

Challenges in Reduction of Stub-to-Carbon Voltage Drop for Amperage Increase

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Abstract

Mahan Aluminium Smelter of Hindalco Industries is in Madhya Pradesh, India. The smelter employs AP30 technology with the design capacity of 360 kt/y. Presently Mahan Smelter is in the process of amperage creep to increase the hot metal production. Potline amperage has been increased from 360 kA to 374.5 kA at present. Pot voltage is the key parameter to be monitored and controlled in any amperage creep projects to ensure minimum change in energy input due to amperage increase. The anode drop forms a major part of the voltage drops of the electrolytic cells and this in turn is significantly influenced by the voltage drop between the stub (also called pin) and carbon anode, called stub-to-carbon voltage drop. There was a significant increase in the stub-to-carbon drop during the amperage increase. Stub-to-carbon drop has been studied extensively at Mahan through inhouse experiments, application of digital tools, Process optimization while finding out the optimum conditions to achieve lower stub-to-carbon drop. Lots of factor lead to the deterioration of the stubs like toe-in effects, erosion, mechanical wear & tear etc. which in turn lead to the change in structure of stub-to-carbon connection increasing the voltage drop. The key causes for the increased voltage drop were found to be uneven pin diameter, elongated pin length and cast-iron composition. Due to the difference in pin diameter, pin length, cast iron thickness the contact pressure was found varying. This paper discusses the practical methods employed at Mahan for reducing the Stub-to-carbon drop by 15 mV which will help in increasing the amperage in the potline.

Keywords: Anode voltage drop, Anode pin length, Anode pin diameter, Cast iron thickness, Contact pressure.

1. Introduction

Mahan Potline uses AP technology with the design amperage of 360 kA. The potline was commissioned with the initial amperage of 367 kA in 2013 and was operated and stabilised at this amperage till 2021. From end of 2021 the project of increasing the amperage of the cells to increase productivity was taken. Since then, the amperage has been gradually increased to 374.5 kA without any major design changes.

The copper insert cathodes which were primarily aimed to reduce the energy consumption have also helped to increase the amperage as they are more stable. However, there are many old design cells also operating at the higher amperage of 374.5 kA. The amperage has been increased mainly

by modifying work practices, optimising process control parameters, increasing heat loss through lower thickness of anode cover and increased metal height.

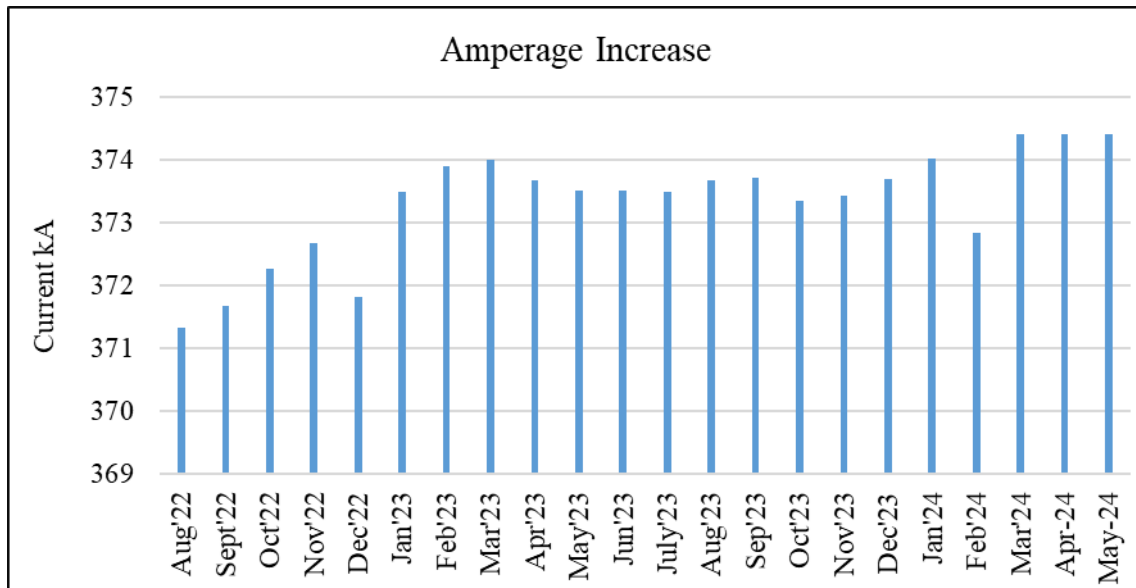


Figure 1. Amperage trend.

