Improving Reliability and Reducing Electric Energy Losses in the 'Rod–Yoke' Connections

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Abstract

In recent years, the most important strategic goal of the global aluminium producers has been to intensify existing technologies in order to minimise electricity consumption. Globally, some companies are gradually implementing technical solutions to achieve the ultimate goal of electricity consumption of less than 12 000 kWh/t Al. One of the main areas in achieving high energy efficiency is to reduce the voltage drop in the connections. The most important connection, on which the operation of the aluminium pot depends, is the 'aluminium rod–yoke' connection through a Fe-Al bimetallic coupling.

During the operation of aluminium pots, approximately up to 35 % of the heat is removed through the top of the anode array, the 'aluminium rod–bimetallic plate–yoke' connection is constantly in the high temperature zone. The passage of high current density leads to heating up the contact up to 300 – 400 °C. As a result, corrosion occurs in places where the joint is poorly welded, and under the influence of high voltage and the presence of the joint breakdown failure source, eddy currents arise, which under the high temperatures provoke electrocorrosion. Over time, the process of the breakdown failure of a welded joint accelerates: the larger the centre of failure, the faster the overall process of joint corrosion. The area of the source of the breakdown failure increases, and the area of the joint decreases. Under its own weight, the lower part of the anode, that is, steel yoke with prebaked anode blocks, breaks off, which leads to an emergency condition in the pot.

This article proposes using a new approach of mounting the yoke to the anode rod through several Fe-Al bimetallic couplings of various configurations and designs. Based on results in terms of reliability and energy efficiency, this technical solution has been included in the technology package of RA-400 and RA-550 technologies.

Key words: RA-400 pot, RA-550 pot, Fe-Al bimetallic coupling, anode rod assembly, energy efficiency.

1. Introduction

Current in the pot is distributed over many parallel branches, the number of which depends on the size and design of the pot. In turn, the parallel branches consist of a number of resistances in series and in parallel. Electric connections exist between the individual elements of different parallel branches, due to which equalisation currents arise.

In the course of operation, the process parameters of the pot vary: the anode is consumed, metal is accumulated, alumina is consumed, anodes are replaced, etc. The above factors, as well as a number of design features of the pot, lead to a continuous redistribution of the current. Uneven and unstable current distribution in the pot leads to internal mechanical stresses, local heat-up, changes in the geometric dimensions and the state of the individual units, as well as increased energy losses.

The purpose of this work is an attempt to eliminate the causes that affect the uneven distribution of the current through the pot, and to assess the impact of the current distribution on the technology and the technical and economic indicators of electrolysis.

2. General

Production of aluminium requires large amounts of electrical energy, and the reduction of its consumption is one of the most important issues in the aluminium industry. This is why it is necessary to know in which parts of the pot there are losses of electrical energy, and what the reasons for this are. The current in all parts of the pot is not the same and the losses of electrical energy are directly proportional to the voltage drop in these parts. Thus, voltage drops in all parts can be calculated or measured directly on the operating pot.

The main area where voltage drops and as a consequence, the uneven distribution of current along parallel branches occur is the 'anode bus to rodded anode' connection. Figure 1 shows a diagram of typical voltage drops in the anode assembly of the RA-400 pot. The voltage distribution in the anode is shown in Fig. 1.

