiency (%)	99	>99

From Table I, it is included that the main techno-economic indices of NEUI400 family HEEP have fully reached or even exceeded the design parameters after being put into operation.

1.4 Amperage Intensifying of NEUI400 Family HEEP

Table II showed the present operating amperage intensity of NEUI400(I-IV) HEEP.

Table II. Present Operating Amperage Intensity of NEUI400(I-IV) HEEP

Name of Potline	Time for Operating	Present Operating Amperage Intensity(kA)
NEUI400(I) HEEP in Henan Zhongfu Industry Co., Ltd.	08, 2008	415
NEUI400(II) HEEP in Linfeng Aluminum and Power Co., Ltd	08, 2009	440
NEUI400(III) HEEP in Shandong Nanshan Aluminum Co., Ltd.	11, 2009	430
NEUI400(IV) HEEP in Jinning Aluminum Co., Ltd.	06, 2010	460

From table II, it is known that the actual operating amperage intensity of NEUI400 family HEEP potlines have completely exceeded 400kA. Take NEUI400(IV) HEEP potlines in Jinning Aluminum Co., Ltd as an example, the present operating amperage intensity has reached 460kA, the reduction pots still run stably and efficiently. This has laid a good foundation for the development of NEUI500 family HEEP technology.

2. Development of NEUI500 Family HEEP Technology

Based on the successful development and application experiences of NEUI400 family HEEP technology, NEUI has developed the NEUI500kA family HEEP technology by continuously following the high amperage reduction pot development mode of incorporating the numerical simulation technology with accumulated experiences. For the NEUI500kA family HEEP technology, the simulation results of characteristic parameters including the busbar arrangement & MHD stability, thermal balance, pot ventilation and superstructure, etc. are more excellent.

2.1 Optimization of Busbar Arrangement and MHD Stability

During the development of NEUI500 family HEEP technology, following requirements shall be met:

(1) The busbar voltage drop shall be reasonably chosen. The busbar consumption shall be reduced as much as possible;

(2) Minimize the voltage drop difference between upstream and downstream cathode busbar to realize balancing current distribution at both sides;

(3) The busbar shall not be overloaded during normal operation or under short circuit status.

Refer to Fig. 1 for the busbar current balance calculation results of NEUI500 family HEEP.

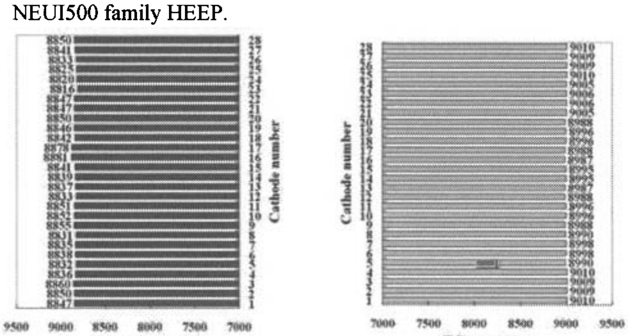

Fig. 1 Current Distribution in the Collector Bar of NEUI500 Family HEEP

Fig. 1 showed that the current distribution of the cathode at upstream and downstream of NEUI500 family HEEP was relatively uniform, with the maximum deviation ratio of 0.88%.

For the busbar arrangement design of NEUI500 family HEEP, the asymmetric magnetic field compensation method of 'Strong Compensation at the Short Side and Multi-point Weak Compensation at the Bottom' was used. The main characteristic of the compensation was most of current on upstream go around the end head of the reduction pot, and less current pass through the bottom of the reduction pot. During the modeling of the electromagnetic field, the whole potline has been brought into the boundary conditions for computation in order to be more close to the actual conditions, and the busbar current parameters are taken from the results of the current balance calculation. In addition, the magnetic field and the current balance are given interative computation to improve the accuracy.

Fig. 2-4 are respectively the simulation results of the magnetic field distribution along X, Y and Z direction in the molten aluminum section.