Monitoring and controlling pot voltage is crucial in amperage increase projects to minimize energy input caused by amperage increases. The increase in pot voltage during amperage increase largely depends on the ohmic voltage drop.

Addressing ohmic voltage drop increases is challenging because it typically necessitates design changes involving significant capital expenditure and longer implementation timelines (such as adjustments to bus bar and anode stem dimensions).

Our primary objective was to prevent any high voltage drops which would be more than the expected increase due to amperage escalation.

1.1 Pot Voltage and Stub-to-Carbon Voltage Drop

In the aluminium electrolysis the voltage components of the cell are:

$$V_{\text{pot}} = V_{\text{anode}} + V_{\text{cathode}} + V_{\text{bath}} + B_{\text{emf}} \quad (1)$$

The anodic voltage drop is a critical component of the overall pot voltage in an electrolytic cell. The anodic voltage drop typically accounts for about 7–9 % of the total pot voltage. Despite its smaller proportion keeping the anode drops in control gives better operating window for amperage increase.

The rodded anode assemblies being used in Mahan Pot lines is shown in the Figure 2. The assembly consists of the anode stem with twice three pins of diameter 180 mm and length 320 mm. with slotted carbon block size of length: 1558 mm, width: 650 mm and height: 680 mm. The anode voltage drop comprises of

- Stem-to-beam drop.
- Stem drop.
- Clad drop.
- Stub-to-carbon drop (including steel bracket and stub drop).

- Carbon block drop.

The values are indicated in Figure 2 and the total anode voltage drop is 365 mV in Mahan anodes.

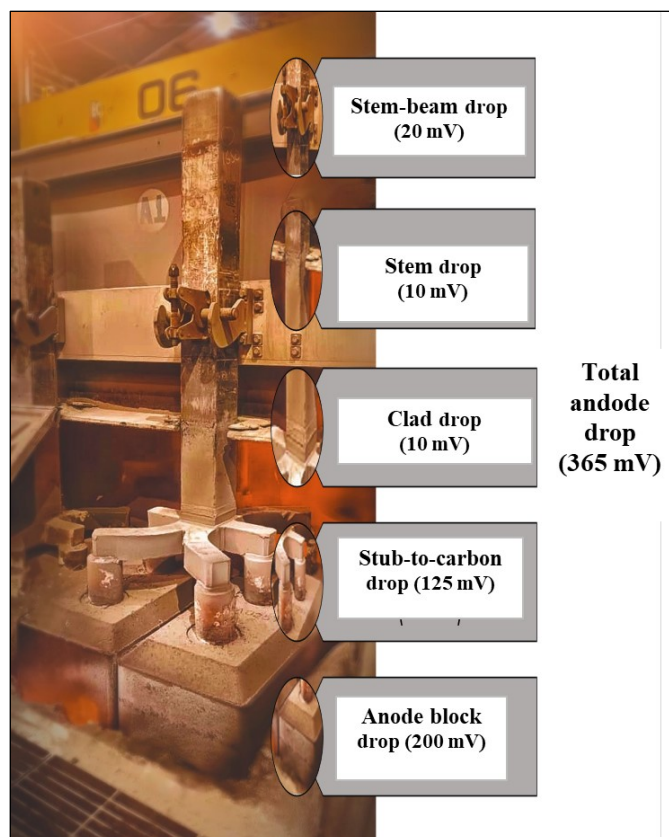


Figure 2. Anode voltage drops.

As seen in Figure 2, stub-to-carbon drop also contributes highly to the anode drop and this paper will discuss on the challenges faced in keeping the anode voltage drops in control during an amperage increase particularly in the stub-to-carbon region, as it significantly impacts the system's overall performance.

Many experimental and modelling studies of anode and stub-to-carbon voltage drop have been made [1-11]. These studies show the importance of stub-to-carbon connection and discuss the improvements in the design and in practice.