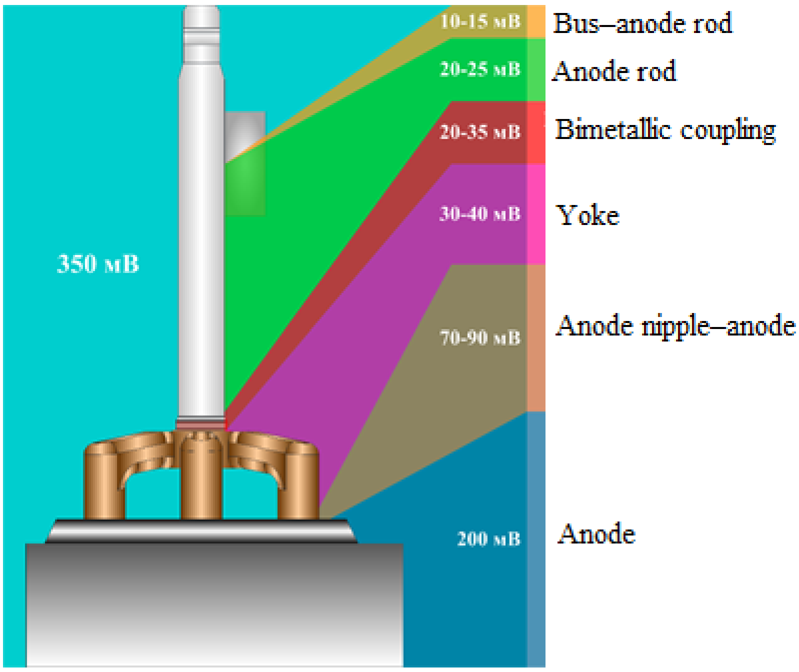

Figure 1. Typical voltage drops in the middle of the service life of an anode of the RA-400 pot.

Voltage drop in the 'bus–rod' connection is due to the design features of the connection, surface contact, as well as the preparation of the surfaces before installing the anode. Over time, due to high temperatures, intermetallic compounds form in this connection, leading to an increase in resistance and, as a result, in a voltage drop. High voltage drops can be eliminated by tapping the joint and tightening the clamp.

Voltage losses in the anode rod and yoke depend on the specific resistance of the material they are made of, current density and the temperature. In terms of the current production, there are virtually no mechanisms for reducing the drops, they are determined at the design stage.

Voltage drop in the anode body depends on the current density, electrical resistivity of the carbon material and the height of the anode. Electrical resistivity of the prebaked anode is determined by its composition and depends on the manufacturing technology. With regard to electricity consumption, it is advantageous to use anodes of small height, but this increases the labour costs for installation and replacement of anodes, as well as gross carbon consumption.

Voltage drops in the 'anode nipple to anode' connection can reach a significant value up to 100 mV and more. The voltage drop in this unit depends on the size of the contact surface of the anode with the stub, i.e. the larger the diameter of the anode stub and the height of the anode stub hole, the greater the contact area and the lower the voltage drop. The diameter of the anode stub is limited by the mechanical strength of the anode, since at the end of the operation of the anode block, the anode butts may crack due to high thermal expansion of the stubs. The depth of the anode stub hole is determined by the cost of electricity and the cost of the anode: at a smaller depth, electricity consumption increases due to a decrease in the contact area, but the gross consumption of anodes decreases. In addition, the composition of the cast iron has a significant effect on the voltage drops in this unit.

Voltage drops in the 'rod–yoke' connection are associated with the design features of the joint, the quality of installation, and the Fe-Al bimetallic plates used.

3. RA-400 Anode Assembly

The RA-400 anode assembly is shown in Figure 2.

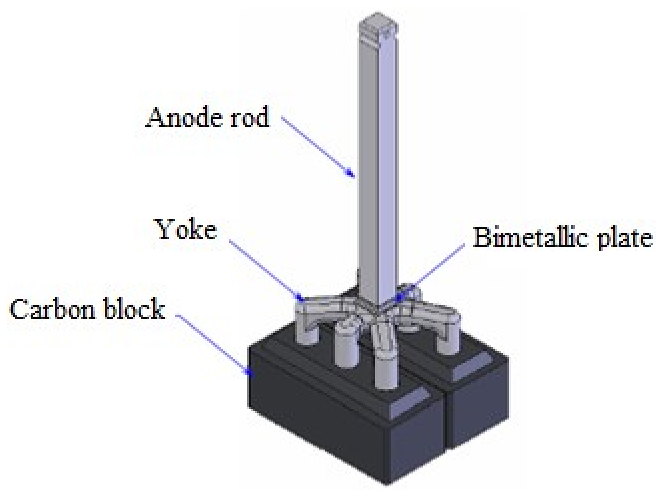

Figure 2. Rodded RA-400 anode.

4. Field Tests

Starting from 2010, at the RA-400 pilot site located in the pilot potroom of the Sayanogorsk Aluminium Smelter, an increased failure of the anode rod assemblies was observed due to the breakdown failure of Fe-Al bimetallic plates. At the end of 2011, up to 50 % of the RA-400 anode rod assemblies in circulation were in repair (Figure 3).

The main reason for the failure of the Fe-Al bimetallic plates was their overheating due to problems with the removal of gases from the pot (failure of the Gas Cleaning Unit equipment). This incident triggered the initiation of the development of technical solutions in the design and manufacturing technology of bimetallic plates for RA-400 pots, aimed at improving the connection reliability and increasing the service life of these plates (determining the life cycle, monitoring the bi-metal state at all stages of the technological cycle).