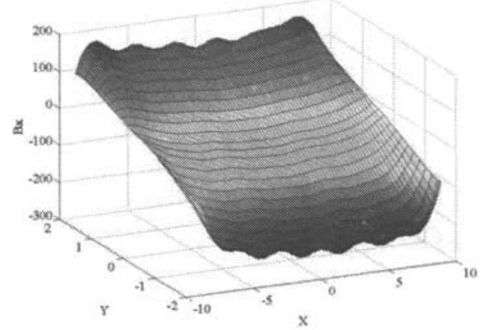

Fig. 2 Magnetic Field Distribution along X Direction inside NEUI500 Family HEEP

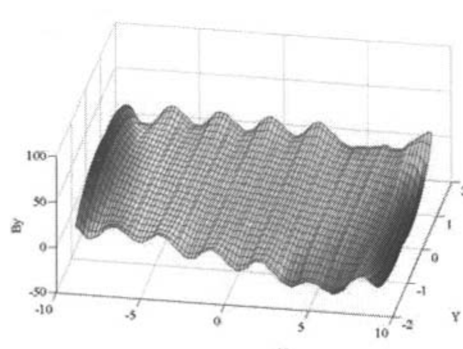

Fig. 3 Magnetic Field Distribution along Y Direction inside NEUI500 Family HEEP

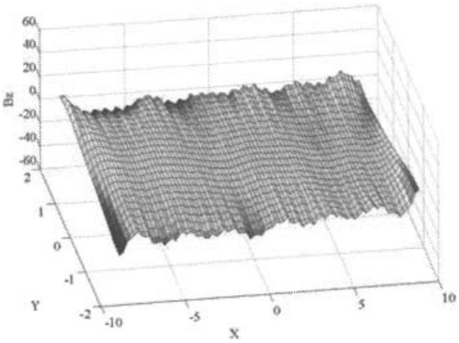

Fig. 4 Magnetic Field Distribution along Z Direction inside NEUI500 Family HEEP

Table III is the comparison of the characteristic parameters including the magnetic field, current balance and busbar consumption, etc. between NEUI500 family and NEUI400 family HEEP.

Table III. Simulation Results of Relevant Characteristic Parameters of the Busbar Systems of NEUI400 Family and NEUI500 Family HEEP

Parameter	Unit	NEUI500 Family HEEP	NEUI400 Family HEEP
$\|Bx\|_{ave}$	Gs	97.07	79.59
$\|By\|_{ave}$	Gs	12.58	10.89
$\|Bz\|_{ave}$	Gs	3.14	3.16
$\|Bz\|_{max}$	Gs	19.87	22.52
$\|Bz\|_{ave1}$	Gs	3.09	3.77
$\|Bz\|_{ave2}$	Gs	3.75	2.63
$\|Bz\|_{ave3}$	Gs	3.08	3.16
$\|Bz\|_{ave4}$	Gs	2.47	3.06
Bz Max. gradient	Gs/dm	3.23	3.76
Total voltage drop of busbar	mV	211.40	202.56
Current ratio at upstream	%	49.56	49.56
Current deviation ratio at upstream	%	0.739	0.605
Current ratio at downstream	%	50.44	50.44
Current deviation ratior at downstream	%	0.256	0.229
Voltage drop during short circuit period	mV	420.5	350.52
Current deviation during short circuit period	%	5.30	5.20
Max. current density during short circuit period	A/mm^2	0.81	0.83
Aluminum consumption per unit current	kg/A	0.1311	0.1351

Table III showed that the maximum value, average value and changing gradient of the vertical magnetic field of NEUI500 family HEEP were better than that of NEUI400 family HEEP. In addition, aluminum consumption per unit current for NEUI500 family HEEP was somewhat less than that of NEUI400 family HEEP, which indicated that the busbar system of NEUI500 family HEEP was more economic. Even when the potline current was intensified by 10%, the busbar was still not overloaded, which suggested that the busbar system has high security. Better MHD stability design guaranteed the stable and efficient operation of NEUI500 family HEEP under low voltage.

2.2 Better Thermal Balance Design

When the amperage of a reduction pot is increased, the sidewall area per unit cavity volume is reduced, and the unit area heat lost on the sidewall will be increased. Besides, comparing with NEUI400 family HEEP, the anode current density of NEUI500 family HEEP was increased obviously, which will increase the heat generation of reduction pots. Accordingly, the heat lost of each area will also increase. Therefore, relevant measures must be adopted in order to obtain a better thermal balance.