1.2 Stub-to-Carbon Voltage Drop Measurement

In the present pot design, there are 20 anodes assemblies installed in the pot with each anode assembly having two anode blocks with 3 steel pins each. These 20 anodes assemblies are at varying stages of their lifespan, with anode change cycle of 80×8 h-shifts. Once the new anode is being changed it takes around 48 hours to conduct the stable average current. The stub-to-carbon (STC) voltage drop is measured after 5 days of changing the new anode, ensuring that the anode has attained the required thermal state. The measurement is done by one probe on the carbon block and the other one at the steel pin. The stub-to-carbon drop measured in four pins after installing the anode until 11 days of operation is shown in the Figure 3. The measurement of the pin near to the centre channels are not taken due to the safety precautions.

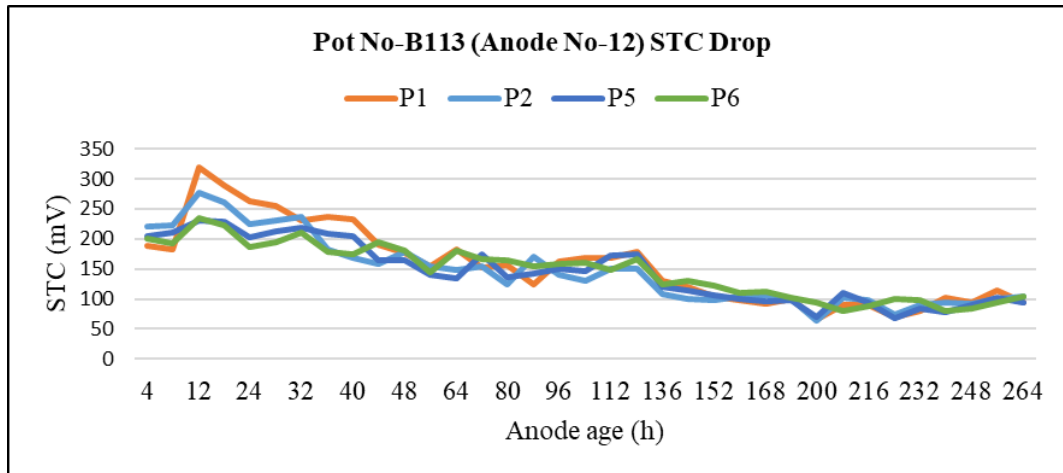


Figure 3. STC of anodes.

1.3 Impact of Increase in the Stub-to Carbon Drop

The energy cost per tonne of metal produced accounts for approximately 40 to 50 percent of the total production cost. Any rise in the stub-to-carbon voltage drop significantly raises the overall cost, thwarting production increases via higher amperage and contributes to a larger carbon footprint.

For instance, a 20 mV increase in stub-to-carbon voltage drop leads to an energy consumption increase of 60 kWh/t Al, equal to approximately \$1.2 million for a 370 kt/a smelter. Therefore, maintaining the lowest possible stub-to-carbon voltage drop is crucial for minimizing production costs.

1.4 Trend of the Stub-to-carbon Drop

The trend of the stub-to-carbon drops is attached in Figure 4. Data shows a consistent rise in stub-to-carbon drop during the amperage increase period. Measurement trends indicate a noticeable 20 mV increase from the baseline preceding the amperage adjustment.