Figure 3. Examples of breakdown of the Fe-Al bimetallic joint of the RA-400 pot.

To eliminate the problem of the increased failure of the bimetallic plates in the RA-400 pots, two types of pilot bimetallic plates were manufactured with changes in the design and manufacturing technology:

- Type 1 (Figure 4) — to eliminate the lower strength of a dovetail welded joint along the edges of bimetallic plates, large-size casting blocks are produced, with subsequent cutting into plates of the required size; along the edges of the bimetallic plate, 2 additional grooves are milled in the direction perpendicular to the main grooves (1 groove from each edge of the plate at a distance of 10 – 20 mm from the edge); to identify the cause of the failure, a zinc 'cartridge' is installed in the Fe-Al joint.
- Type 2 (Figure 5) — to eliminate the lower strength of the dovetail welded joint along the edges of bimetallic plates, large-size casting blocks are produced, with subsequent cutting into plates of the required size; an additional titanium sublayer is used between the aluminium and steel parts.
- Type 3 (Figure 6) — large-size casting block with subsequent cutting into plates of the required size, the aluminium plate is overlap-welded to the flat surface of the iron plate.

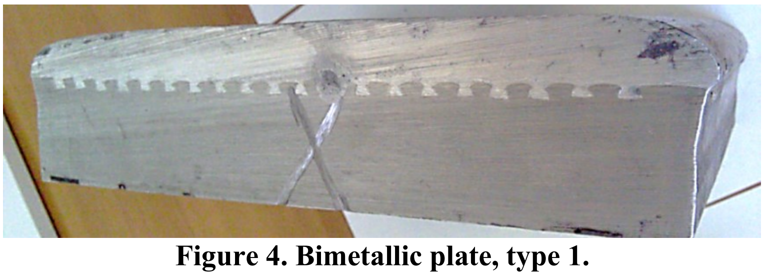

Figure 4. Bimetallic plate, type 1.

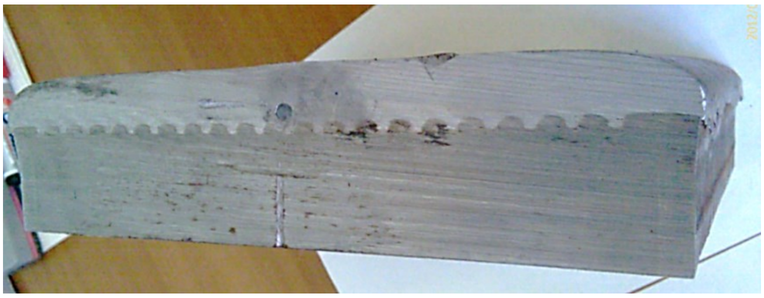

Figure 5. Bimetallic plate, type 2 with titanium interlayer.

Figure 6. Bimetallic plate, type 3.

To track the life cycle during installation of the pilot plates, the rods of the anode rod assemblies were marked in the zone located 20 – 25 cm below the tip of the rod. Marking was made on 4 faces of the anode rod with numbering in the order of involvement of the pilot plates in the operation.

Pilot bimetallic plates were used to measure the voltage drop and the temperature of the Fe-Al contact during one anode changing cycle.

To measure the voltage drop, the oxide film on the anode yoke was pierced at the rod–yoke contact by lightly striking the probe tip installed visually 10 – 20 mm below the weld on the yoke, the tip of the second probe was at a distance of visually 10 – 20 mm above the weld on the yoke (Figure 7).

Figure 7. Position of probes while measuring the 'rod–yoke' voltage drop.

Table 1 presents the results of measurements of temperature and voltage drop on the pilot bimetallic plates in the eighth cycle of the installation of the anodes.