(1) Favorable Conditions for Realizing Better Thermal Balance

One of the good conditions to realize better thermal balance is the lower pot voltage, and then the thermal input will be reduced. It is benefit to realize ideal thermal balance and regular pot cavity.

The better MHD stability design of NEUI500 family HEEP provides favorable conditions for the stable and efficient operation of NEUI500 family HEEP under low voltage. The actual operation of NEUI400 family HEEP, has shown that all reduction pots can run stably and efficiently under the working voltage of 3.75-3.9V. As the characteristic parameters of MHD stability of NEUI500 family HEEP are more excellent, which are sufficient enough to assure the stable and efficient operation under low voltage, and accordingly, in favor of realizing better thermal balance.

(2) Regulating Measures for Realizing Better Thermal Balance

- Regulating Structural Parameters

① Increase the pot cavity depth

The increase of the pot cavity depth can lower the heat flux of per unit pot cavity sidewall area, which can achieve the purpose of increasing heat lost.

② Increase dimensions of the stub and the collector bar

The increase of the stub dimension and collector bar dimension will reduce their own resistance, reduce the heat generation, and increase the heat radiation volume.

③ Reduce the width of the side block, and adhesively bonded with the pot shell

Reducing the width of the side block will be in favor of reducing the thermal resistance increased due to the pot shell deformation. The adhesive bonding between the side block and the shell internal wall will further reduce the thermal resistance, which will guarantee a smooth heat passage.

④ Strengthen the heat radiation potential of the pot shell

Single strap or no strap and low width pot brim were used in shell design to strengthen ventilation. Besides, radiating ribs will be added to strengthen the heat radiation of the side shell.

- Low resistivity and high thermal conductivity cathode blocks were selected

The low resistivity and high thermal conductivity cathode blocks can not only increase the heat lost volume of the pot shell opposite to the cathode block, which will lower the temperature of the pot shell below the cathode block and make the temperature drop gentle, but also can lower the voltage drop of the cathode itself, which is in favor of realizing better thermo-electric balance.

● Choose Reasonable Process Parameters

Proper technical process conditions are chosen for the thermal balance design of NEUI500 family HEEP. The effective measures such as the selecting the bath which is of low electrolysis temperature and proper superheat, maintaining a lower anode effect frequency, maintaining proper height of liquid aluminum pad, lowering the thickness of the cover material to increase the radiation at the top, as well as selecting of reasonable gas exhaust volume, etc. to keep a good and stable heat balance

(3) Application of Compressible Pot Lining Structure Technology

The compressible lining structure developed by NEUI was used at the end of cathode block in NEUI500 family HEEP, i.e. the cathode paste, high strength castables and high temperature resistant calcium silicate board (or ceramic fiber board) are organically combined to form the compressible structure. The structure was equivalent to a stress buffering area between the cathode block and the pot shell, which can effectively absorb the cathode swelling stress, reduce the bottom upheaving, and prolong the pot life.

(4) Thermo-Electric Field Simulation

Fig. 5 and 6 are respectively the temperature contour and temperature isotherm of NEUI500 family HEEP.