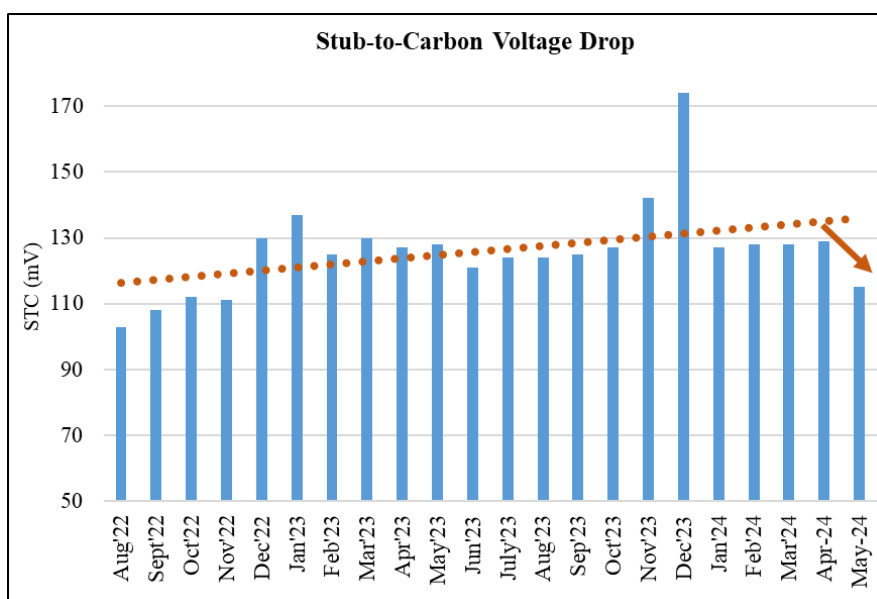


Figure 4. STC trend.

To identify the root causes of the increased STC drop, the data were analysed with a focus on the following areas:

- Assessing the cast iron composition to determine any factors impacting voltage drops.
- Assessment of operating practices to understand their contribution to the observed increase of the drops.
- Examining pin specifications to identify potential mismatches or deviations.

1.4.1 Cast Iron Composition

The composition of cast iron plays a crucial role in determining the stub-to-carbon voltage drop. The primary alloying elements used in cast iron include carbon, phosphorus, silicon, and manganese. Sulphur may also be present as a contaminant, introduced into the system through uncleaned thimbles adhering to the carbon at the stub hole. The desired composition specifications for cast iron are:

- Carbon: 3.3 % to 4.0 %
- Phosphorus: Less than 0.1 %
- Silicon: 2.5 % to 3.0 %
- Manganese: 0.4 % to 1.0 %.

The trends of the composition of the cast iron during the period of amperage increase is shown in the below graphs.

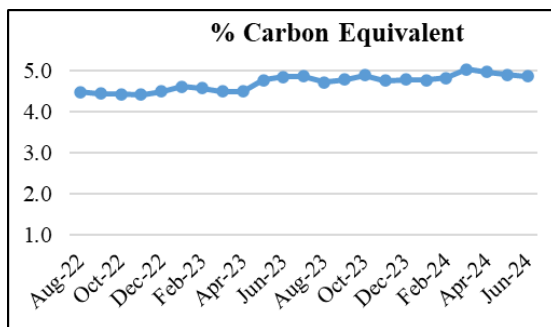


Figure 5. Carbon equivalent trend.

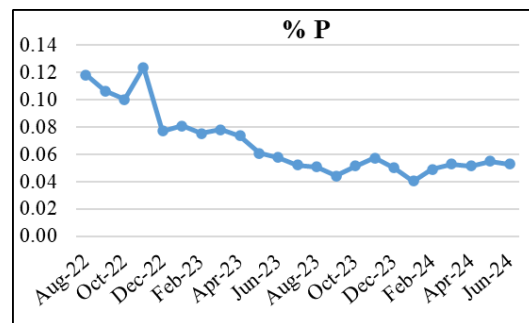


Figure 5. P trend.

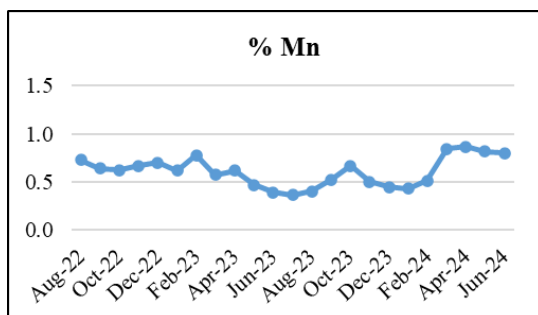


Figure 5. Mn trend.