Table 1

	Type 1	**Type 2**	**Type 3**
Average value (mV)	28.0	28.3	27.3
Standard deviation (mV)	7.83	6.77	4.08
Average voltage drops on Fe-Al contact on the third day after anode installation (full load on anode) (mV)	24.9	22.5	25.1
Daily increment of voltage drops on Fe-Al contact (mV)	~ 0.29	~ 0.53	~ 0.23
Average voltage drops on Fe-Al contact on the twenty-seventh day after anode installation (before anode replacement) (mV)	31.9	35.2	30.5
Average voltage drops on Fe-Al contact per anode installation cycle (mV)	**28.1**	**28.3**	**27.6**
Average temperature of Fe-Al contact (°C)	~ 185	~ 185	~ 165
Average deviation of Fe-Al contact temperature (°C)	~ 44.2	~ 40.6	~ 17.3
Fe-Al contact temperature after 12 days from anode installation (°C)	~ 100–260	~ 120–180	~ 140–180
Daily increment of Fe-Al contact temperature (°C)	~ 1.8	~ 3.5	~ 0.65

During the test period, an increase in voltage drop began to be observed on type 1 bimetallic plates starting from the sixth anode changing cycle (in comparison with the first cycle); on type 2 and type 3 bimetallic plates the voltage drop remained the same.

An increase in the voltage drop in the Fe-Al contact with an increase in the number of type 1 bimetallic plate installation cycles, as well as large variations in the values of the voltage drop and temperature are associated with a lifetime limit.

Figure 8 shows photos of the state of the bimetallic plate No. 10 (type 1). On 19 December 2012, two type 1 plates with the same failure behaviour were found.

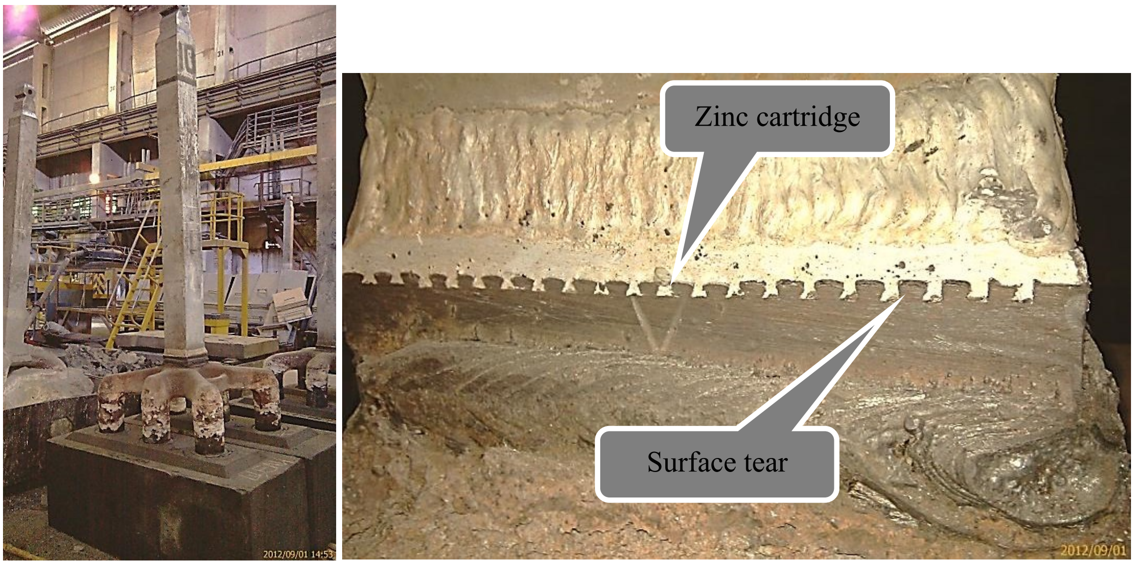

Figure 8. State of bimetallic plate No. 10 (type 1).

From these photos it can be seen that on one side of the plate there is a surface tear of the Fe-Al contact, while the zinc cartridge (indicator characterizing that the joint was not overheated) is intact.

The average service life of the RA-400 type 2 and 3 bimetallic plates of anode rod assemblies was ~15 – 20 anode changing cycles (~ 420 – 560 days). Thus, the technical solutions tested in 2011 – 2014 made it possible to increase the service life of bimetallic plates of OU RA-400 pots, but the problem of failure in the medium term was not solved.

In 2016, it was decided at RUSAL Sayanogorsk JSC to continue testing the modified technology of welding the rod to the bimetallic plate (Figure 9) in order to further improve the reliability of the welding of bimetallic plates to the anode rod of the anode rod assemblies of OU RA-400 pots.

- Type 4 — type 2 or 3 bimetallic plate is welded to the yoke according to current technology, and the rod is welded through transitional 10 mm thick Al plates.
- Type 5 — type 1, 2 or 3 bimetallic plate is welded to the yoke according to current technology, type 2 or 3 bimetallic plates are welded from the sides in the same way.