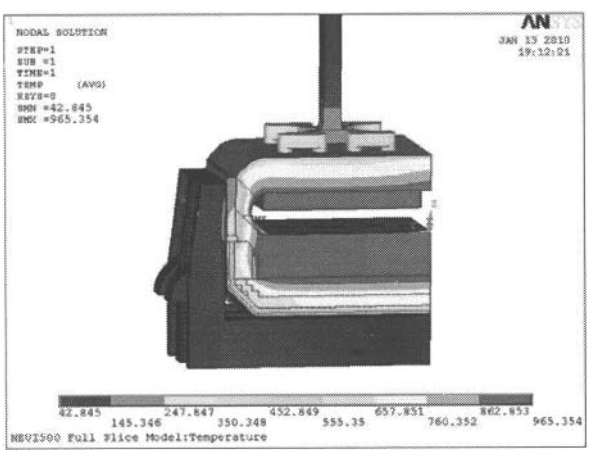

Fig. 5 NEUI500 Family HEEP Cross Section Temperature Contour

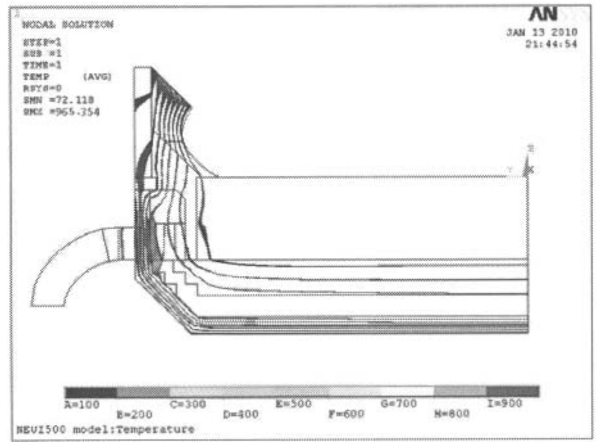

Fig. 6 Thermal Field Temperature Isotherm Distribution of NEUI500 Family HEEP

It can be seen from the simulation results (Fig. 4 and 5) that NEUI500 family HEEP can maintain a rather ideal temperature distribution, each isotherm in the cathode lining was located in the rational location, the temperature of each area was within reasonable range, which indicated that the design of the pot lining structure was reasonable.

(5) Comparative Analysis of Heat Emission Distribution

Refer to Table IV for the heat lost distribution comparison between NEUI400 family HEEP and NEUI500 family HEEP.

Table IV. Thermal Balance Comparison between NEUI400 and NEUI500 Family HEEP

Parameter \ Pot Technology	NEUI500 Family HEEP	NEUI400 Family HEEP	
	Simulation Result	Simulation Result	Measured Result
1. Heat input (excluding reaction energy consumption)	—	—	—
2. Heat loss	100%	100%	100%
2.1 Heat loss of anode	46.5%	48.1%	52.6%
of which: packing material	21.8%	24.9%	26.4%
Stub	18.4%	17.8%	18.9%
Rod	6.3%	5.4%	7.3%
2.2 Heat loss of cathode	53.5%	51.9%	47.4%
of which: pot shell	28.9%	27.4%	42.8%
Cradle	17.0%	18.8%	
Collector bar and flexible	7.6%	5.7%	4.6%
3.Heat unbalancing degree	1.90%	2.61%	3.56%

Table IV showed that the unbalance between the heat generation and the heat loss of NEUI500 family HEEP is 1.90%, which is within the allowable computing error. Based on the heat radiation characteristics of NEUI500 family HEEP, after corresponding thermal balance regulating measures were taken, the heat radiation ratio of the cathode is somewhat increased comparing with that of NEUI400 family HEEP, which strengthened the heat radiation of the pot shell opposite to the cathode block, and the anticipated target for heat balance has been achieved.

The potlines which are adopted with NEUI400 family HEEP have realized good thermal balance after being put into commercial operation. The measuring results and the simulation results are almost the same. For NEUI500 family HEEP which was developed with the same development mode of NEUI400 family HEEP, corresponding thermal balance regulating measures are taken to adapt to the change of the heat radiation characteristics of the reduction pot. The simulation results indicated that the thermal balance design of NEUI500 family HEEP is also very good.

2.3 High Efficiency Ventilation Technology

The sub-section high level gas collection technology was also used for the ventilation structure design of NEUI500 family HEEP. Based on the characteristics of NEUI500 family HEEP, the ventilation structure has been optimized to further increase the hooding efficiency.

(1) Advantages of the Sub-section High Level Gas Collection Technology

The sub-section high level gas collection technology developed by NEUI has following advantages:

- The pressure distribution inside the hood is uniform, which is good for increasing the hooding efficiency.
- The negative pressure caused by the hot fume itself is fully used, which is in favor of the effective gas collecting, the gas volume per ton aluminum production is reduced and the operating load of the scrubbing system is reduced.
- Spaces within the superstructure and the pipe truss girder are fully used.
- The overall structure is compact, which provides enough spaces for the process operations such as anode change and tapping, etc.

(2) Application Effect of Sub-section High Level Gas Collection Technology for NEUI400 Family HEEP

This technology has been applied to NEUI400(III) and (IV) HEEP. The operation results suggest that the hooding efficiency has reached over 99%, which provide favorable conditions for achieving the environmental indices including the total fluoride discharge of no more than 0.6kg/t-Al and dust emission of no more than 1.0kg/t-Al.