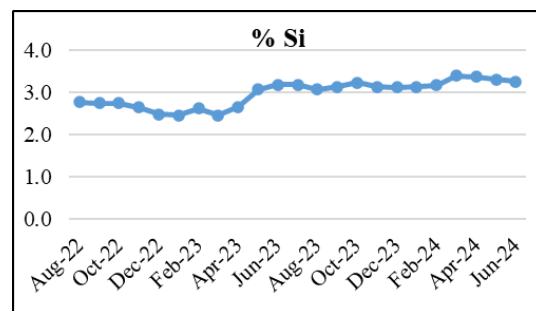


Figure 5. Si trend.

The root cause of the cast iron composition contributing to the increase in voltage drops was eliminated as there was no significant change.

1.4.2 Operational Practices

A comprehensive audit of the operational practices related to rodding, reviewing each step from butt cleaning till stub centring and pouring of cast iron was conducted. The audit confirmed that there were no significant deviations from the Standard Operating Procedures (SOPs), which were strictly followed.

Minor opportunity was identified for improvement regarding the cleanliness of the recycled cast iron, for maintaining the sulphur percentage. Teams are actively working to enhance the cleanliness of the recycled cast iron thimbles to address this issue.

1.4.3 Pin Specification

The diameter and length of pins play a critical role in reducing the stub-to-carbon voltage drop in aluminium electrolysis cells. These dimensions directly affect the electrical contact resistance at the stub-to-carbon interface, which is a significant factor in the overall cell performance.

Increasing the pin diameter and reducing length leads to a more efficient electrical connection by minimizing the distance and resistance that the current must travel. A smaller diameter increases the resistance, while an optimized length ensures better contact pressure and uniform current distribution. These changes result in a lower voltage drop across the interface, thereby reducing energy loss and improving the overall efficiency of the electrolysis process.

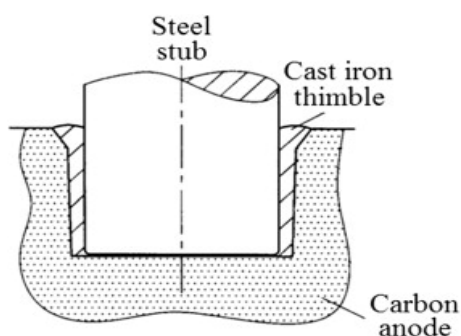


Figure 9. Steel pin with anode contact.

Moreover, optimized pin dimensions contribute to the stability and durability of the connection. This stability is crucial for maintaining low resistance and preventing fluctuations in the voltage drop.

1.5 Trials with Different Pin Dimensions

At Mahan smelter, the spare inventory of rodded anodes was only sufficient for 2.5 days of daily consumption for the potline. To address this shortage and increase the inventory, capital expenditure was proposed to fabricate and install 100 new stems with new pins. This initiative also provided an opportunity to study the impact of pin geometry (length of 320 - 340 mm and diameter of 160 - 180 mm) on stub-to-carbon drop.

Trials were done in 3 pots by installing anodes assemblies made with new anode stems and pins and the results are shown in Figure10. The data shows a decrease of approximately 25 mV compared with the normal steel pins. This improvement is considered highly significant.