Type 4 Type 5

Figure 9. Technical solution to improve the connection reliability.

Figure 10 shows values of the voltage drop in the 'rod–yoke' contact of bimetallic plates mounted according to types 1 – 5. The measurements obtained demonstrate that the type 5 connection shows the lowest values of voltage drop.

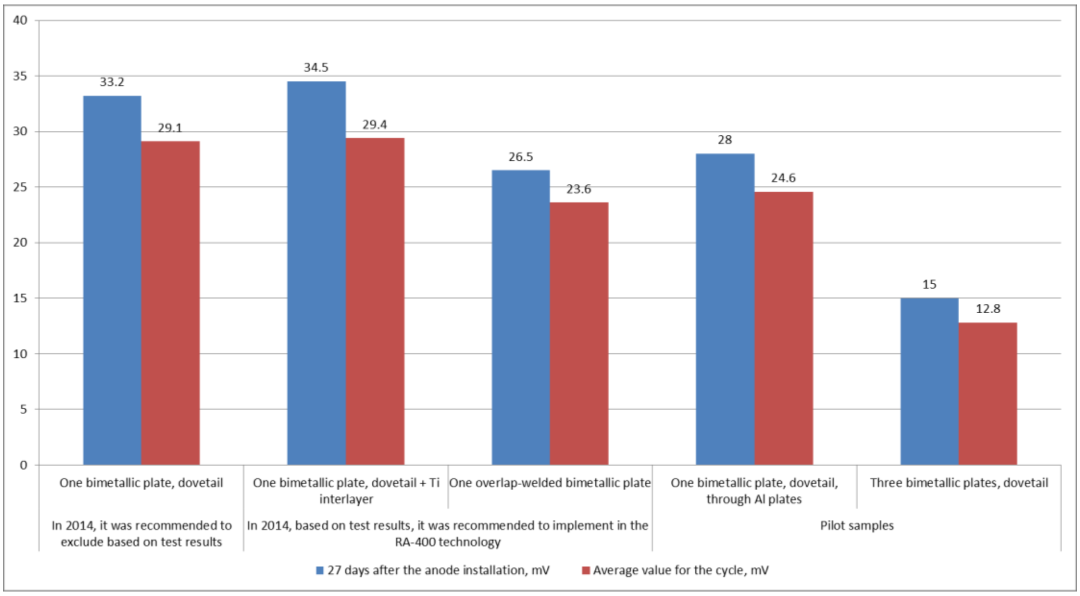

Figure 10. Voltage drop in the 'rod–yoke' contact of bimetallic plates mounted according to types 1 – 5.

Figure 12. Monitoring of the voltage drop in the 'rod–yoke' contact of bimetallic plates mounted according to type 5.

5. Economic Assessment

The estimated cost for the repair of anode rod assemblies of the RA-400 pots using the new type 5 technology, including the consumption of materials as well as labour costs is double the current cost estimate. The rise in the cost of repair of one anode rod assembly using the new technology is about RUB 12 000.

At the same time, by increasing the inter-operation mode and reducing the voltage drop in the 'rod-yoke' contact on an annualized basis, the cost savings for repairing anode rod assemblies using the new OU RA-400 pot technology at RUSAL Sayanogorsk JSC is about RUB 500 000 per year. The break-even point of this project: the cost of the repair of 1 anode rod assembly is 36 000 RUB/piece. With this cost, the increase in repair costs is offset by the effect of reducing electricity consumption, and the resulting effect of the project is '0'.

6. Conclusions

On the basis of the obtained results with respect to reliability and energy efficiency, the technical solution for mounting the rod to the yoke using type 5 connection is economically attractive, the margin of stability at the accepted cost of one anode rod assembly repair in the project is 74 %:

- The technical solution has the lowest voltage drop (12.8 mV, which is 15 mV lower for typical connections), as well as the lowest temperature at the end of the anode changing cycle (180 ° C, which is lower by ~ 25 - 27 ° C for typical connections).
- The connection is more reliable and allows increasing the energy efficiency of the RA-400 technology (reduction of specific energy consumption ~ 47 kWh/t Al).

The technical solution has been included in the technological package of RA-400 and RA-550 technologies.

The authors are aware that not all of the above considerations and technical solutions are indisputable, and are grateful in advance for any positive criticism and meaningful suggestions, which can be sent by e-mail: Ilya.Puzanov@rusal.com.

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