(3) Development of the Sub-section Gas Collection Structure of NEUI500 Family HEEP

Based on the application experiences on the sub-section high level gas collection technology for NEUI400 family HEEP, the sub-section high level gas collection technology for NEUI500 family HEEP was optimized according to its own characteristics. The 8-subsection high level gas collection structure was adopted and each individual area can be regulated independently.

(4) Simulation of the Gas Collection System

The ventilation structure for NEUI500 family HEEP was simulated by using the 'Physical Field Numerical Simulation and Analysis Software Package for Aluminum Reduction Pots' which is redeveloped based on the CFD software platform. To be more close to the actual conditions, the whole potroom was brought into the computing system, and the boundary conditions were extended to outside the potroom. Refer to Fig. 7-9 for the simulation results.

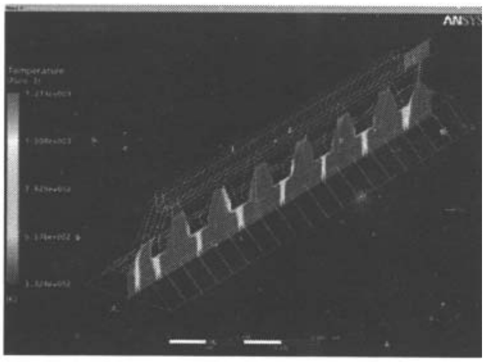

Fig. 7 Temperature Field of the Section

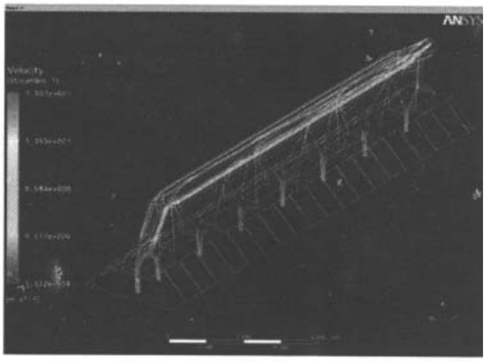

Fig. 8 Inlet Streamline Diagram

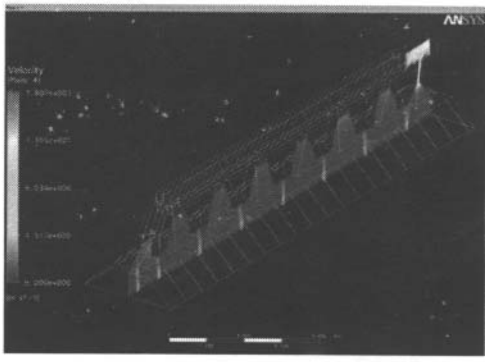

Fig. 9 Velocity Field Section

The simulation results indicated that the fume exhaust system of NEUI500 family HEEP has realized the uniform distribution of the negative pressure, velocity and temperature, etc. Comparing with traditional 'V' shape low level gas collection structure, this structure has significantly reduced the resistance of the system, reduced the fume exhausting resistance by 80Pa, reduced the fume exhaust volume for per ton aluminum production by 25%, which has reduced the operating load of the gas treatment center, and lowered the power consumption of gas treatment center to less than 150kWh/t-Al.

2.4 Optimized Design of the Superstructure

The superstructure with the pipe truss girder developed by NEUI has been used for NEUI500 family HEEP, and the design has been optimized based on the increased span and increased load of NEUI500 family HEEP.

(1) Advantages of Pipe Truss Girder Superstructure

Advantages of pipe truss girder superstructure are as follows:

- The strength-steel consumption ratio is high;
- Good ventilation and heat radiation effect;
- Simple structure and esthetic appearance;
- Easy to be fabricated, installed and maintained;
- Good for the arrangement, safe and stable operation of the servo system.

(2) Simulation Results

The simulation results of the pipe truss girder of NEUI500 family HEEP were shown in Fig. 10-11.