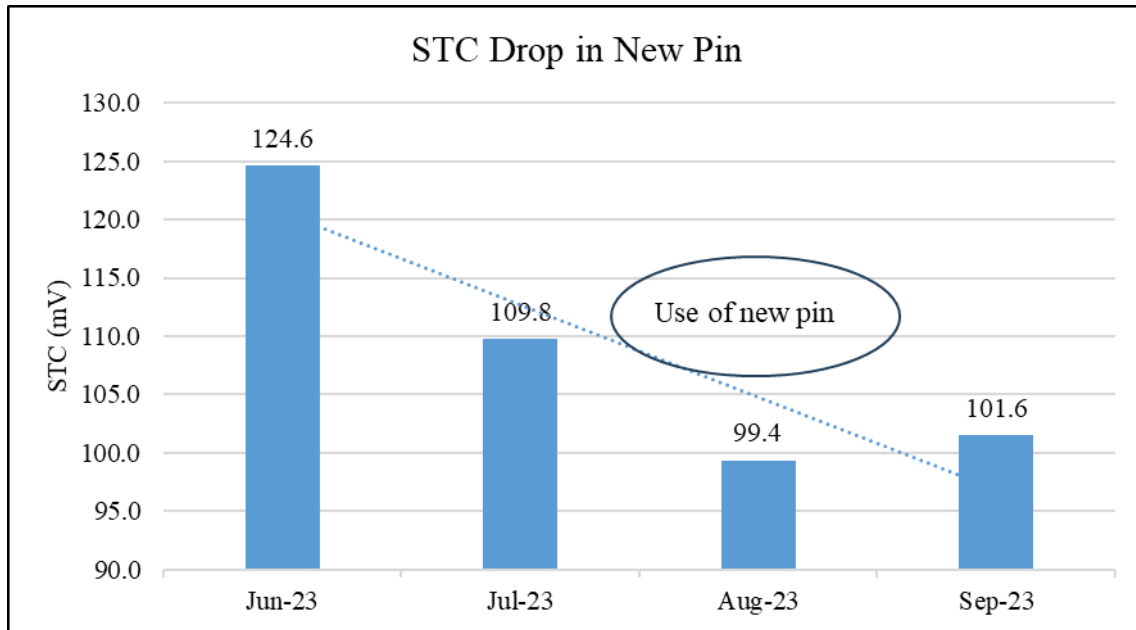


Figure 10. STC with new pins.

Given the significant cost involved in converting all 8 500 stems to new ones, trials were conducted with different pin dimensions to explore alternatives. Measurements of the stub-to-carbon drop were performed for pins with reduced diameters and lengths and the inference was as below, voltage drops were observed to be higher when there was less contact between the pin and the carbon at the bottom. The amount of cast iron under the pin impacts the voltage drop, i.e., if there is more cast iron below the steel pin, there is more voltage drop due less contact which is shown in Table 1.

Cast iron thickness at bottom of the pin	Stub-to-carbon drop in millivolts (mV)	Cast iron thickness at bottom of the pin	Stub to Carbon drop in millivolts (mV)
Less than 5 mm	78	11 mm to 20 mm	105
	90		109
	68		120
	73		122
5 mm to 10 mm	80	Greater than 20 mm	130
	80		130
	90		160
	100		130
	90		146

Table 1: Stub to carbon voltage drop measurements considering different cast iron thickness under pin

1.6 Actions Taken

Upon identifying the root cause, we proceeded to develop a machine designed to uniformly trim the excess length of pins (Figure 11). This ensures that all pins within the anodes are consistently

dimensioned lengthwise, thereby achieving uniform contact surfaces between the pin bottoms and the carbon.

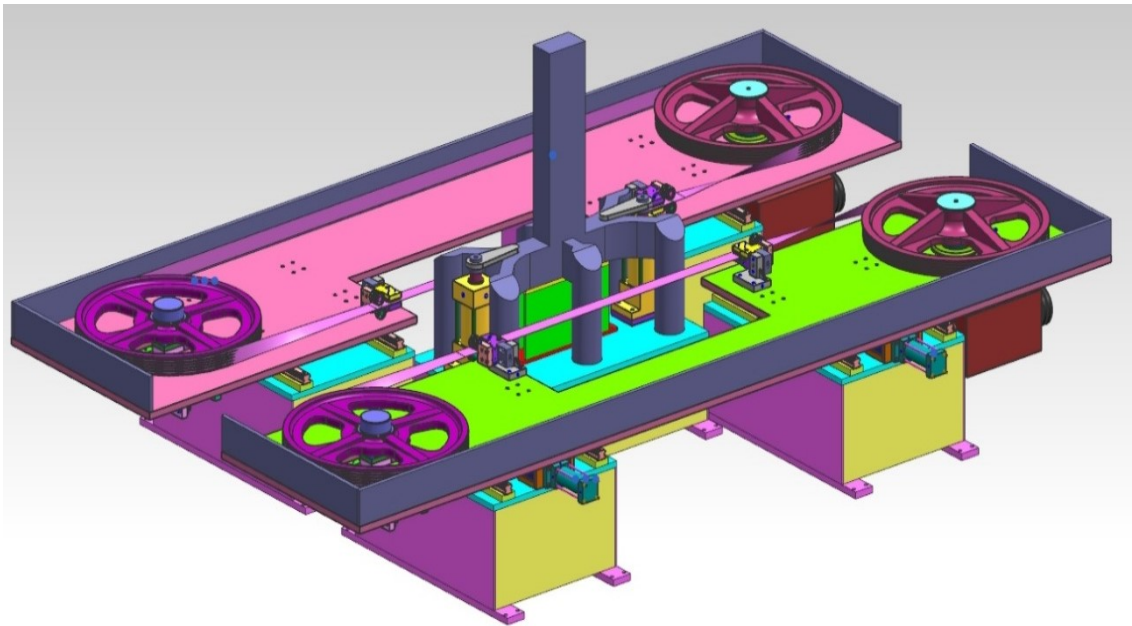


Figure 11. Trimming machine.

A robust machine was designed with a horizontal trimming mechanism, adjustable cutting length capability and high-quality blades featuring a precise blade guiding system for accurate trimming. Initially, challenges such as blade durability and achieving consistently straight cut surfaces were resolved through internal innovations and modifications. To ensure safety, the equipment is guarded and provided with sensors to detect any anomalies.

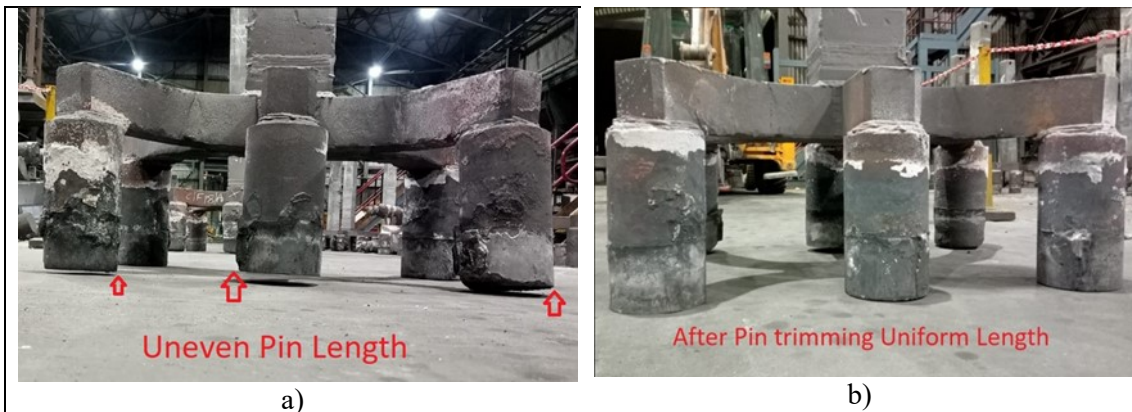


Figure 12. a) Before pin trimming one stem, b) After pin trimming one stem.

1.7 Results

Trials conducted on six pots by using the trimmed pins demonstrated a reduction of 14 mV in the stub-to-carbon drops, as shown in Figure 13.