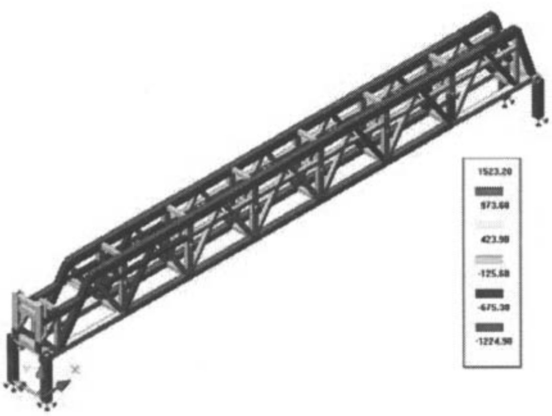

Fig. 10 Axial Force Distribution of Members (kN)

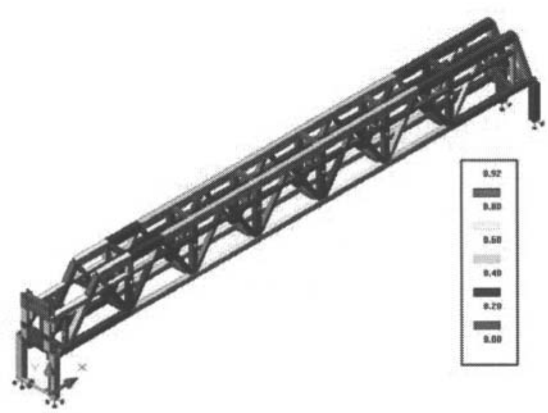

Fig. 11 Maximum Stress Distribution of Members

Table V. Simulation Results of the Superstructure of NEUI500 Family HEEP

Parameter	Span (m)	Midspan displacement (mm)	Deflection	Basic period (s)	Max. stress ratio	Steel consumption (t)	Equivalent steel consumption (kg/kA)
Value	20.7	32.1	1/645	0.79	0.92	14.8	29.6

The simulation results showed the ratio between the strength and steel consumption of the optimized superstructure is higher and can meet requirements under different working status. Comparing with solid web girders, the steel consumption of the support structure is reduced by 30%, which is more economic.

2.5 Auxiliary Technologies and Equipment

Besides developing key technologies for NEUI500 Family HEEP, NEUI has also developed following auxiliary technologies and equipment:

- Potroom high efficiency ventilation technology;
- Intelligent control technology for aluminum reduction;
- Powder material conveying technology;
- High efficiency rectification and power supply technology.

3. Comprehensive Analysis and Conclusions

On the basis of the summarizing the successful development and application experiences of NEUI400 family HEEP, NEUI continues to adopt the high amperage reduction pot development mode of incorporating the numerical simulation technology with experiences to develop the NEUI500 family HEEP technology. The simulation results of NEUI500 family HEEP are more excellent than that of NEUI400 family HEEP, which guarantees core technologies for achieving the anticipated techno-economic indices in Table VI.

Table VI. Anticipated Indices of NEUI500 Family HEEP after being Put into Operation

Item	Anticipated Value
Amperage (kA)	500±10%
Anode effect frequency (AE/pot · day)	<0.015
Average cell voltage(V)	3.85V
DC current consumption of per ton Aluminum (kWh/t-Al)	<12500
Hooding efficiency (%)	>99
Pot life (day)	>2000

Meanwhile, NEUI has also developed auxiliary process and equipment technologies of NEUI500 family HEEP.

Acknowledgement

The project is jointly completed by NEUI's aluminum reduction technology R&D team. The project is organized by Mr. Lu Dingxiong, Mrs. Mao Jihong, Mr. Qi Xiquan and Mr. Yang Qingchen, etc., who are also the technical advisors of the project. The development of the busbar arrangement and magnetic fluid stability technology is mainly completed by Mrs. Mao Jihong and Mr. Mao Yu; the thermal balance simulation of aluminum reduction pots is mainly completed by Mr. Ban Yungang; the ventilation structure design is mainly completed by Mr. Chen Gaoqiang and the design and simulation of the pot superstructure is mainly completed by Mr. Dong Hui and Mr. Huang Kuisheng. Thanks for the technical data they have provided for this paper.

Reference

[1] NEUI500 HEEP Technology R&D Report (internal documentation), 06-2010.