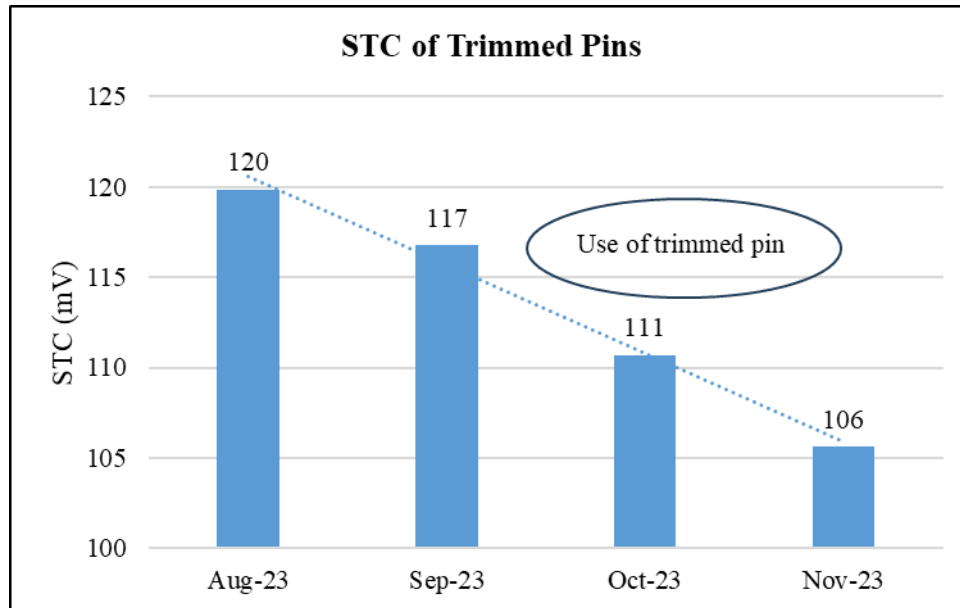


Figure 13. STC with trimmed pins.

2. Digitization

To facilitate widespread implementation of trimming, the anode tracking mechanism for individual anode stems was introduced. This digital transformation involves the integration of advanced technologies to monitor, record, and analyze the performance and lifecycle of anode pins throughout the smelting process. Here are the key components and benefits of digitizing the anode pin tracking system:

- **Cloud-Based Platforms:** Data from RFID tags and sensors is transmitted to a centralized, cloud-based platform for aggregation, storage, and processing.
- **Predictive Maintenance:** Machine learning algorithms analyze historical and real-time data to predict maintenance or replacement needs of anode pins, reducing downtime and extending lifespan.
- **Performance Optimization:** Data analytics identify patterns and inefficiencies, optimizing the smelting process.
- **Real-time Dashboards:** Critical information on anode pin status, performance metrics and alerts for potential issues are displayed on real-time dashboards.
- **Automated Reports:** Automated reports provide insights into pin usage, efficiency and maintenance schedules.

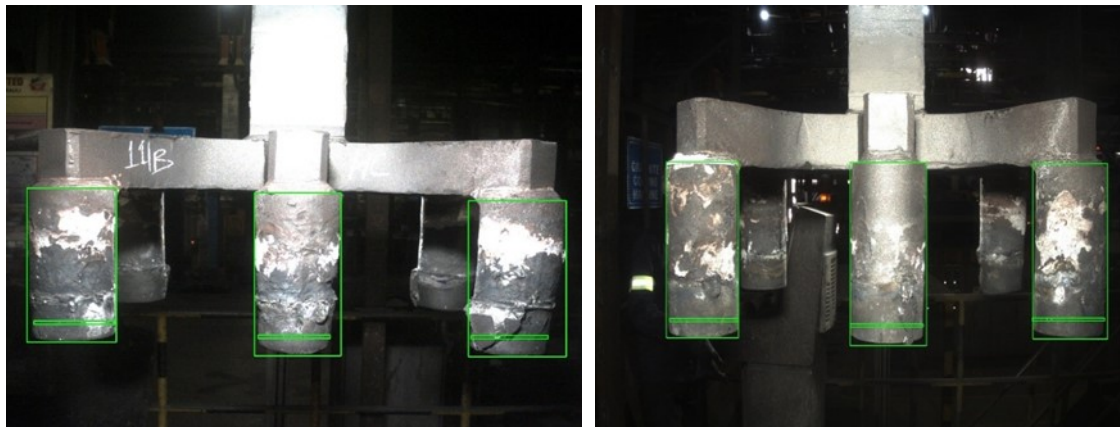


Figure14. Pin dimensions imaging.

This system enables tracking of anode stem deterioration across cycles, determining which require trimming and reuse. It facilitates proactive budget planning for stem repairs and estimates voltage drops from stub-to-carbon in advance, enabling planned adjustments to amperage changes.

3. Conclusions

The pin dimension analysis has demonstrated a clear correlation between the reduction in variation in pin length and the subsequent decrease in the stub-to-carbon voltage drop. By optimizing these dimensions, the electrical contact resistance within the stub-to-carbon interface is significantly reduced. This optimization is crucial for enhancing the overall efficiency of the aluminium electrolysis process, as it minimizes energy waste and improves system performance. The findings underscore the importance of precise pin manufacturing and trimming techniques in achieving optimal electrical performance in potlines. Implementing these dimensional adjustments can lead to substantial energy savings, operational improvements, and unhindered amperage increase.

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